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A New Heterogeneous Nanocatalyst for Sulfoxidation of Sulfids to Corresponding Adrafinil Analogous: Synthesis, Properties and Applications of VO3-/NH3+-SiO2/Fe3O4

M.J. Taghizadeh*[1], A. Javidan[1], and O. Hosseinchi[2]

[1]*Department of Chemistry, Faculty of Sciences, University of Imam Hossein, Tehran, Islamic Republic of Iran*
[2]*Department of Chemistry, Faculty of Sciences, University of Science and Technology, Tehran, Islamic Republic of Iran*

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Abstract

A new magnetic nanocatalyst has been prepared using immobilization of vanadate onto aminopropyl functionalized SiO_2/Fe_3O_4(VO_3^-/NH_3^+-SiO_2/Fe_3O_4). The obtained magnetic catalyst was characterized by FT-IR, XRD, VSM and SEM techniques and used for sulfoxidation of sulfide compounds to the correspondingsulfoxides in presence of H_2O_2 as oxidant at room temperature. The optimum of reaction conditions and reusability of catalyst have been investigated.

Keywords: Sulfoxidation; Fe_3O_4 nanoparticles; SiO_2/Fe_3O_4 nanoparticles; Adrafinil analogues.

Introduction

The selective oxidation of sulfides to sulfoxides is an attractive and important method in organic chemistry, since sulfoxides are useful building blocks especially as chiral auxiliaries in organic synthesis [1]. They also play key roles in the activation of enzymes [2]. However, this transformation is conventionally achieved using stoichiometric amounts of both organic [3] and inorganic [4] reagents, most of which are not suitable for medium to large scale operations and which also lead to large a volume of toxic wastes. Moreover, overoxidation of the sulfoxides to their sulfones is a common problem during the oxidation of sulfides. In recent years, the newly coined term “green chemistry” has become increasingly important, with the objective to create new products, industrial and laboratory processes, and services that achieve social and economic progress without environmental detriment. The use of H_2O_2 as oxidant offers the advantages that it is a cheap, environmentally benign, and readily available reagent and produces water as the only side product [5].

Among the several transition metal complexes, vanadium complexes activate hydrogen peroxide forming peroxovanadium complexes which are well-known catalysts for oxygen-transfer reactions [5,6]. The study of vanadium has been attravtive due to its presence in biological systems and its ability to serve as an oxidation catalyst. Although the oxidation of sulfides by vanadium complexes is not new, but the exact mechanism by which it is accomplished is still a subject of study. Consistently, the active species is a vanadium(V) complex associated with hydrogen peroxide or organic peroxides [7].

Recently, preparation of magnetically separated catalysts by applying an appropriate magnetic field has

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* Corresponding author: Tel: +982177104936; Fax: +982173829506; Email: mohammadjavadtaghizadeh31@yahoo.com

been presented. Magnetic Fe_3O_4 nanoparticles have captured the attention of scientists due to its unique magnetic properties and feasibility of preparation [8].

In this study -a novel research- vanadate catalyst was immobilized onto functionalized aminopropyl SiO_2/Fe_3O_4. Fe_3O_4 nanopaticles were synthesized and then coated by SiO_2 shell. There after, the surface of SiO_2/Fe_3O_4 nanoparticles were funtionalized by aminopropyl groups followed by acidification of amino groups using triflicacid and ion exchange of triflate ion by vanadate. The prepared catalyst was used to sulfoxide several sulfide compounds (the corresponding sulfoxides consisted of important drug compounds: adrafinil and modafinil) in presence of H_2O_2 as oxidant. The time and amount of catalyst in sulfoxidation reactions were investigated.

Materials and Methods

All of the materials used in this work were analytical grade reagents and used without further purification. Deionized water was used to prepare all solutions. The FT-IR analyses were carried out on a Shimadzu FTIR-8400S spectrophotometer using a KBr pellet for sample preparation. 500 MHz ^1H NMR and ^{13}C NMR spectra were recorded on a DRX-500 AvanceBruker spectrometer and 250 MHz on a Bruker ADVANCE DPX-250. The samples were characterized by X-ray powder diffraction (XRD) using JEOL X-ray diffractometer with Cu Kα radiation. The low angle XRD pattern of mesoporous materials were exhibited by a diffractometer(PANalytical, model X'Pert Pro MPD) with monochromatized Cu Kα radiation (λ= 1.54060 Å, 40.0 kV, 40.0 mA). Magnetic properties of the samples were determined by a vibrating sample magnetometer (VSM, Lakeshore). The particle morphologies of the as-prepared powders were observed by a Tescan (model Vega II) scanning electron microscopy (SEM) at 30 kV.DRS spectra were prepared via a Shimadzu (MPC-2200) spectrophotometer. Thin layer chromatography (TLC) was performed on silica gel Analtech plates using either n-hexane:EtOAc, 1:1 or $CHCl_3$:MeOH, 1:9 as eluent and visualized with 254 nm UV light. An HPLC system (Agalent, knawer, shimadzu) was used to identify the products.

Preparation of Fe_3O_4 nanoparticles

$FeCl_3.6H_2O$ and $FeCl_2.4H_2O$ (molar ratio of 2:1) were dissolved in deoxygenated water and stirred for 2 h to make sure that the salt was completely dissolved. The ammonia aqueous solution was added into the solution under nitrogen atmosphere, until the pH of the solution reached 12. The mixture was refluxed for additional 30 min and then let stand 2 h. Finally, the precipitate was collected and washed for several times with deionized water and ethanol until the pH was dropped to 7. The sample was dried at temperature of 60˚C for 12h.

Preparation of SiO_2/Fe_3O_4 nanoparticles

Stober method was used for preparation of inner layers of SiO_2 [9,10]. In a typical process, the formed Fe_3O_4 nanoparticles (2g) were dispersed in a mixture of ethanol (160mL), deionized water (40mL), and concentrated ammonia aqueous solution (25wt%, 5mL) by ultrasonication for 20 min. Subsequently, 5mL of tetraethylorthosilicate (TEOS) was added dropwise. After stirring for 12h, the products were collected and washed with deionized water and then dried under vacuum at 60˚C for further use.

Preparation of APTS modified SiO2/Fe3O4 nanoparticles (NH3+-SiO2/Fe3O4)

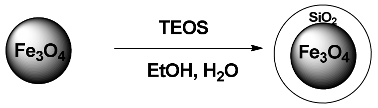
The surface of SiO_2/Fe_3O_4 nanoparticles modified with NH_3^+ was prepared by refluxing the SiO_2/Fe_3O_4 (2 g) with 3-aminopropyltrimethoxysilane (0.28 mmol) in 10 mL of dry toluene for 18h. To convert NH_2 groups to NH_4^+, 1mL CF_3COOH was added drop wise to the sample that dispersed in dichloromethane and stirred at room temperature overnight.The Final product containing NH_3^+-SiO_2/Fe_3O_4 nanoparticles was filtered and washed with water, ethanol and chloroform several times and then was dried at 60°C for 24h.

Preparation of VO3-/NH3+-SiO2/Fe3O4 nanoparticles catalyst

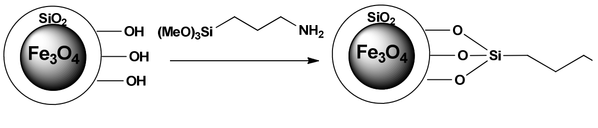
For forming the catalyst, mixture of NH_3^+-SiO_2/Fe_3O_4 nanoparticles (2g) and an aqueous solution of three fold excess NH_4VO_3 in 35 mL deionized water was stirred at room temperature for 24 h. After stirring, the solid was filtered off, washed with about 500 mL deionized water, ethanol and ether. It was then dried in an oven at 60 ºC overnight.

Typical procedure of sulfoxidation(for synthesis of adrafinilanalogues)

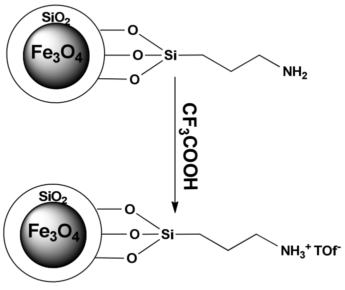
1mmol of (diphenylmethanetio)acetohydroxamicacid was solved at 2mL of acetonitrile. Then 1.5mL 30% H_2O_2 and 5 mol% of catalyst were added. The mixture was stirred at room temperature for 45min. The monitoring of the sulfoxideformation was done by TLC (n-hexanes:EtOAc, 1:1 or $CHCl_3$:MeOH, 9:1 as eluent). After completion of the reaction, the solvent evaporated and the crude product was purified by recrystallization method (using EtOAC/n-hexane) to give the desired sulfoxide((diphenylmethanesulfinyl)acetohydroxamicacid,



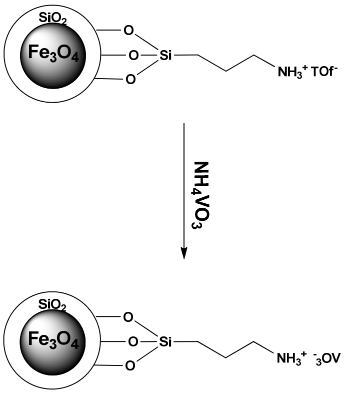
Scheme 1



Scheme 2



Scheme 3



Scheme 4

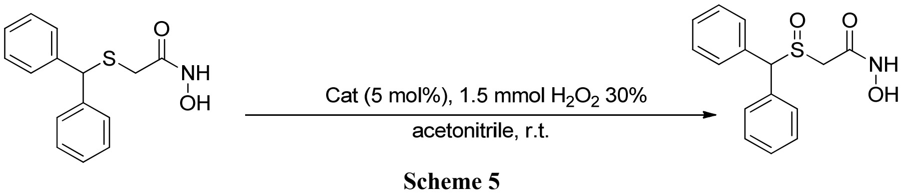
adrafinil) (Scheme 1). To investigat the reusability of catalyst, after reaction completion, the nanoparticles were separated magnetically, then washed several times with EtOAC and MeOH and dried at 60ºC for 8h. The recycled catalyst was applied for further reactions.

Results and Discussion

Characterization of VO3-/NH3+-SiO2/Fe3O4 nanoparticles catalyst

Fig. 1 demonstrates FT-IR spectra of pure Fe_3O_4, SiO_2/Fe_3O_4, NH_3^+-SiO_2/Fe_3O_4 and VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst. The band from 400–650cm^{-1} is assigned to the stretching vibrations of Fe-O band in Fe_3O_4. The band at about 1100,970 and 800cm^{-1} are ascribed to stretch of Si-O asymmetrical stretching bond, the Si-OH bending and in-plane bending of germinal silanol of silica, respectively. The spectra of Fe_3O_4 and SiO_2/Fe_3O_4exhibited bands assigned to adsorbed water at 3420cm^{-1} (the O-H stretching of adsorbed water and the hydrogenbondedsilanol groups) and 1640cm^{-1} (the O-H bending of adsorbed water). At the spectrum of NH_3^+-SiO_2/Fe_3O_4, the peak observed at 2846 and 2918cm^{-1} are due to C-H stretching. The vibration of V-O is below 1000 cm^{-1} but this peak was not observed at VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst duo to presence of strong peaks corresponded to SiO_2 and Fe_3O_4. The X-ray diffraction pattern of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst is shown in Fig. 2. Thesmoothly varying peak intensity in the 10-30° range results from the amorphous silica template. The sharp peaks correspond to the diffraction on the crystal structure of Fe_3O_4.

The morphology and size details were investigated by SEM measurement which is illustrated in Fig. 3. The SEM image of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst indicated the mean diameter of the particles is smaller than 100 nm. Magnetic measurements were carried out by using vibrating sample magnetometer (VSM) at 300 K. The magnetization curves measured for Fe_3O_4 nanoparticles and VO_3^-/NH_3^+-SiO_2/Fe_3O_4 are compared in Fig. 4. There was smal hysteresis in the magnetization for the two nanoparticles. The values of the saturation magnetization were 59 and 24 emu/g for Fe_3O_4 and VO_3^-/NH_3^+-SiO_2/Fe_3O_4nanoparticles, respectively. The reduction of 35emu/g of the saturation magnetization suggests the presence of some VO_3^-/NH_3^+-SiO_2/Fe_3O_4on the surface of the magnetic supports. Even with this falling in the saturation magnetization, the catalyst still can be competently separated easily from the solution with the employ of an external magnetic force.



Scheme 5

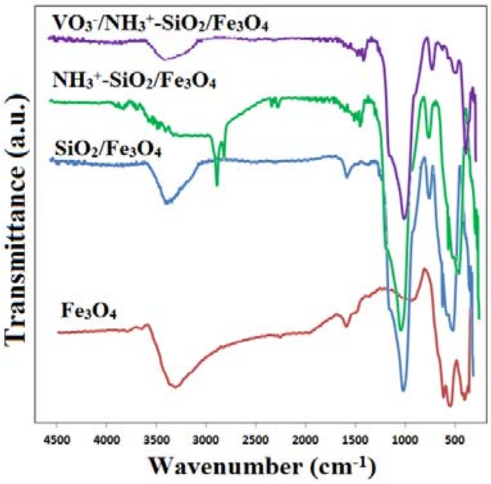


Figure 1. The FT-IR spectra of Fe_3O_4, SiO_2/Fe_3O_4, NH_3^+-SiO_2/Fe_3O_4 and VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst.

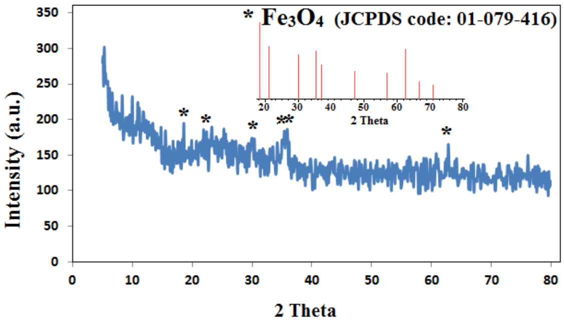


Figure 2. The XRD pattern of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst.

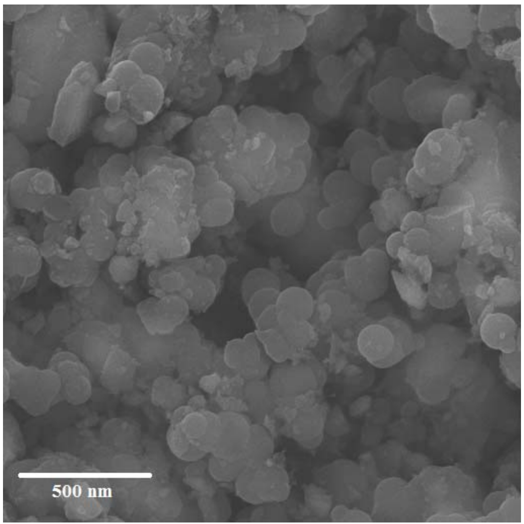


Figure 3. The SEM image of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles catalyst.

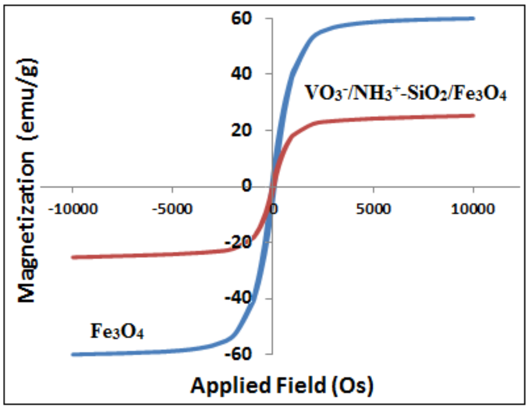


Figure 4. Magnetization curves of Fe_3O_4 and VO_3^-/NH_3^+-SiO_2/Fe_3O_4

Table 1. Sulfoxidation of (diphenylmethanetio) acetohydroxamicacid using H_2O_2 as oxidant in the presence of the VO_3^-/NH_3^+-SiO_2/Fe_3O_4 at different conditions.

Entry	Catalyst(mol%)	Tim (min)	Yield (%)
1	0	240	20
2	2	240	60
3	3	240	85
4	4	90	89
5	5	45	91
6	5	90	91
7	10	45	92

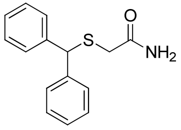
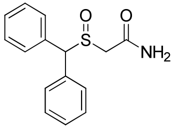
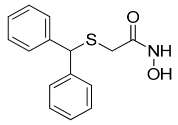
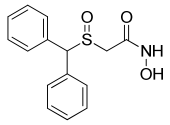
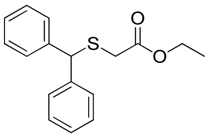
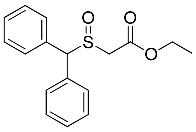
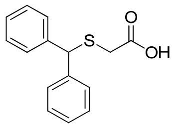
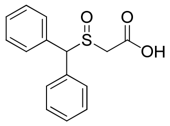
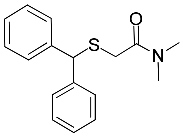
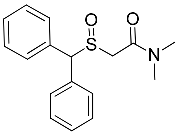
Study of sulfoxidation procedure

The catalytic activity of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles in the sulfoxidation of sulfide compounds by H_2O_2 as oxygen transfer agent were investigated. First, the effect of reaction time on the sulfoxidation of sulfide compounds in the presence of presented catalyst was studied. As it can be seen in Table 1, the percent conversion after 45 min was the best and maximum amount of substrate was converted to products. These results confirm the optimized reaction time for sulfoxidation is 45 min. With increasing time, no significant change was observed in conversion of substrate. In addition, Table 1 shows the influence of catalyst amount on the sulfoxidation reaction. When the catalyst amount was increased, the yield of product improved. It seems that the best result could be obtained with catalyst amount of 5 mol% (Entry 5). The results of sulfoxidation of sulfide compounds using H_2O_2 as oxidant in the presence of the 5 mol% VO_3^-/NH_3^+-SiO_2/Fe_3O_4 catalyst are summarized in Table 2.

The magnetic VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles can be removed conveniently from water with the help of an external magnet. As shown in Fig. 5, the magnetic nanoparticles in reaction potwerebrown emulsion and it could be easily separated from solution in a short time under an external magnetic field.

The reusability and stability of the heterogeneous magnetic catalyst were studied for several times. After finishing the sulfoxidation reaction, the catalysts were

Table 2. Sulfoxidation of sulfide compounds with hydrogen peroxideusing 5 mol% VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles catalyst.

Entry	Sulfide	Product	Time (min)	Yield (%)[a]	m.p. (°C)	Reference
1			45	93	161-162	158-159[11]
2			50	92	160-161	159-160[11]
3			45	91	84-85	84-85[11]
4			40	94	149-150	148-149[11]
5			45	91	128-129	129-130[12]

[a] Isolated yield

separated by a magnet, washed with EtOAC, followed by methanol and dried at 60 °C for 8 h before using in subsequent run. The recycled catalysts were used in the fresh reaction mixture under the same reaction conditions (Fig. 6). The experiment showed that catalyst was reused for three times, and no significant change was observed in catalytic activity.

Representative spectral data

^{1}*H*NMR (CD_3OD): d7.56–7.51 (4H, m), 7.44–7.32 (6H, m), 5.40 (1H, s),3.41 (1H, d, J = 13.7 Hz), 3.23 (1H, d, J = 13.7Hz);^{13}*C* NMR (CD_3OD): d 163.5 (CO), 137.2 (C), 135.6(C), 130.9 (2CH), 130.3 (2CH), 129.9 (2CH), 129.8(2CH), 129.6 (2CH), 72.1 (CH), 54.0 (CH_2); IR3209, 3027, 1686, 1656, 1496, 1451, 1061, 1005, 703 cm^{-1}; HPLC ($CHCl_3$:MeOH, 1:9; flow rate 1 mL/ min; t_R6.50 min).

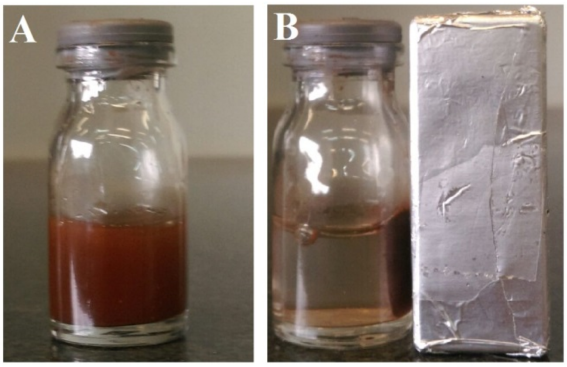


Figure 5. Photo of the aqueous solution (A) with dispersed magnetic VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles catalyst and (B) after magnetic separation using an external magnetic field.

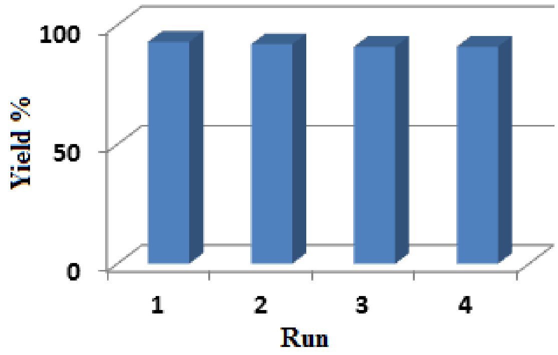


Figure 6. Reusability of VO_3^-/NH_3^+-SiO_2/Fe_3O_4 nanoparticles catalyst for sulfoxidation (Condition reaction: 1 mmol (diphenylmethanetio)acetohydroxamicacid, 2 mL acetonitrile, 5 mol% catalyst).

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