Articles

Metalloporphyrin-Catalyzed Chemoselective Oxidation of Sulfides with Polyvinylpyrrolidone-Supported Hydrogen Peroxide: A Simple Catalytic System for Selective Oxidation of Sulfides to Sulfoxides

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Room temperature oxidation of organic sulfides with polyvinylpyrrolidone-supported hydrogen peroxide (PVP-H_2O_2) in the presence of Mn(III) complexes of *meso*-tetraphenylporphyrin, Mn(TPP)X (X = OCN, SCN, OAc, Cl) and imidazole (ImH) leads to the highly chemoselective (ca. 90%) oxidation of sulfides to the corresponding sulfoxide. The efficiency of reaction has been shown to be influenced by different reaction parameters such as the nature of counterion (X) and solvent as well as the molar ratio of reactants. Using Mn(TPP)OCN and ImH in 1:15 molar ratio and acetone as the solvent leads to the efficient oxidation of different sulfides.

Key Words : Mn(III)-*meso*-tetraphenylporphyrin, PVP-H_2O_2, Oxidation of sulfides, Sulfoxide

Introduction

The selective oxidation of sulfides to sulfoxides has been an important challenge in synthetic organic chemistry. Sulfoxides are important intermediates in organic synthesis which are useful in the synthesis of natural products and biologically significant molecules. They have also been employed as ligands in asymmetric catalysis and as oxo-transfer reagents.[1-4] Hydrogen peroxide may be used as an electrophilic reagent for the direct oxidation of sulfides to sulfoxides. However, the rate and/or the enantioselectivity of reaction can be greatly improved by the use of catalysts such as polyoxometalates, transition-metal Schiff-base complexes, Fenton's reagent and hexafluoro-2-proponal.[1,5] On the other hand, urea-hydrogen peroxide (UHP) has been proven to be a suitable substitute for the concentrated hydrogen peroxide in organic synthesis.[6,7] Ti-Beta zeolite catalyzed oxidation of sulfides to sulfoxides with UHP has been reported.[7] No reaction took place in the absence of the catalyst. Metalloporphyrins have been used as catalysts in the selective oxidation of sulfides to sulfoxides or sulfones with different oxygen donors.[8-11] Polymer supported reagents have had much attention in recent years due to their selectivity, stability and easy handling. Polyvinylpyrrolidone-supported hydrogen peroxide (PVP-H_2O_2) introduced by Pourali *et al.*,[12] has been successfully employed for iodination of aromatic compounds as well as the oxidation of α, β-enones.[13] The reagent is easily prepared from cheap aqueous 30% hydrogen peroxide and polyvinylpyrrolidone K-30. The reagent

can be stored in a refrigerator for several months without loss of its weight or activity.[12] We have recently reported the selective oxidation of alkenes to epoxides catalyzed by metalloporphyrins using polyvinylpyrrolidone-supported hydrogen peroxide (PVP-H_2O_2) as the oxygen atom donor.[14] It is has been shown that in oxidation of alkenes with tetra-*n*-butylammonium periodate catalyzed by Mn-porphyrins in dichloromethane, the presence of H_2O leads to the formation of a high-valent Mn-oxo species which can be easily monitored by the UV-vis spectroscopy.[15,16] On the other hand, the oxidizing ability of oxidant depends on the nature of active oxidant involved in the catalytic cycle i.e. the high-valent Mn-oxo species and the six coordinate one, Mn(III)-porphyrin(oxidant)(axial base).[15,17-19] PVP-H_2O_2 has the advantage that the vacuum dried reagent may be used as a nearly water-free peroxide source. In the present work, the oxidation of different organic sulfides with PVP-H_2O_2 in the presence of manganese(III) *meso*-tetraphenylporphyrin, Mn(TPP)X (X= SCN, OCN, Cl, OAc) has been studied.

Experimental

Instruments and Reagents. ^{1}H NMR spectra were obtained in $CDCl_3$ solutions with a Bruker FT-NMR 250 (250 MHz) spectrometer. The residual $CHCl_3$ in conventional 99.8% $CDCl_3$ gives a signal at δ = 7.26 ppm, which was used for calibration of the chemical shift scale. The absorption spectra were recorded on a double beam GBC-916 UV-vis spectrophotometer. The reaction products of oxidation were

analyzed by a Varian 3800 gas chromatograph equipped with a HP-5 capillary column (phenylmethyl siloxane 30 m × 320 μm × 0.25 μm) and flame-ionization detector. PVP-H_2O_2 has been prepared according to the literature.[12] Pyrrole (for synthesis), propionic acid (for synthesis), imidazole, benzaldehyde (for synthesis), $Mn(NO_3)_2 \cdot 4H_2O$, acetone (for synthesis), petroleum ether (bp 40-60 °C), hydrogen peroxide (30%), and the sulfides were purchased from Merck and Aldrich. Polyvinylpyrrolidone K30 was obtained from Fluka. General procedure for the preparation of PVP supported hydrogen peroxide was as described before.[13] The hydrogen peroxide content of the reagent was determined by iodometric titration to be ca. 7 mmoL per gram of the solid reagent.

Preparation and Metallation of *meso*-Tetraphenylporphyrin (H₂TPP). H₂TPP and Mn(TPP)OAc were prepared and purified as reported previously.[20,21] Mn(TPP)X complexes ($X^- = Cl^-$, SCN^-, OCN^-, OAc^-) were obtained using Mn(TPP)OAc and corresponding NaX salts by a ligand exchange reaction according to the procedure of Ogoshi *et al.*[22] The Soret band (λ/nm in CH_2Cl_2) of Mn(TPP)Cl, Mn(TPP)SCN, Mn(TPP)OCN and Mn(TPP)OAc appears at 478, 483, 475 and 479 nm, respectively.

Oxidation of Sulfides. Stock solutions of Mn(TPP)X (0.003 M) and imidazole (0.5 M) were prepared in CH_2Cl_2. In a 10 mL round-bottom flask, the reagents were added in the following order: catalyst (0.003 mmoL, 1.0 mL), sulfide (0.15 mmoL), imidazole (0.045 mmoL, 90 μL). PVP-H_2O_2 (0.45 mmoL, 0.07 g) was then added to the reaction solution at room temperature. The mixture was stirred thoroughly for the required time at ambient temperature in air. It should be noted that the atmospheric conditions had little effects on the conversion and reaction selectivity compared to the anaerobic ones for a 30 min reaction time. The progress of reaction was monitored by thin layer chromatography on commercial Merck precoated TLC plates (silica gel 60 F254). In the case of other solvents (acetone, chloroform, dioxane), the dichloromethane solutions of catalyst and imidazole have been added to the flask and after evaporating dichloromethane, the alternate solvent has been added. The reaction solutions were analyzed by GC. Isolated yields have been obtained using a silica gel column (70-230 mesh) by petroleum ether (bp 40-60) and petroleum ether/ethyl acetate as eluent, respectively.

Results and Discussion

Oxidation of Methyl Phenyl Sulfide. Oxidation of methyl phenyl sulfide with PVP-H_2O_2 in the presence of catalytic amounts of Mn(TPP)OAc at room temperature led to the selective sulfoxidation of the substrate. The effect of varying a number of reaction parameters has been studied.

Effect of Solvent. Among the different solvents tested (dichloromethane, chloroform, dioxane, acetone) the highest yields were achieved in acetone; PVP-H_2O_2 is almost insoluble in most of the common organic solvents. It seems that the formation of hydrogen bonds between the polymer-supported hydrogen peroxide molecules and acetone as the
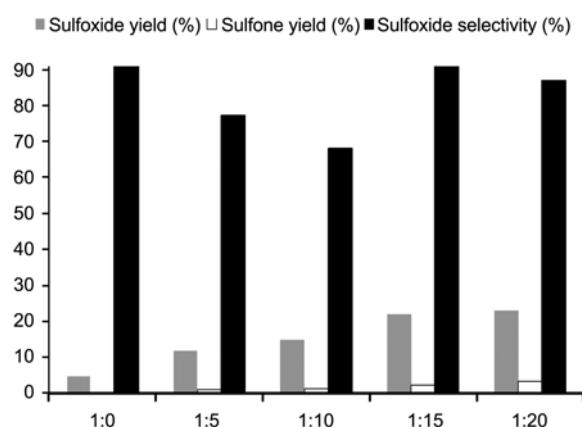

Figure 1. Effect of Mn(TPP)OAc: ImH molar ratio on the oxidation of methyl phenyl sulfide with PVP-H_2O_2 in acetone at room temperature. The molar ratio of Mn(TPP)OAc, sulfide and PVP-H_2O_2 are as 1:50:150.

solvent causes the release of H_2O_2 and the higher reactivity of PVP-H_2O_2 in acetone relative to the other solvents. It should be noted that the use of protic solvents such as methanol leads to the formation of high valent Mn-oxo species[15,23] and consequently the overoxidation of the sulfoxide to the corresponding sulfone.

Effect of Nitrogenous Donor. Catalytic activity of metalloporphyrins has been found to be significantly dependent on the presence of nitrogen donors such as imidazole.[15,24-26] Figure 1 shows the effect of different molar ratios of ImH to Mn(TPP)OAc on the conversion and selectivity of the reaction of phenyl methyl sulfide with PVP-H_2O_2. The yield of sulfoxide increases up to 1:20 molar ratio of ImH to the catalyst. Addition of ImH up to 1:10 molar ratio is accompanied with a decrease in the selectivity of product. This observation may be due to the involvement of a high-valent Mn-oxo species in the catalytic cycle; ImH as a σ and π electron donor, increases the electron density on the metal centre and facilitates the formation of a high-valent Mn-oxo species.[15] Interestingly, further addition of ImH results in an increased selectivity comparable with that observed in the
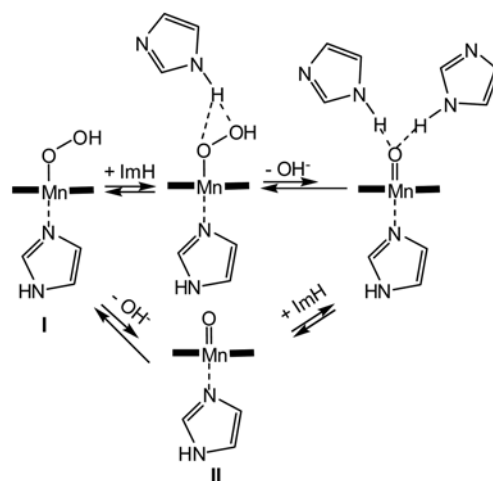

Figure 2. Schematic presentation of hydrogen bond formation between ImH and the possible active intermediates.
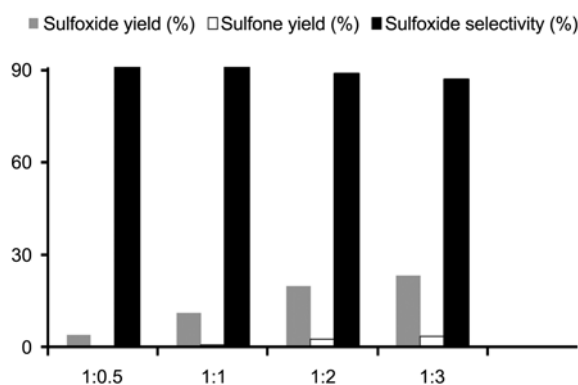
Figure 3. Effect of the molar ratio of PVP-H$_2$O$_2$ to methyl phenyl sulfide on the oxidation of methyl phenyl sulfide with PVP-H$_2$O$_2$ in acetone at room temperature. The molar ratio of Mn(TPP)OAc, ImH and sulfide are as 1:15:50.

absence of nitrogen donor. It seems that the increased steric hindrance around the reaction centre caused by the hydrogen bond formation between ImH and methyl phenyl sulfoxide as well as the active oxidant (Fig. 2) hinders the further oxidation of methyl phenyl sulfoxide to the corresponding sulfone. The ratio of 1:15 is the best one to achieve the highest yield and selectivity of sulfoxide. Beyond this ratio, a small decrease in the selectivity of sulfoxide has been observed.

Effect of the Molar Ratio of Oxidant to Substrate. Using various equivalents of hydrogen peroxide for the oxidation of methyl phenyl sulfide (Fig. 3) had little or no effect on the selectivity of products, but the highest yield was achieved with 3 equivalent of hydrogen peroxide.

Effect of Anionic Counterion (X). The catalytic activity

Table 1. Oxidation of methyl phenyl sulfide with PVP-H$_2$O$_2$ in the presence of Mn(TPP)X in acetone at room temperature[a]

Mn(TPP)X	Conversion[b] (%)	Sulfoxide yield[b] (%)	Time (min)
None	10[c]	8	120[d]
Mn(TPP)OAc	15	12	30
Mn(TPP)Cl	7	6	30
Mn(TPP)SCN	50	45	30
Mn(TPP)OCN	70	61	30

[a]The molar ratios for Mn(TPP)X:ImH:sulfide:oxidant are 1:15:50:150. [b]Analyzed by GC. Authentic samples were prepared according to the literature [9,30]. [c]Control reaction in the absence of Mn(TPP)X and ImH. [d]The conversion was very low in 30 min.

of Mn(TPP)X (X = SCN, OCN, Cl, OAc) was significantly influenced by the nature of counterion (Table 1). The observed relative activities of Mn(TPP)X may be possibly due to the leaving group ability of the anionic counter ions in the reaction conditions which may be improved by hydrogen bond interactions with strong hydrogen bond donors; departure of anionic counterion (X⁻) as the leaving groups is an important factor influencing the catalytic activity of metalloporphyrins in organic solvents.[27,28] Acetone is an aprotic dipolar solvent which has a very small hydrogen bond donor ability and does not solvate anions by hydrogen bonding interactions to any appreciable extent.[29] Therefore, the departure of the leaving group seems to be facilitated by hydrogen bond formation between X⁻ and ImH.[15]

Oxidation of Different Sulfides. Oxidation of different sulfides with PVP-H$_2$O$_2$ has been summarized in Table 2. The comparable reactivity of different sulfides towards oxidation with PVP-H$_2$O$_2$ suggests that the steric and electronic

Table 2. Oxidation of organic sulfides with PVP-H$_2$O$_2$ in the presence of Mn(TPP)OCN in acetone at room temperature[a]

Entry	Sulfide	Conversion (%)	Sulfoxide yield[b,c] (%)	Selectivity (%)	Time (min)
1		80	72 (70)	90	30
2		82	72(68)	88	30
3		85	77(70)	90	30
4		60	55(52)	92	30
5		70	(60)	86	30
6		75	68(70)	91	30
7		80	74(68)	92	30

[a]The molar ratios for Mn(TPP)OCN:ImH:sulfide:oxidant are 1:15:50:150. [b]Analyzed by GC. Authentic samples were prepared according to the literature [9,30]. [c]The data in parentheses represent isolated yields.
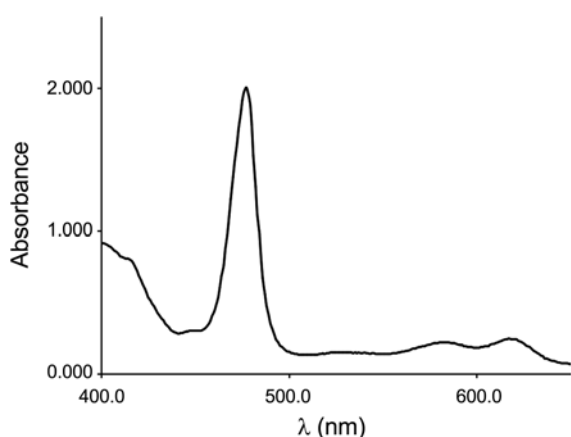
Figure 4. UV-vis spectra of reaction mixture for oxidation of methyl phenyl sulfide with PVP-H_2O_2 in dichloromethane in the presence of Mn(TPP)OAc and ImH 10 min after the addition of the oxidant.

properties of substituents attached to the sulfur atom of the sulfides have little effect on their reactivity.

The Nature of Active Oxidant. Formation of high valent Mn(IV or V)-Oxo species as the active oxidant is accompanied with the shift of the Soret band of the catalyst precursor, Mn(TPP)X, to shorter wavelengths which can be observed in protic solvents such as alcohols or mixed solvents such as acetonitrile/H_2O[31] or dichloromethane/alcohol.[23] In protic solvents, formation of hydrogen bonds leads to the stabilization of high valent metal oxo species. Therefore, with the exception of highly electron-deficient Mn-porphyrins such as *meso*-tetra(pentafluorophenyl)porphyrin-atomanganese(III) acetate or those with bulky groups at the *ortho* positions of aryl groups, little information about the high valent metal-oxo species may be obtained by the study of the UV-vis spectra of the reaction mixtures in nonprotic solvents such as dichloromethane.[27] On the other hand, the formation of a six coordinate Mn(III) species, i.e. (porphyrin)(imidazole)(Mn(III)(oxidant) has little effect on the position of the Soret band of the metalloporphyrin in the UV-vis spectra. As we have previously reported[14] little or no shift of the Soret band has been observed in catalytic system containing Mn(TPP)X and PVP-H_2O_2 in dichloromethane. Indeed, there is no evidence for the formation of a high valent Mn(IV) or Mn(V)-oxo species in the UV-vis spectra (Fig. 4) of the reaction mixture. However, as we have previously proposed,[9] in spite of the absence of the Soret band due to a high valent Mn-Oxo species in the UV-vis spectra, the contribution of this species can not be excluded and may be due to the high activity of this species towards oxidation of sulfides.

Conclusion

In summary, efficient and selective oxidation of different organic sulfides to the corresponding sulfoxides with PVP-H_2O_2 in the presence of a simple metalloporphyrin, Mn

(TPP)OCN, in acetone at room temperature is reported. Further studies based on using electron-deficient Mn-porphyrins as more efficient and stable catalysts are in progress.

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