ISSN 1070-4280, Russian Journal of Organic Chemistry, 2006, Vol. 42, No. 7, pp. 959–961. © Pleiades Publishing, Inc., 2006.
Published in Russian in Zhurnal Organicheskoi Khimii, 2006, Vol. 42, No. 7, pp. 979–981.

Controllable Oxidation of Sulfides to Sulfoxides and Sulfones with Aqueous Hydrogen Peroxide in the Presence of β-Cyclodextrin*

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Received May 12, 2005

Abstract—A facile procedure has been developed for the transition metal-free oxidation of sulfides to sulfoxides and sulfones and of sulfoxides to sulfones with hydrogen peroxide in aqueous medium in the presence of β-cyclodextrin as catalyst. The procedure allows formation of sulfoxide or sulfone to be controlled.

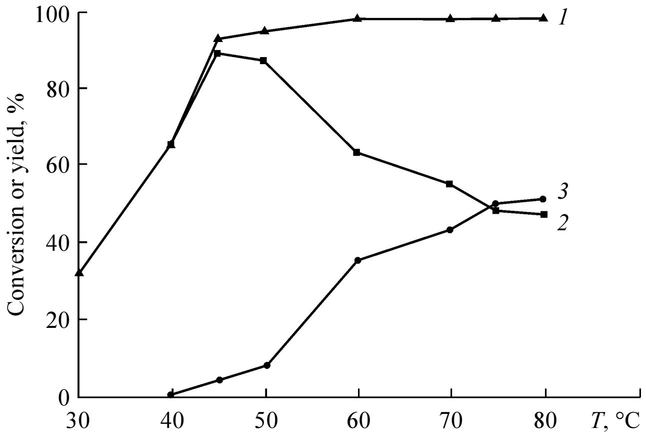
DOI: 10.1134/S1070428006070049

Oxidations of sulfides to sulfoxides or sulfones and of sulfoxides to sulfones are very important reactions in synthetic organic chemistry [1]. In the recent time, much attention is given to “green” oxidation of sulfides and sulfoxides with the use of environmentally safe oxidants such as molecular oxygen [2–5] or hydrogen peroxide [6–8] in homogeneous, heterogeneous, and biocatalytic systems. However, the known procedures require the use of organic solvents and metal compounds. In addition, controllable formation of sulfoxides and sulfones via oxidation of sulfides attracts strong interest.

On the basis of the results of our studies on dioxolane (ethylene acetal) deprotection [9] and oxidation of alcohols [10] in the presence of β-cyclodextrin, the present communication describes a convenient method for the transition metal-free oxidation of sulfides with hydrogen peroxide in water as the only solvent using β-cyclodextrin as catalyst. As compared to known heterogeneous catalytic systems, the proposed procedure is more advantageous due to homogeneous conditions and the possibility for controlling formation of sulfoxide or sulfone by varying the reaction conditions.

The oxidation was carried as follows. β-Cyclodextrin, 1 mmol, was dissolved in 25 ml of deionized water at 45°C, 5 mmol of methyl phenyl sulfide was added under stirring, 2 ml of hydrogen peroxide was slowly added, and, after 1.5 h, an additional 1-ml portion of hydrogen peroxide was added. When the reaction was complete, the mixture was extracted with ethyl acetate (2 × 30 ml), the extract was dried over anhydrous sodium sulfate, the solvent was removed under reduced pressure, and the crude product was analyzed by GLC (Shimadzu GC-14C) and compared with an authentic sample.

Effect of temperature. Temperature can essentially affect the reaction rate and the yield and ratio of the oxidation products (sulfoxide and sulfone). Moreover, elevated temperature promotes decomposition of hydrogen peroxide. Figure (curves *2* and *3*) shows the temperature dependence of the yields of methyl phenyl sulfoxide and methyl phenyl sulfone in the oxidation of methyl phenyl sulfide in the temperature range from



Plots of (*1*) the substrate conversion and the yields of (*2*) methyl phenyl sulfoxide and (*3*) methyl phenyl sulfone versus temperature in the oxidation of methyl phenyl sulfide. Reaction conditions: β-cyclodextrin, 1 mmol; methyl phenyl sulfide, 5 mmol; H_2O_2, 2 ml at the start and 1 ml in 1.5 h; H_2O, 25 ml; reaction time 4 h.

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* The original text was submitted by the authors in English.

Table 1. Effect of the amount of hydrogen peroxide on the oxidation of methyl phenyl sulfide in water in the presence of β-cyclodextrin[a]

Run no.	Temperature, °C	Amount of H_2O_2, ml	Conversion, %	Yield of methyl phenyl sulfoxide, %	Yield of methyl phenyl sulfone, %
1	45	3	85	81	4
2[b]	45	2 + 1	93	89	4
3	45	10	93	68	25
4	75	3	99	74	25
5	75	10	98	15	83
6[c]	75	5 + 5	99	8	91

[a] Amounts of the reactants: β-cyclodextrin, 1 mmol; methyl phenyl sulfide, 5 mmol; H_2O, 25 ml; reaction time 4 h.
[b] 2 ml of H_2O_2 was added at the start of the process, and 1 ml, after 1.5 h.
[c] 5 ml of H_2O_2 was added at the start of the process, and 5 ml, after 1.5 h.

30 to 80°C. These data indicate that the reaction temperature strongly affects the yields of methyl phenyl sulfoxide and methyl phenyl sulfone. At a relatively low temperature, the process stops at the sage of formation of methyl phenyl sulfoxide as the major product (kinetically controlled). It should be noted that β-cyclodextrin is poorly soluble in the reaction mixture at low temperature; therefore, the reaction occurs at an appreciably reduced rate. A slightly elevated temperature (about 45°C) is optimal for the synthesis of methyl phenyl sulfoxide. The reaction rate considerably increases as the temperature rises; correspondingly, the fraction of methyl phenyl sulfone increases. Taking into account that high temperature favors decomposition of hydrogen sulfide, a temperature of 75°C may be regarded as optimal for the formation of methyl phenyl sulfone. Under these conditions (reaction time 4 h), the yields of methyl phenyl sulfoxide and methyl phenyl sulfone were 50 and 48%, respectively. Thus rise in temperature considerably changes the sulfoxide-to-sulfone ratio toward the latter. Since hydrogen peroxide is sensitive to elevated temperature, the effects of other factors should be examined to raise the fraction of sulfone among the oxidation products.

Effect of the amount of hydrogen peroxide. The data in Table 1 show the results of studying the effect of the amount of hydrogen peroxide and the mode of its addition on the product ratio. Increase of the amount of hydrogen peroxide from 3 to 10 ml (45°C) increases the conversion of methyl phenyl sulfide from 85 to 93% and the yield of methyl phenyl sulfone from 4 to 25%, respectively (run nos. 1, 3). Much stronger effect was achieved at 75°C: in this case, the yield of methyl phenyl sulfone sharply rose from 25 to 91% (run nos. 4, 6). The substrate conversion and the product ratio were also found to depend on the mode of addition of hydrogen peroxide (in one or two portions). When hydrogen peroxide (3 ml) was added in two portions (2 ml + 1 ml) at 45°C, the conversion of methyl phenyl sulfide increased to 93% against 85% (addition at once; run nos. 1, 2), and the substrate was transformed almost completely into methyl phenyl sulfoxide. A different pattern was observed at elevated temperature. The yield of methyl phenyl sulfone changed from 83 to 91% when 10 ml of H_2O_2 was added in two equal portions (5 ml + 5 ml; run nos. 5, 6), while the yield of methyl phenyl sulfoxide decreased from 15 to 8%. We can conclude that the addition of

Table 2. Effect of the amount of β-cyclodextrin on the oxidation of methyl phenyl sulfide with hydrogen peroxide[a]

Run no.	Temperature, °C	Amount of H_2O_2, ml	Amount of β-cyclodextrin, ml	Conversion, %	Yield of methyl phenyl sulfoxide, %	Yield of methyl phenyl sulfone, %
1[b]	45	0.5 + 0.5	0.1	56	53	3
2[b]	45	0.5 + 0.5	1	93	87	6
3[c]	75	3 + 3	0.1	95	78	17
4[c]	75	3 + 3	1	96	42	54

[a] Methyl phenyl sulfide, 5 mmol; H_2O, 25 ml; reaction time 4 h.
[b] 0.5 ml of H_2O_2 was added at the start of the process, and 0.5 ml, after 1.5 h.
[c] 3 ml of H_2O_2 was added at the start of the process, and 3 ml, after 1.5 h.

hydrogen peroxide in several portions at elevated temperature (75°C) favors formation of the corresponding sulfone.

Effect of the amount of β-cyclodextrin. β-Cyclodextrin is better soluble in water than methyl phenyl sulfide. Therefore, oxidation of this substrate should be preceded by its inclusion into the cavity of β-cyclodextrin. The effect of the amount of the latter on the oxidation of methyl phenyl sulfide is illustrated by the data in Table 2. Rise in the amount of β-cyclodextrin strongly increases the conversion of methyl phenyl sulfide from 56 to 93% at 45°C (run nos. 1, 2) and the yield of methyl phenyl sulfone at 75°C (run nos. 3, 4).

Oxidation of diphenyl sulfide and diphenyl sulfoxide. After studying the influence of the reaction conditions on the oxidation of methyl phenyl sulfide, the same system was applied to the oxidation of diphenyl sulfide. Treatment of the latter with hydrogen peroxide (5 ml + 5 ml) in 25 ml of water in the presence of 1 mmol of β-cyclodextrin at 75°C (reaction time 10 h) gave 19% of diphenyl sulfoxide and 81% of diphenyl sulfone, the substrate conversion being 100%. We also performed oxidation of diphenyl sulfoxide under analogous conditions (H_2O_2, 3 ml + 3 ml; H_2O, 25 ml; β-cyclodextrin, 1 mmol; 75°C). Here, the yield of diphenyl sulfone was 61% (conversion 61%) and 98% (conversion 98%) in 1 and 8 h, respectively. Thus the proposed oxidizing system is effective for the transformation of sulfoxides into sulfones in almost quantitative yield.

The authors thank National Natural Science Foundation of China (grant no. 20306009) and Guangdong Provincial Natural Science Foundation (grant no. 31412) for the financial support.

REFERENCES

1. Ji, H.B. and She, Y.B., *Green Oxidation and Reduction*, Beijing: China Petrochemical, 2005.
2. Reetz, M.T., Daligault, F., Brunner, B., Hinrichs, H., and Deege, A., *Angew.Chem., Int. Ed. Engl.*, 2004, vol. 43, p. 4078.
3. Huynh, M.H.V., Witham, L.M., Lasker, J.M., Wetzler, M., Mort, B., Jameson, D.L., White, P.S., and Takeuchi, K.J., *J. Am. Chem. Soc.*, 2003, vol. 125, p. 308.
4. Imada, Y., Iida, H., Ono, S., and Murahashi, S., *J. Am. Chem. Soc.*, 2003, vol. 125, p. 2868.
5. Zen, J.-M., Liou, S.-L., Kumar, A.S., and Hsia, M.-S., *Angew. Chem., Int. Ed. Engl.*, 2003, vol. 42, p. 577.
6. Trevisan, V., Signoretto, M., Colonna, S., Pironti, V., and Strukul, G., *Angew. Chem. Int. Ed. Engl.*, 2004, vol. 43, p. 4097.
7. Legros, J. and Bolm, C., *Angew. Chem., Int. Ed. Engl.*, 2004, vol. 43, p. 4225.
8. Legros, J. and Bolm, C., *Angew. Chem., Int. Ed. Engl.*, 2003, vol. 42, p. 5487.
9. Ji, H.B., *Eur. J. Org. Chem.*, 2003, p. 3659.
10. Ji, H.B., Shi, D.P., Shao, M., Li, Z., and Wang, L.F., *Tetrahedron Lett.*, 2005, vol. 46, p. 2517.