Tetrahedron Letters 53 (2012) 127-131

Contents lists available at SciVerse ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet





Selective oxidation of sulfides and oxidative bromination of organic substrates catalyzed by polymer anchored Cu(II) complex

S. M. Islam^{a,*}, Anupam Singha Roy^a, Paramita Mondal^a, Kazi Tuhina^b, Manir Mobarak^a, John Mondal^c

^a Department of Chemistry, University of Kalyani, Kalyani, Nadia 741235, WB, India ^b Department of Chemistry, B.S. College, Canning S-24PGS, WB, India ^c Department of Material Science, IACS, Kolkata 700032, WB, India

ARTICLE INFO

Article history: Received 5 April 2011 Revised 19 October 2011 Accepted 22 October 2011 Available online 6 November 2011

Keywords: Oxidative bromination Polymer-anchored Cu(II) catalyst Sulfide oxidation Hydrogen peroxide

ABSTRACT

A new polymer-anchored Cu(II) complex has been synthesized and characterized. The catalytic performance of the complex has been tested for the oxidation of sulfides and in oxidative bromination reaction with hydrogen peroxide as the oxidant. Sulfides have been selectively oxidized to the corresponding sulfoxides in excellent yields and in the presence of KBr as the bromine source, organic substrates have been selectively converted to mono bromo substituted compounds using polymer-anchored Cu(II) catalyst. This catalyst showed excellent catalytic activity, high selectivity, and recyclability. The polymer-anchored Cu(II) catalyst could be easily recovered by filtration and reused more than five times without appreciable loss of its initial activity.

© 2011 Elsevier Ltd. All rights reserved.

Sulfoxides and sulfones are useful synthetic intermediates for the synthesis of several important organic compounds.¹ There are also many biologically important compounds which contain a sulfoxide or sulfone moiety. Sulfoxides and sulfones are generally prepared via oxidation of the corresponding sulfides; however, it is often very difficult to stop the oxidation of the sulfoxide. In the oxidation of sulfides, other oxidizable functional groups, such as alcohols or olefins, present in sulfides sometimes react as well-producing undesirable compounds.¹ A large number of methods have been developed to overcome this drawback; however, most of these reactions require a stoichiometric amount of oxidant, resulting in undesirable waste.² Recently aqueous 30% hydrogen peroxide has been used as an attractive and environmental friendly oxidant³ for the oxidation of sulfides, because it is inexpensive, easy to handle, safely stored, and produces only water as a byproduct. Since the oxidation of sulfides with aqueous hydrogen peroxide in the absence of any catalyst is slow, several transition metal (Ti, Fe, V, Cu, and Mn) compounds have been used as catalysts for this reaction.⁴ Aryl halides are important synthetic intermediates for a variety of transformations including carboncarbon bond formation via cross-coupling reactions such as Stille-Suzuki, Heck, and Sonogashira and carbon-heteroatom bond formation via aromatic functionalization protocols.⁵ A variety of methods for the bromination of aromatics have been reported in the literature.⁶⁻⁹ The classical direct bromination of aromatic systems suffers from being wasteful in the bromine employed as one-half ends up as hydrogen bromide. In large-scale operations this is an environmental as well as an economical problem. In oxybromination,^{10,11} HBr as a bromine source and $H_2O_2/TBHP$ as oxidants were thought to be a possible solution to overcome these difficulties and met with partial success, since HBr is highly toxic and corrosive and is as harmful as molecular bromine to the environment. The oxidative bromination of aromatics is an attractive, mild alternative to the more widely used bromine in glacial acetic acid. Recently the oxidative bromination of aromatic compounds has been described using potassium bromide, hydrogen peroxide, and various metal-oxo compounds as catalysts.^{12–15}

Homogeneous catalysts have been used in organic reactions since a very long time.^{16–18} However, these homogeneous catalysts face the problem of separation from the reaction mixture and its reuse. Homogeneous catalyst can be recovered and reused if it is heterogenized by supporting on an insoluble support. A variety of supports have been tested, including inorganic carriers such as molecular sieves,¹⁹ silica,²⁰ zeolites,²¹ clays,²² as well as polymers²³ and resins.²⁴ In recent years, chloromethylated polystyrene cross linked with divinylbenzene is one of the most widely used macromolecular supports for immobilization of homogeneous catalysts.²⁵ Activity and selectivity of heterogeneous metal complexes were controlled by polymeric supports.²⁶ Heterogenization or immobilization of homogeneous and heterogeneous catalysts due to their easy separation from the products by filtration and the possibility of recycling them by continuous operation.²⁷

^{*} Corresponding author. Tel.: +91 33 2582 8750; fax: +91 33 2582 8282. *E-mail address:* manir65@rediffmail.com (S. M. Islam).

^{0040-4039/\$ -} see front matter \odot 2011 Elsevier Ltd. All rights reserved. doi:10.1016/j.tetlet.2011.10.138

In this Letter, we report the synthesis and characterization of a polymer-anchored Cu(II) catalyst. The catalytic activity of the complex was tested in oxidation of sulfides and oxidative bromination reaction of aromatic compounds. This catalyst shows high catalytic activity and selectivity in the above two reactions. This polymeranchored catalyst can be separated and reused for more than five times without any significant loss in its activities.

Polymer-anchored Cu(II) catalyst can be prepared in two steps which is shown in Scheme 1. Polymer-anchored ligand was prepared according to the literature method.²⁸ Then polymer-anchored ligand (1.0 g) was reacted with CuCl₂ (0.10 g) in ethanol (15 mL) at 70 °C to obtained the brown colored catalyst.

Due to insolubilities of the polymer-anchored ligand and copper complex in all common organic solvents, their characterization was limited to their physicochemical properties, elemental analysis. SEM. TGA. FT-IR. diffuse reflectance UV-vis and atomic absorption spectroscopy which confirm the immobilization of copper onto polymer-anchored ligand. Elemental analyses of the ligand and complex support the formulation of the complex. Atomic absorption spectroscopy suggested 4.77% of Cu in the complex. The polymer-anchored ligand shows a peak around 3448-3425, 1685, 1598, and 1450 cm⁻¹ for –NH (secondary amine), v(C=0), v_{a-1} _{sym} (COO) and v_{sym} (COO) stretching vibrations. The lowering in frequency of the above peaks indicates the coordination of metal center with the ligand. The polymer-anchored Cu(II) complex also exhibited peaks at 548 cm⁻¹ (Cu-N),²⁹ 652 cm^{-1} (Cu-O)²⁹ and 315 cm⁻¹ (Cu–Cl).³⁰ The diffuse reflectance (DR)-UV-vis spectra of the copper complex shows that a broad band centered at 440 nm may be assigned to charge transfer transition, while the shoulder at around 600 nm may be attributed to ${}^{2}B_{1g} \rightarrow {}^{2}A_{1g}$ transition in a square-planar stereochemistry.³¹ The scanning electron micrographs of polymer-anchored ligand and the supported catalyst clearly show the morphological change which occurred on the surface of polystyrene after loading of the metal. The catalyst is thermally stable up to 430 °C.

Oxidation of sulfides is the most straightforward method for the synthesis of sulfoxides and sulfones, both of which are important

as commodity chemicals and, in some cases, as pharmaceuticals. To test the catalytic activity of the present catalyst, first oxidation of sulfides were conducted with hydrogen peroxide at room temperature. For optimization of reaction conditions, we choose oxidation of diphenyl sulfide as a probe reaction. The effects of solvent, temperature, and amount of H₂O₂ were examined and the results are presented in Table 1. The oxidation of diphenyl sulfide with 30% hydrogen peroxide using polymer-anchored Cu(II) complex as a catalyst was examined in several solvents (Table 1). The less polar solvents which are immiscible with aqueous hydrogen peroxide were not effective (runs 1–3). In the polar solvents, diphenyl sulfide was efficiently oxidized into the corresponding sulfoxide. The oxidative ability of this reaction system in more polar solvents like CH₃CN (run 4), MeOH (run 6) and EtOH (run 7) is greater than that in less polar solvents like CH₃CH₂CN (run 5), iPrOH (run 8), and tBuOH (run 9). The best condition to prepare the sulfoxide selectively is the reaction in CH₃CN at room temperature (run 4). The effect of temperature was investigated for the oxidation of diphenyl sulfide and the results are shown in Table 1. When reaction temperature increases from room temperature (run 4) to 40 °C (run 10) there was a slight increase in conversion but further increase in temperature (conversion kept constant on run 11) had no effect on conversion. Amount of H₂O₂ has a significant effect on the conversion and selectivity of diphenyl sulfide oxidation reaction. Conversion increased when amount of H₂O₂ increased from 5 mmol (run 12) to 10 mmol (run 4) but there was no significant change in conversion when amount changed to 15 mmol (run 13) in the same reaction condition. The selectivity of sulfoxide decreased with the increase of the amount of H₂O₂. This is due to further oxidation of sulfoxide.

To examine the reactivity of the catalyst further, oxidation of other sulfides also has been investigated (Table 2). Substrate scope is extended to methyl phenyl sulfide, ethyl phenyl sulfide, dibutyl sulfide, and diethyl sulfide etc. The sulfoxides were selectively obtained in all cases. A series of substrates, aryl alkyl, aryl allyl, and dialkyl sulfides, could be oxidized to the corresponding sulfoxides. The reactivity and conversion were dependent on the nature of the



Scheme 1. Preparation of polymer-anchored Cu(II) complex.

Table 1 Effect of different solvents on oxidation of diphenyl sulfide with polymer-anchored Cu(II) catalyst^a

Run	Solvent	Time (h)	Conversion ^b (%)	Selectivity of sulfoxide ^{b,c} (%)
1	CH ₂ Cl ₂	6	40	23
2	AcOEt	6	51	55
3	Toluene	6	32	12
4	CH₃CN	3	96	94
5	CH ₃ CH ₂ CN	4	86	82
6	MeOH	3	90	86
7	EtOH	3	88	89
8	ⁱ PrOH	4	66	78
9	^t BuOH	4	64	69
10 ^d	CH₃CN	3	97	91
11 ^e	CH₃CN	3	97	88
12 ^f	CH₃CN	3	62	93
13 ^g	CH_3CN	3	96	75

Conditions: diphenyl sulfide (5 mmol); 30% aq H₂O₂ (10 mmol); solvent (10 mL); 50 mg catalyst at room temperature.

Conversion and selectivity were determined by GC с

Products were characterized by GC-MS.

Reaction temperature was 40 °C.

e Reaction temperature was 50 °C.

5 mmol 30% H₂O₂ was used.

g 15 mmol 30% H2O2 was used.

Table 2

Oxi

substituent. In the case of allyl sulfides, less oxidation was observed at the carbon-carbon double bond. Similarly, benzylic sulfides could be oxidized to the corresponding sulfoxides with small oxidation products of the benzylic C-H bond.

The salt effect was also studied for the oxidative bromination reaction of salicylaldehyde. The catalyst was employed using H_2O_2 as an oxidant and MBr (M = Li, Na, K) as a bromine source (Table 3). Among the three salts, KBr has been found to be the most efficient bromine source and a monoselective product is obtained. The use of sodium bromide did not produce regioselective products. LiBr, though efficient, is less selective than KBr. Influence of temperature was also studied but there was no effect on the conversion of salicylaldehyde. With increase of temperature the conversion of salicylaldehyde was almost the same. A wide range of solvents have been employed in this reaction including, carbon tetrachloride, hexane, methanol, acetonitrile, and acetic acid. The best results were obtained when acetic acid was used as a solvent compared to others. The role of hydrogen peroxide was confirmed by conducting a blank experiment where the formation of bromo compound was not observed. All substrates selectively converted to their monobrominated products (Table 4). Substrates like phenol, resorcinol, anisole and N,N-dimethylaniline showed excellent para-selectivity. The activated aromatic substrates, like phenol, resorcinol, aniline, anisole and N,N-dimethylaniline, have shown high conversion into their respective monoselective products. The inactive substrates, like benzene, have shown low conversion and required longer reaction time. On the other hand, deactivated aromatic ring did not show any conversion in this reaction condition. 4-substituted aromatics selectively converted to 2-bromo derivatives and vice-versa.

In order to find out the effect of immobilization of homogeneous complex on polymer, the catalytic activity of the present

(%)

Entry	Sulfide	Conversion ^b (%)/time (h)	Selectivity of Sulfoxide ^{b,c}
1	\sim s \sim	82 (3)	73
2	$\wedge \sim \sim$	88 (6)	77
3 ^d	S C	96, 95, 94, 94, 93 (3)	94
4	S CH3	93 (3)	90
5	S C ₂ H ₅	91 (3)	88
6	S C ₆ H ₁₃	85 (6)	89
7	S S	87 (3)	86
8	S S	68 (6)	87
9	Me SC ₆ H ₁₃	79 (6)	86
10	MeO S C ₆ H ₁₃	78 (6)	84

Conditions: sulfide (5 mmol); 30% aq H₂O₂ (10 mmol); CH₃CN (10 mL); 50 mg catalyst at room temperature.

^b Conversion and selectivity were determined by GC.

^c Products were characterized by GC–MS and NMR.

^d Catalytic runs to test recyclability.

Table 3				
Effect of different bromine sources on the oxidative bromination of salicylaldehyde using polymer-anchored Cu(II) catalyst ^a				
			Let a second	and the second sec

Entry	Salt	Conversion ^b (%)	Selectivity ^{b,c}
1	LiBr	89	5-Bromo-2-hydroxy benzaldehyde (79) + 3, 5-dibromo-2-hydroxy benzaldehyde (21)
2	NaBr	79	5-Bromo-2-hydroxy benzaldehyde (64) + 3, 5-dibromo-2-hydroxy benzaldehyde (36)
3	KBr	95	5-Bromo-2-hydroxy benzaldehyde (100)

^a Conditions: salicylaldehyde (2 mmol); MBr (2.2 mmol); glacial acetic acid (5 mL); 30% aq H₂O₂ (2.2 mmol), 50 mg catalyst at room temperature.

^b Conversion and selectivity were determined by GC.

^c Products were characterized by GC-MS and NMR.

Table 4			
Oxidative bromination of various organic substrate	es catalyzed by	polymer-anchored	Cu(II) catalyst

Entry	Substrate	Conversion ^b (%) (time/h)	Product selectivity ^{b,c}
1 ^d	Salicylaldehyde	95, 94, 94, 92, 90 (3.0)	5-Bromo-2-hydroxy benzaldehyde (100)
2	Phenol	96 (2.5)	4-Bromophenol (100)
3	Resorcinol	95 (2.5)	4-Bromo-1,3-dihydroxybenzene (100)
4	4-Methylphenol	93 (2.5)	2-Bromo-4-methylphenol (100)
5	4-Nitrophenol	80 (6)	2-Bromo-4-nitrophenol (100)
6	4-Aminophenol	76 (3)	2-Bromo-4-aminophenol (100)
7	Anisole	93 (3)	4-Bromoanisole (100)
8	4-Methylanisole	90 (3)	2-Bromo-4-Methylanisole (100)
9	Aniline	96 (2.5)	4-Bromoaniline (83) 2-Bromoaniline (10)
10	4-Nitroaniline	88 (3)	2-Bromo-4-nitroaniline (100)
11	4-Methylaniline	93 (3)	2-Bromo-4-methylaniline (85)
12	4-Chloroaniline	86 (3)	2-Bromo-4-chloroaniline (100)
13	2-Methylaniline	88 (3)	4-Bromo-2-methylaniline (80)
			6-Bromo-2-methylaniline (15)
14	2-Chloroaniline	92 (3)	4-Bromo-2-chloroaniline (91)
			6-Bromo-2-chloroaniline (9)
15	2-Nitroaniline	82 (3)	4-Bromo-2-nitroaniline (76)
			6-Bromo-2-nitroaniline (24)
16	N,N-Dimethylaniline	92 (3)	4-Bromo-N,N-dimethylaniline (100)
17	Benzene	10 (6.0)	Bromobenzene (100)
18	Nitrobenzene	-	-

^a Conditions: substrate (2 mmol); KBr (2.2 mmol); glacial acetic acid (5 mL); 30% aq H₂O₂ (2.2 mmol), 50 mg catalyst at room temperature.

^b Conversion and selectivity were determined by GC.

 \underline{c} Products were characterized by GC–MS and NMR.

 $\frac{d}{}$ Catalytic runs to test recyclability.

polymer-anchored Cu(II) was compared with its homogeneous analog in oxidation and oxidative bromination reaction. From the results it is seen that the present polymer-anchored copper catalyst is more active than the corresponding homogeneous catalyst. Homogeneous catalyst oxidized diphenyl sulfide with 79% conversion while polymer-anchored copper catalyst performed well with 96% conversion with H₂O₂ at room temperature. In oxidative bromination of salicylaldehyde, homogeneous complex shows 82% conversion whereas heterogeneous catalyst shows 95% conversion by GC analysis. Also, the homogeneous catalyst cannot be recovered or reused. In the absence of the catalyst, H₂O₂ alone shows slight activity in oxidation reaction of sulfides but is unable to oxyhalogenate the substrates to any significant extent. The catalytic activity of this catalyst was also superior with other reported heterogeneous catalysts for the oxidation reaction of sulfides and oxidative bromination reaction of organic substrates with H₂O₂.³²

The recyclability of the catalyst is important for the catalysis reaction. The reusability of polymer-anchored Cu(II) complex was investigated in the oxidation of diphenyl sulfide and oxidative bromination of salicylaldehyde. Catalyst was separated by filtration after the first catalytic run, washed with solvent and dried under vacuum then subjected to the second run under the same reaction conditions. The catalytic run was repeated with further addition of substrates under optimum reaction conditions and the nature and yield of the final products were comparable to that of the original one. It is found that the catalytic activity or selectivity does not change significantly after five consecutive runs.

To check the leaching of copper into the solution during the reaction, oxidation of diphenyl sulfide and oxidative bromination of salicylaldehyde were carried out under the optimum reaction conditions. The reaction is stopped after the reaction proceeds for 2 h. The catalyst was separated from the reaction mixture by filtration and the conversion was determined. The separated filtrate is allowed to react for another 2 h under the same reaction conditions, but no further increment in conversion is observed in gas chromatographic analyses. The UV–vis spectroscopy was also used to determine the stability of the heterogeneous catalyst. The UV– vis spectra of the reaction solution, at the first run, do not show any absorption peaks characteristic of copper metal, indicating that the leaching of copper does not take place during the course of the oxidation or oxidative bromination reaction. These results suggest that the catalyst is heterogeneous in nature.

In conclusion we have prepared a polymer-anchored Cu(II) complex which was used as a heterogeneous catalyst for oxidation of sulfides and oxidative bromination of aromatic substrates with H_2O_2 as oxygen source at room temperature. The catalyst shows high catalytic activity and selectivity. This catalyst is air-stable, inexpensive and easy to make. Leaching test indicates that the catalytic reaction is mainly heterogeneous in nature. The reusability of this catalyst is high and can be reused five times without significant decrease in its initial activity.

Acknowledgments

We thank the Department of Material Science, Indian Association of Cultivation of Science, Kolkata, for providing the instrumental support. MI acknowledges the DST, CSIR, and UGC, New Delhi, India for funding.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2011.10.138.

References and notes

- (a) Drabowicz, J.; Kielbsinski, P.; Mikolajczyk, M. In *The Chemistry of Sulphone* and *Sulphoxide*; Patai, S., Rappoport, Z., Stirling, C., Eds.; John Wiley and Sons: NY, 1988; (b) Frenanez, I.; Khiar, N. *Chem. Rev.* 2003, 103, 3651.
- (a) Hajipour, A. R.; Kooshki, B.; Ruoho, A. E. Tetrahedron Lett. 2005, 46, 5503; (b) Ozanne-Beaudenon, A.; Quideau, S. Tetrahedron Lett. 2006, 47, 586; (c) Iranpoor, N.; Firouzabadi, H.; Pourali, A.-R. Synlett 2004, 347; (d) Nicolaous, K. C.; Magolda, R. L.; Sipio, W. J.; Lysenko, W. E.; Joullie, M. M. J. Am. Chem. Soc. 1980, 102, 3784.
- 3. Noyori, R.; Aoki, M.; Sato, K. Chem. Commun. 2003, 1977.
- (a) Kaczorowska, K.; Kolarska, Z.; Mitka, K.; Kowalski, P. Tetrahedron 2005, 61, 8315; (b) Maurya, M. R.; Chandrakar, A. K.; Chand, S. J. Mol. Catal. A: Chem. 2007, 274, 192; (c) Egami, H.; Katsuki, T. J. Am. Chem. Soc. 2007, 129, 8940; (d) Blakemore, P. R.; Burge, M. S. J. Am. Chem. Soc. 2007, 129, 3068; (e) Mohammadpoor-Baltork, I.; Hill, M.; Caggiano, L.; Jackson, R. F. W. Synlett 2006, 3540; (f) Kelly, P.; Lawrence, S. E.; Maguire, A. R. Synlett 2007, 1501; (g) Hosseinpoor, F.; Golchoubian, H. Tetrahedron Lett. 2006, 47, 5195; (h) Alonso, D. A.; Nájera, C.; Varea, M. Tetrahedron Lett. 2002, 43, 3459.
- Diederich, F.; Stang, P. J. Metal-Catalyzed Cross-Coupling Reactions; John Wiley & Sons: New York, 1997.
- Paul, V.; Sudalai, A.; Daniel, T.; Srinivasan, K. V. Tetrahedron Lett. 1994, 35, 7055.
 Auerbach, J.; Weissman, S. A.; Blacklock, T. J.; Angeless, M. R.; Hoogsteen, K. Tetrahedon Lett. 1993, 34, 931.
- 8. Smith, K.; Bahzad, D. J. Chem. Soc. Chem. Commun. **1996**, 467.
- 9. Singh, A. P.; Marajkar, S. P.; Sharma, S. J. Mol. Catal. A: Chem. **1999**, 150, 241.
- Barhate, N. B.; Gajare, A. S.; Wakharkar, R. D.; Badekar, A. V. *Tetrahedron Lett.* 1998, 39, 6349.
- 11. Neumann, R.; Assael, I. J. Chem. Soc. Chem. Commun. 1988, 1285.

- 12. Choudary, B. M.; Sudha, Y.; Reddy, P. N. Synlett 1994, 450.
- 13. Conte, V.; di Furia, F.; Maro, S. Tetrahedron Lett. 1994, 45, 7429.
- 14. Kalita, D.; Sarmah, S.; Das, S. P.; Baishya, D.; Patowary, A.; Baruah, S.; Islam, N. S. *React. Funct. Polym.* **2008**, 68, 876.
- 15. Maurya, M. R.; Sikarwar, S.; Joseph, T.; Manikandan, P.; Halligudi, S. B. React. Funct. Polym. 2005, 63, 71.
- Feng, X.-M.; Wang, Z.; Bian, N.-sheng; Wang, Z-lin Inorg. Chimi. Acta. 2007, 360, 4103.
- 17. Velusamy, S.; Kumar, A. V.; Saini, R.; Punniyamurthy, T. Tetrahedron Lett. 2005, 46, 3819.
- Moriuchi, T.; Yamaguchi, M.; Kikushima, K.; Hirao, T. Tetrahedron Lett. 2007, 48, 2667.
- Zimowska, M.; Michalik-Zym, A.; Połtowicz, J.; Bazarnik, M.; Bahranowski, K.; Serwicka, E. M. Catal. Today 2007, 124, 55.
- Bakala, P. C.; Briot, E.; Salles, L.; Brégeault, J. M. Appl. Catal. A: Gen. 2006, 300, 91.
- 21. Medina, J. C.; Gabriunas, N.; Páez-Mozo, E. J. Mol. Catal. A: Chem. 1997, 115, 233.
- 22. Gigante, B.; Corma, A.; Garćıa, H.; Sabater, M. J. Catal. Lett. 2000, 68, 113.
- 23. Mathew, T.; Padmanabhan, M.; Kuriakose, S. J. Appl. Polym. Sci. 1996, 59, 23.
- 24. Kotov, St. V.; Balbolov, E. J. Mol. Catal. A: Chem. 2001, 176, 41.
- (a) Sherrington, D. C. *Catal. Today* **2000**, *57*, 87; (b) Antony, R.; Tembe, G. L.; Ravindranathan, M.; Ram, R. N. *J. Appl. Polym. Sci.* **2003**, *90*, 370; (c) Grivani, G.; Tangestaninejad, S.; Halili, A. *Inorg. Chem. Commun.* **2007**, *10*, 914; (d) Maurya, M. R.; Arya, A.; Ada~o, P.; Pessoa, J. C. *Appl. Catal. A: Gen.* **2008**, *351*, 239.
- 26. Chacko, A.; Mathew, B. J. Appl. Polym. Sci. 2003, 90, 3708.
- Sherrington, D. C. Supported Reagents and Catalysts in Chemistry; Royal Society of Chemistry: Cambridge, 1998.
- 28. Holy, N. L. J. Org. Chem. 1979, 44, 239.
- 29. Sallam, S. A.; Orabi, A. S. Transit. Met. Chem. 2002, 27, 447.
- 30. Gnanasoundari, V. G.; Natarajan, K. Transit. Met. Chem. 2004, 29, 511.
- Lever, A. B. P. Inorganic electronic spectroscopy, second ed.; Elsevier science publication: New York, 1986.
- (a) Maurya, M. R.; Kumar, M.; Kumar, U. J. Mol. Catal. A: Chem. 2007, 273, 133;
 (b) Hazarika, P.; Kalita, D.; Sarmah, S.; Borah, R.; Islam, N. S. Polyhedron 2006, 25, 3501.