Oxidizing *O,O,O*-trimethyl phosphorothioate with hydrogen peroxide or ozone

Xinzhi Chen · Guihua Li · Chao Qian

Abstract Oxidization of *O,O,O*-trimethyl phosphorothioate to the corresponding oxo (P=O) compound is accomplished under mild conditions with hydrogen peroxide or ozone. Urea hydroperoxide was found to be a serviceable solid-state source of hydrogen peroxide; it was a better oxidizing agent than 30% hydrogen peroxide and resulted in better yield. It was also proved that ozone was the most effective oxidizer, with formation of purer products in higher yield (90.1%) than with hydrogen peroxide.

Keywords *O,O,O*-Trimethyl phosphorothioate · Hydrogen peroxide · Urea hydroperoxide · Ozone

Introduction

Organophosphate insecticides are an important class of water-soluble pesticides mainly used in agriculture to control pests (insects) on fruits, vegetables, and cotton [1]. Acephate is especially useful [2]. The byproduct obtained during production of *O,O*-dimethyl phosphorochloridothioate, *O,O,O*-trimethyl phosphorothioate (**1**, TMTP, Scheme 1), is a major disposal problem and affects the purity of the acephate. Because there are currently no uses of **1**, the search for an efficient, inexpensive, and environmentally sound application of this material is extremely urgent.

As far as we are aware, three methods for conversion of TMTP to other products have been reported in the literature:

1 Rearrangement of TMTP;
2 Chlorination of TMTP; and
3 Oxidation of TMTP.

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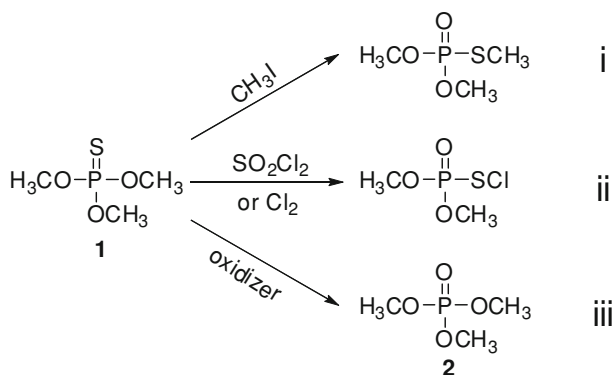
Scheme 1 The conversions of TMTP

Unfortunately:

1 The isomerizing agent used for the rearrangement was methyl iodide which is an expensive reagent, and a use for the isomeric compound has not been found [3];
2 Thionyl chloride or chlorine was the chlorination agent, and both are toxic reagents [4]; and
3 Ozone was reported to oxidize TMTP to trimethyl phosphate (TMP) at very low temperature (−75 °C) [5], but this route also suffered from several disadvantages, for example harsh conditions, relatively low ozone utilization, and long reaction time, although the product has widespread industrial uses as a fire retardant in plastics production [6].

We therefore further studied the oxidation of TMTP.

The conversion of thiophosphoryl (P=S) compounds to the corresponding oxo (P=O) compounds by oxidation has been a subject of chemical and biochemical investigation for a long time. For instance, oxone ($2 \cdot KHSO_5 \cdot KHSO_4 \cdot K_2SO_4$) [7, 8], trifluoroacetic anhydride (($CF_3CO)_2O$) [9], and magnesium monoperoxyphthalate (MMPP) [10] have been developed for this purpose. However, many of these procedures have limitations because of their properties, e.g., low effective oxygen content, environmentally unfavorable by-products, and high cost.

For these reasons we turned our attention to hydrogen peroxide or ozone to oxidize TMTP. We used hydrogen peroxide (30%) and solid-state hydrogen peroxide which can release oxidative species in an organic medium. Solid-state hydrogen peroxide, for example urea hydroperoxide ($CO(NH_2)_2 \cdot H_2O_2$; UHP) [11], sodium perborate ($NaBO_3 \cdot nH_2O$, $n = 1$ or 4; SPB) [12], and sodium percarbonate ($NaCO_3 \cdot 1.5H_2O_2$; SPC) [13] can result in formation of highly reactive hydrogen peroxide molecules. These chemicals are inexpensive and are extensively used in the detergent industry as bleaching and antiseptic agents. Ozone, because of its high oxidizing power without pollution, has also received much attention in organic chemistry [14].

Herein we present the results of our studies on the application of hydrogen peroxide and ozone for oxidation of TMTP.

Experimental procedure

Materials and methods

^{1}H, ^{13}C, and ^{31}P NMR were recorded in CDCl$_3$, using 400 MHz for ^{1}H, 100 MHz for ^{13}C, and 160 MHz for [31]P. Chemical shifts in parts per million (ppm) were relative to TMS (^{1}H and ^{13}C) or 85% H$_3$PO$_4$ (^{31}P) as internal references. The products were analyzed by use of an Agilent 1790F gas chromatograph (GC) with a hydrogen flame ionization detector and a glass column (45 m × 0.53 mm). Raw materials and reagents were purchased commercially and used without further purification.

The ozone concentration was determined by bubbling the ozone/oxygen gas mixture through a solution of potassium iodide and then titrating with a standardized solution of sodium thiosulfate [14]. At a flow rate of 30 L/h (measured by use of a flow meter), the concentration of ozone is approximately 3–4% (*v/v*).

General procedure for oxidization of TMTP using hydrogen peroxide

Hydrogen peroxide (50 mmol) was added slowly to a solution of TMTP (7.8 g, 50 mmol) in methanol (20 mL) in a 100-mL, round-bottomed flask fitted with a paddle stirrer, reflux condenser, and thermometer. After heating the mixture to reflux with stirring for 1 h, elemental sulfur and the corresponding salt formed in the reaction were isolated by filtration, for recycling, and the solvent was removed. The residue was dried with magnesium sulfate and yielded TMP. ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 3.77 (s, 9H, CH$_3$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 54.6; ^{31}P NMR (CDCl$_3$, 100 MHz) δ (ppm): 2.85.

Ozonation of TMTP

To a 100-mL round-bottomed flask equipped with a magnetic stir bar was added TMTP (7.8 g, 50 mmol), and the solution was heated at 50 °C. A tube supplying ozone generated by use of ozonizer was bubbled into the rapidly stirred mixture at a rate of 30 L/h for 2.5 h. The exiting gas was passed through sodium hydroxide solution to absorb the sulfur trioxide formed. After completion of the reaction, the liquid was purified by distillation. The colorless clear liquid **2** (6.31 g, 90.1%) was obtained. The identity of the product was confirmed by comparison with the standard sample using GC. ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 3.75 (s, 9H, CH$_3$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 54.5; ^{31}P NMR (CDCl$_3$, 100 MHz) δ (ppm): 2.85.

Results and discussion

When TMTP was oxidized by hydrogen peroxide (30%), although the conversion reached 100%, much of the desired product readily hydrolyzed and we obtained low yield. Concentrated hydrogen peroxide is not readily available and, furthermore,

contains water, so we choose solid-state hydrogen peroxide, i.e. anhydrous hydrogen peroxide.

According to reports, UHP [11], SPB [12], and SPC [13] have been used for the oxidation of a wide range of material and proved to be interesting eco-friendly reagents. Their stability at room temperature, high hydrogen peroxide content, the potential for releasing hydrogen peroxide in a controlled manner, and their solubility in organic solvents make them good and safe substitutes for anhydrous hydrogen peroxide in most oxidation reactions. The results of oxidizing TMTP with different oxidizers are shown in Table 1. During investigation, it was found that UHP was a good and safe oxidizer for the oxidation reaction because of its high hydrogen peroxide content (36.2%) and good solubility in organic solvents.

Although, the yield was higher when we used solid-state hydrogen peroxide than when 30% aqueous hydrogen peroxide was used, hydrolysis still occurred because of the small amount water present in these oxidants. So we turned our attention to an anhydrous system. Ozone is well known for its oxidizing properties and has been used in a wide range of oxidation procedures without water. Previous work [5] indicated ozone had been used for the thionate–oxon conversion with 1,2-dichloroethane as solvent at -75 °C to yield TMP. This method had great potential for use under mild reaction conditions.

In this work we used ozone, solvent-free at 50 °C, to oxidize TMTP, and obtained good yield (90.1%). By testing the exiting gas with KI–starch paper we found that utilization of ozone reached 99%. The reaction was tried at 20–70 °C. It was found 50 °C was the optimum temperature to obtain a high yield in a short reaction time. Increasing the reaction temperature would obviously accelerate the reaction. However, increasing the temperature to 60 °C or higher is dangerous because ozone readily explodes at such high concentrations at relatively high temperature.

Conclusion

In general, because TMP is readily hydrolyzed, the oxidation should be performed under water-free conditions. Comparison of the results obtained by use of hydrogen peroxide (30%), solid-state hydrogen peroxide, and ozone revealed the second

Table 1 Oxidizing TMTP with hydrogen peroxide

Entry	Oxidizer	Reaction conditions		Conversion (%)	Yield[a] (%)
		Time (h)	Temp (°C)		
1	H_2O_2 (30%)	1.0	60	100	37.4
2	UHP	1.0	60	100	85.3
3	SPB	2.0	60	100	73.7
4	SPC	2.0	60	100	73.5

[a] The yield refers to isolated product

option results in high yield, and is operationally simple, least expensive, safer, and easier to handle, whereas ozone results in the highest yield and best quality product.

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