

Short Communication

Ion Exchange Resin Catalyzed Selective Oxidation of Sulfides to Sulfoxides Using Hydrogen Peroxide

Moslem Mansour Lakouraj*, Mahmood Tajbakhsh,
and Hamed Tashakkorian

Department of Chemistry, Faculty of Basic Science, University of Mazandaran, Babolsar, Iran

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Summary. An efficient method for the selective oxidation of sulfides to sulfoxides under mild and environmentally safe conditions is achieved using hydrogen peroxide in the presence of Amberlyst 15 and Amberlite IR-400 at room temperature. This procedure can be applied for dialkyl and diaryl sulfides with a variety of functional groups. Functional groups such as hydroxyl, methoxy, amino, aldehyde, and olefinic double bonds remain intact.

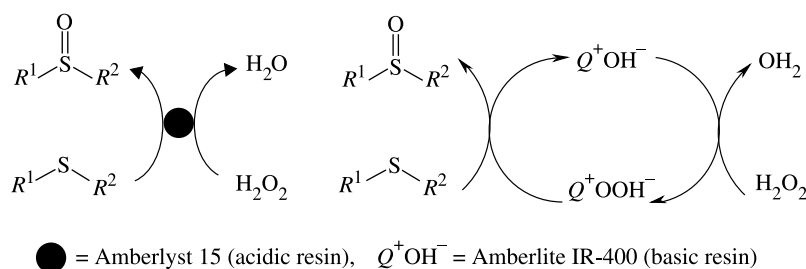
Keywords. Amberlyst 15; Amberlite IR-400; Hydrogen peroxide; Sulfide; Sulfoxide.

Introduction

Transformation of sulfides to sulfoxides can be achieved by employing oxygenating agents as well as halogenating ones [1–5], but halogenating agents give rise to aromatic halogenation or formation of α -derivatives, and C–S bond cleavage. Oxidation of sulfides is the standard method for the preparation of sulfoxides, although the undesired over-oxidation to sulfones is a quite frequent competing reaction [6]. To avoid the facile conversion of sulfoxides into sulfones, careful selection of oxidizing agent and reaction conditions are required [7].

Several methods have been introduced for this purpose [8–24]. However, most of the existing methods use sophisticated reagents, complex catalysts, toxic metallic compounds, or rare oxidizing agents that are difficult to prepare. Many of these procedures also suffer from poor selectivity. In contrast to other oxidizing agents, H_2O_2 is the most attractive oxidant from an environmental viewpoint and shows safety in operation and is relatively cheap [25, 26]. However, H_2O_2 alone has to be

* Corresponding author. E-mail: Lakouraj@umz.ac.ir



Scheme 1

used in a controlled manner to reduce the possibility of an over-oxidation reaction [27]. Therefore, there is a need to improve the utility of H_2O_2 for the selective conversion of sulfides to sulfoxides. Ion exchange resins are extensively studied and used for different purposes in organic synthesis [28]. To the best of our knowledge no report exists for the selective conversion of sulfides to sulfoxides with commercial H_2O_2 in the presence of recyclable cation or anion exchange resins as catalyst.

In continuation of our investigation on the application of the Amberlyst OH^- form and H_2O_2 for selective conversion of nitriles to amides [29] and epoxidation of α,β -unsaturated carbonyls [30] along with selective oxidation of thioethers to sulfoxides [31, 32], herein we introduce a simple method for selective oxidation of thioethers to their corresponding sulfoxides with H_2O_2 (35%) in the presence of acidic and/or basic ion exchange resin as a promoter (Scheme 1).

Results and Discussion

In this study, a number of sulfides have been prepared [33] and treated with Amberlyst 15/ H_2O_2 and/or Amberlite IR-400/ H_2O_2 . The results are summarized in Tables 1 and 2. As can be seen in these Tables, different types of sulfides were selectively oxidized to their corresponding sulfoxides in excellent yields at room temperature. Aliphatic sulfides were completely converted to the corresponding sulfoxides in less than 2 h (Table 1, entries 13–16), whereas aromatic sulfides required 3–11 h for complete conversion (Table 1, entries 1–11). The substituents on sulfides showed significant effects on the reaction times. For example, electron withdrawing groups such as chloro, nitro, and cyano or phenyl groups show some rate retardation, while methoxy, methyl, and amino groups show little rate enhancement due to their electron-donating properties. The Amberlyst 15/ H_2O_2 and Amberlite IR-400/ H_2O_2 systems were chemo-selective, tolerating various functional groups such as methoxy, amino, carbonyl, nitrile, halide, hydroxyl, and olefinic double bonds. Although the hydroxyl groups are readily oxidized by common reagents [34], with this reagent the hydroxyl and aldehyde groups resisted oxidation.

In order to demonstrate the chemoselectivity of this method, we investigated the competitive reactions of sulfides with sulfoxides, alcohols, aldehydes, and nitriles. As shown in Scheme 2, sulfides are converted to the corresponding sulfoxide in good to high yield with excellent selectivity. However, in the reaction of

Table 1. Selective oxidation of sulfides to sulfoxides with Amberlyst 15/H₂O₂^{a,b}

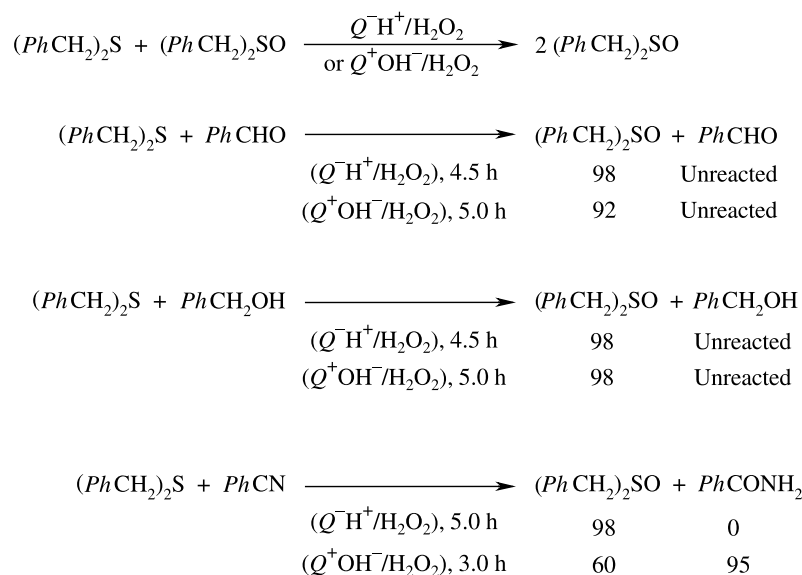
Entry	<i>R</i> ¹	<i>R</i> ²	Time/h	Yield/% ^c	Lit. mp (Found mp)/°C	Ref.
1	<i>Ph</i>	<i>Me</i>	3	98	33–34 (31.5–32.5)	[35]
2	<i>Ph</i>	<i>PhCH</i> ₂	6.5	95	117–121 (116–118)	[9]
3	4- <i>MeC</i> ₆ H ₄	<i>PhCH</i> ₂	6	98	135–136 (136.5–137.5)	[4]
4	4- <i>ClC</i> ₆ H ₄	<i>PhCH</i> ₂	9	85	– (128–130)	–
5	4- <i>MeOC</i> ₆ H ₄	<i>PhCH</i> ₂	5.5	98	– (105–107)	–
6 ^d	4- <i>O</i> ₂ <i>NC</i> ₆ H ₄	<i>Ph</i>	15	70	100–101 (101–103)	[36]
7	2- <i>H</i> ₂ <i>NC</i> ₆ H ₄	<i>Ph</i>	5	98	oil	–
8	<i>PhCH</i> ₂	<i>PhCH</i> ₂	4.5	98	133–135 (134.5)	[35]
9	<i>Ph</i>	CH ₂ CH ₂ OH	6.5	95	150–152.2 (151–152)	[37]
10	<i>Ph</i>	CH ₂ COOH	7.5	95	112.5–113 (113–114)	[38]
11	4- <i>ClC</i> ₆ H ₄	CH ₂ CN	9	85	69–73 (70–71)	[32]
12	Cyclohexyl	<i>PhCH</i> ₂	2.5	95	oil	[39]
13	CH ₂ =CHCH ₂	CH ₂ =CHCH ₂	0.5	98	40–40.5 (40–41)	[40]
14	<i>Me</i>	CH ₂ CH ₂ CHO	0.1	98	oil	–
15	–CH ₂ CH ₂ CH ₂ CH ₂ –		0.2	98	105–107 (104–105)	[41]
16	<i>n-Bu</i>	<i>n-Bu</i>	2	98	32.6 (32)	[42]

^a All reactions were carried out at room temperature using an optimized ratio of 1/0.5/2 of sulfide/*Q*[–]H⁺/H₂O₂ in methanol; ^b all products were characterized spectroscopically (¹H NMR, IR) and showed physical and spectral data in accordance with their expected structure and by comparison with authentic samples; ^c yields refer to pure isolated products; ^d the reaction was carried out in methanol/dioxone (1:1)

Table 2. Selective oxidation of sulfides to sulfoxides with Amberlite IR-400/H₂O₂^{a,b}

Entry	<i>R</i> ¹	<i>R</i> ²	Time/h	Yield/% ^c	Lit. mp (Found mp)/°C	Ref.
1	<i>Ph</i>	<i>Me</i>	3.5	98	33–34 (31.5–32.5)	[35]
2	<i>Ph</i>	<i>PhCH</i> ₂	7.5	92	117–121 (116–118)	[9]
3	4- <i>MeC</i> ₆ H ₄	<i>PhCH</i> ₂	6.5	93	135–136 (136.5)	[4]
4	4- <i>ClC</i> ₆ H ₄	<i>PhCH</i> ₂	9	85	– (128–130)	–
5	4- <i>MeOC</i> ₆ H ₄	<i>PhCH</i> ₂	6	95	– (105–107)	–
6 ^d	4- <i>O</i> ₂ <i>NC</i> ₆ H ₄	<i>Ph</i>	16	65	100–101 (101–103)	[36]
7	2- <i>H</i> ₂ <i>NC</i> ₆ H ₄	<i>Ph</i>	5.5	93	oil	–
8	<i>PhCH</i> ₂	<i>PhCH</i> ₂	5	92	133–135 (134.5)	[35]
9	<i>Ph</i>	CH ₂ CH ₂ OH	7	93	150–152.2 (151–152)	[37]
10	<i>Ph</i>	CH ₂ COOH	7.5	93	112.5–113 (113–114)	[38]
11	Cyclohexyl	<i>PhCH</i> ₂	3	92	oil	[39]
12	CH ₂ =CHCH ₂	CH ₂ =CHCH ₂	0.5	98	40–40.5 (40–41)	[40]
13	<i>Me</i>	CH ₂ CH ₂ CHO	0.1	98	oil	–
14	–CH ₂ CH ₂ CH ₂ CH ₂ –		0.2	98	105–107 (104–105)	[41]
15	<i>n-Bu</i>	<i>n-Bu</i>	2	98	32.6 (32)	[42]

^a All reactions were carried out at room temperature using an optimized ratio of 1/0.5/3 of sulfide/*Q*⁺OH[–]/H₂O₂; ^b all products were characterized spectroscopically (¹H NMR, IR) and showed physical and spectral data in accordance with their expected structure and by comparison with authentic samples; ^c yields refer to pure isolated products; ^d the reaction was carried out in methanol/dioxone (1:1)

**Scheme 2**

sulfide in the presence of nitrile using basic resin, hydrolysis of nitrile to the corresponding amide was observed.

To test the role of the catalytic activation of the resin, a model run was carried out with thioanisole in the absence of resin. It was found that using even a six-fold excess of H_2O_2 , after a long reaction time (12 h) the reaction was not completed.

The effect of solvent on the oxidation efficiency of the reagent was evaluated by carrying out the oxidation of thioanisole in a series of solvents such as dichloromethane, *n*-hexane, dioxane, and methanol at room temperature. It was found that polar solvents, such as methanol seem to increase the oxygenation yield due to good miscibility with reactant and resin. Therefore, reactions were preformed in methanol as solvent of choice at ambient temperature. The influence of molar ratios of sulfide/catalyst/ H_2O_2 on the progress of the sulfoxidation reaction of thioanisole is presented in Table 3. As evident, sulfoxide formation was achieved

Table 3. Optimization of the reaction conditions in methanol at 25°C

<i>PhSMe</i> / H_2O_2 /Catalyst			Yield/% (Time/h) Amberlite IR-400	Yield/% (Time/h) Amberlyst 15
1	1	0	30 (8)	30 (8)
1	1	0.5	95 (6)	90 (5.5)
1	1	1	90 (6)	95 (5.5)
1	3	0.5	98 (3.5)	98 (3)
1	3	0.3	85 (4.5)	90 (4)
1	2	0.5	98 (4.5)	98 (3)
1	2	1	90 (5)	95 (4)
1	3	1	98 (4)	98 (3.5)

using an optimized ratio of 1/0.5/2 of sulfide/ Q^-H^+ / H_2O_2 in methanol. In the case of basic resin, the ratio of sulfide/ Q^+OH^- / H_2O_2 was 1/0.5/3.

In conclusion, the oxidizing agent H_2O_2 is inexpensive and the reactions are highly clean affording quantitative yields of sulfoxides. This oxidation system is an ideal waste-avoiding oxidant since water is the only theoretical by-product. Owing to the remarkable chemo-selectivity, high yield, and the convenient procedure, Amberlyst 15 and Amberlite IR-400 are the best catalysts for the oxidative conversion of sulfide to sulfoxide with H_2O_2 . Furthermore, the procedure is well suitable for preparative and large scale reactions or industrial usage because of high efficiency, reusability of the catalysts, and cheapness.

Experimental

Chemicals were purchased from Merck, Fluka, and Aldrich chemical companies. A number of sulfides were prepared using the standard synthesis method [35]. All sulfoxides were separated and purified by chromatographic techniques and also identified by comparison of their mp, IR, NMR, and bp with those reported in literature [36]. 1H NMR spectra were recorded on a JEOL 90 MHz NMR spectrometer. IR spectra were recorded on a Pye-Unicam SP 1100 spectrophotometer.

General Procedure for Oxidation of Sulfides Using Cation Exchange Resin

To a solution of 1 mmol sulfide in 4 cm³ methanol, 2 mmol H_2O_2 (0.18 cm³ of a 35% aqueous solution) and 0.5 mmol Amberlyst 15 were added. The resulting mixture was stirred at room temperature and monitored by TLC. On completion of the reaction, the cation exchange resin was removed by filtration. Evaporation of the solvent under reduced pressure gave the desired sulfoxide. Further purification was performed by recrystallization from ethanol-water.

General Procedure for Oxidation of Sulfides Using Anion Exchange Resin

To a solution of 1 mmol sulfide in 4 cm³ methanol, 3 mmol H_2O_2 (0.26 cm³ of a 35% aqueous solution) and 0.5 mmol Amberlite IR-400 were added. The resulting mixture was stirred at room temperature. The progress of the reaction was monitored by TLC (*n*-hexane:ethylacetate = 2:1). After completion of the reaction, the reaction mixture was filtered and the solvent was removed under reduced pressure. Recrystallization from ethanol-water afforded the pure sulfoxide in excellent yield.

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