

Molybdenyl acetylacetonate-assisted oxidation of α -functionalized alcohols by sodium percarbonate, influence of the reaction temperature

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Abstract

In acetonitrile, the course and the efficiency of the oxidation by sodium percarbonate of benzylic alcohols, α -substituted by a keto, hydroxy, ester or an acid group and of 2-hydroxycyclohexanone is often largely influenced by the reaction temperature and the presence of catalytic amounts of $\text{MoO}_2(\text{acac})_2$. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Various methods have been reported for the oxidation of 1,2-diols and related compounds to afford carbonyl compounds with or without carbon–carbon bond cleavage [1–6]. Nevertheless, alternative methodologies which would be harmless to the environment and are easy to carry out, are clearly desirable. Oxidation processes which use catalytic amounts of transition metals are of great importance from an economical point of view and usually are relatively compatible with 'green' chemistry.

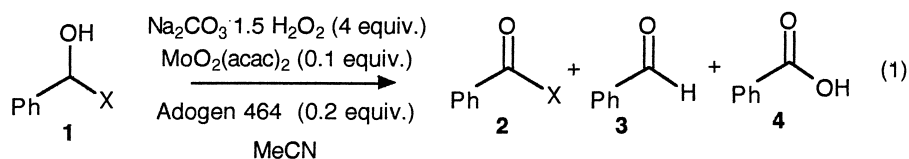
In the course of studies in this area, we have recently disclosed the use of sodium percarbonate (SPC) ¹ in the presence of catalytic quanti-

ties of chromium(VI) to carry out the oxidative cleavage of the $\text{C}(\text{OH})\text{--C}_\alpha$ bond of benzylic alcohols, α -substituted by a keto, hydroxy, ester or an acid group [9,10]. Nevertheless, the toxicity of chromium salts [11,12], even if only catalytic amounts are required, could preclude the development of these procedures. Therefore, we pursued our efforts in looking for other metal catalysts. Recently, it was gratifying to observe the effective oxidation of alcohols by SPC in the presence of catalytic amounts of molybdenyl acetylacetonate and Adogen 464 ² [13]. This observation led us to investigate the reactivity of benzylic alcohols **1a–1e** (Eq. (1)) and 2-hydroxycyclohexanone under these conditions.

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¹ SPC is a perhydrate— $\text{Na}_2\text{CO}_3 \cdot 1.5\text{H}_2\text{O}_2$ —produced on a large scale for the detergent industry. For reviews on its use as oxidizing agent in organic chemistry, see Refs. [7,8].

² Adogen 464 is a registered trademark of Ashland Chemical for methyltrialkyl($\text{C}_8\text{--C}_{10}$)ammonium chloride.



X: COPh (**a**), CH(OH)Ph (**b**), CH₂OH (**c**), CO₂Me (**d**), CO₂H (**e**). (1)

2. Results and discussion

The oxidations have been firstly carried out with benzoin (**1a**) as substrate (Table 1). Reflux of an efficiently stirred slurry of SPC in acetonitrile containing **1a** and small quantities of both $\text{MoO}_2(\text{acac})_2$ and Adogen 464 afforded a fast reaction with formation of a mixture of benzil (**2a**), benzaldehyde and benzoic acid, the latter being the main compound (run 1).³

During the course of the present work, it was reported in the literature that the uncatalyzed oxidative cleavage of **1a** by SPC in aqueous acetone was assisted by ultrasonic irradiation [14]. This led us to subject **1a** to Mo-conditions with ultrasound instead of magnetic stirring/oil-bath heating (run 2): the reaction rate dropped considerably but interestingly, the oxidative cleavage was greatly reduced, a good yield of benzil being obtained. When $\text{MoO}_2(\text{acac})_2$ was omitted, the reaction became both less effective and less selective (run 3).

We have remarked that our ultrasound-bath induced heating to 60°C of the mixture. Therefore, experiments have been repeated at 60°C without ultrasonic irradiation but with stirring (runs 4 and 5): similar results were obtained except that the reactions proceeded more quickly. In decreasing the reaction temperature to 40°C, we again observed a large difference in reactivity between reactions with and without Mo-assistance (runs 6 and 7).

Subsequently, α -diol **1b** instead of α -ketol **1a** was subjected to similar oxidative conditions (Table 2). The comparison of the results collected in Tables 1 and 2 reveals a large similarity between the reactivities of **1a** and **1b**. At 80°C under the Mo-conditions, a high conversion of hydrobenzoin was quickly obtained giving a mixture of benzil and benzoic acid, the latter being again the main compound (run 8). As for **1a**, the ultrasound/ $\text{MoO}_2(\text{acac})_2$ procedure induced a slow reaction and the oxidative cleavage was greatly reduced: small amounts of α -ketol **2b** and a good yield of α -dione **2a** were obtained (run 9). Under sonication without the Mo-catalyst, the relative quantity of **2b** increased but the conversion was much lower (run 10). As above for **1a**, switching from ultrasound (runs 9 and 10) to heating at 60°C and magnetic stirring (runs 11 and 12) led to similar results from **1b** except for a reduced reaction time.

From these experiments, it appears that ultrasonication is not useful under our oxidative conditions. Consequently, this technique was not used for the oxidation of alcohols **1c–1e**. The results obtained from these compounds at 60 and 80°C are collected in Table 3.

Whatever the temperature—60 or 80°C—the oxidative cleavage was the sole reaction observed from α -diol **1c** (runs 13 to 15); this is in agreement with the easier C–C bond cleavage of α -diols having a primary hydroxy group [4–6]. Nevertheless, the conversion was very low in the absence of the Mo-catalyst (run 15).

Methyl mandelate (**1d**) led to a relatively fair yield of the corresponding α -ketoester (**2d**) solely when the reaction was performed at 60°C under catalysis (run 17). It has been surprising

³ A lower amount of cleavage product and a longer reaction time have been previously reported [9,10]. That seems to be essentially due to differences in the efficiency of the stirring.

Table 1
Oxidation of benzoin^a

Run	Mo-catalyst	<i>t</i> (°C)	Time (h)	Conv. (%)	PhCOCOPh (%) ^b	PhCHO (%) ^b	PhCO ₂ H (%) ^b
1	0.1	80	3.5	100	14	12	56
2 ^c	0.1	^d	35	98	72	0	4
3 ^c	0	^d	35	60	25	15	10
4	0.1	60	3.5	100	75	0	3
5	0	60	3.5	55	22	18	11
6	0.1	40	21	100	30	0	41
7	0	40	21	57	10	0	32

^aSPC (4 equiv.), MoO₂(acac)₂ (0 or 0.1 equiv.), Adogen 464 (0.2 equiv.), MeCN (10 ml/mmol of substrate), high-speed magnetic stirring, air atmosphere.

^bIsolated yields calculated on the quantity of substrate introduced.

^cReaction carried out in an ultrasound-bath (Bransonic 221, frequency: 47.6 kHz, HF-outpower: 70 W).

^dThe temperature stabilized at 60°C in the course of the reaction.

Table 2
Oxidation of hydrobenzoin^a

Run	Mo-catalyst	<i>t</i> (°C)	Time (h)	Conv. (%)	PhCOCH(OH)Ph (%) ^b	PhCOCOPh (%) ^b	PhCO ₂ H (%) ^b
8	0.1	80	2.5	96	0	25	63 ^c
9 ^c	0.1	^d	25	100	4	76	9
10 ^c	0	^d	25	50	19	15	2
11	0.1	60	8.5	100	10	76	3
12	0	60	8.5	20	12	6	1

^{a,b,c,d}As in Table 1.

^eTraces of **3** have been detected in the course of the oxidation reaction.

to isolate almost exclusively cleavage products when this reaction was conducted at the same temperature without the Mo-catalyst (run 18).

Mandelic acid (**1e**) afforded **4** with high selectivity whatever the experimental conditions we used (runs 19 to 21). It seems that **3** here

Table 3
Oxidation of alcohols **1c–1e**^a

Run	Substrate	Mo-catalyst	<i>t</i> (°C)	Time (h)	Conv. (%)	Yield (%) ^b		
						2	3	4
13	1c	0.1	80	3	85	c	0	78
14	1c	0.1	60	8	100	c	0	70
15	1c	0	60	8	8	c	0	3
16	1d	0.1	80	23	75	d	8	50
17	1d	0.1	60	96	90	d	45	traces
18	1d	0	60	96	80	d	2	13
19	1e	0.1	80	3.5	34	e	0	29
20	1e	0.1	60	44	88	e	0	78
21	1e	0	60	44	49	e	0	45

^{a,b,c,d}As in Table 1.

was not an intermediate in the formation of **4** since the presence of this aldehyde was not detected when the disappearance of **1e** was monitored by TLC. Therefore, this reaction could involve an oxidative decarboxylation as recently documented for α -hydroxy acids using copper bromide and lithium *tert*-butoxide [15].

Finally, the oxidation of 2-hydroxycyclohexanone was examined at 60°C. Adipic acid was the main oxidation compound. A complete conversion leading to 73% yield was obtained in 28 h in the presence of MoO₂(acac)₂. In the absence of the latter, similar conditions afford lower conversion (57%) and yield (39%).

3. Conclusion

Sodium percarbonate oxidizes α -functionalized alcohols to give corresponding ketones

and/or C(OH)–C $_{\alpha}$ bond cleavage. The course and the efficiency of the oxidation can be greatly modified by addition of small amounts of molybdenyl acetylacetonate. In addition, the ratio between the two processes depends on the nature of the α -function and the substituents and is partially controlled by the reaction temperature. Ultrasonic irradiation has little influence on these reactions.

4. Experimental

4.1. Reagents and solvents

Reagents, solvents, **1a**, **1c**, **1d**, **1e** and 2-hydroxycyclohexanone are commercial and were used as received; **1b** was obtained by NaBH₄ reduction of **1a** in MeOH; **1d** was esterified into **1e** in refluxing MeOH containing catalytic amounts of sulfuric acid.

4.2. General procedure for oxidation of **1a–1d**

In a round-bottomed flask containing the substrate (1 mmol) and acetonitrile (8 ml), were added sequentially SPC (4 mmol), Adogen 464 (0.2 mmol) in MeCN (2 ml) and MoO₂(acac)₂ (0.1 mmol). The mixture was heated at *t*^oC under air atmosphere for the times indicated in the tables. After cooling to room temperature, the slurry was filtered. The filtrate was evaporated, diluted in methylene chloride (20 ml), washed with aqueous Na₂CO₃ (30 ml), dried on MgSO₄ and evaporated at room temperature under reduced pressure. The residue was subjected to preparative TLC eluted with EtOAc/petroleum ether to afford the products. The precipitate and the aqueous phase were combined and treated with 2 N HCl to liberate benzoic acid which was extracted with methy-

lene chloride and then purified on preparative TLC eluted with EtOAc/petroleum ether (1/1).

For **1e**, diethyl ether was used as solvent instead of methylene chloride.

2-Hydroxycyclohexanone was oxidized using the general procedure, except that the acidification was made with concentrated H₂SO₄ and adipic acid was extracted with diethyl ether.

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References

- [1] For a highlight review, see: A.H. Haines, *Methods for the Oxidation of Organic Compounds*, Academic Press, London, 1988, p. 277.
- [2] S.O. Nwaukwa, P.M. Keehn, *Tetrahedron Lett.* 23 (1982) 3135, and cited references.
- [3] A.R. Kore, A.D. Sagar, M.M. Salunkhe, *Org. Prep. Proc. Int.* 27 (1995) 373.
- [4] H. Firouzabadi, A. Sardarian, H. Badparva, *Bull. Chem. Soc. Jpn.* 69 (1996) 685.
- [5] V. Le Boisselier, C. Coin, M. Postel, E. Dunach, *Tetrahedron* 51 (1995) 4991.
- [6] C. Coin, T. Zevaco, E. Dunach, M. Postel, *Bull. Soc. Chim. Fr.* 133 (1996) 913.
- [7] A. McKillop, W.R. Sanderson, *Tetrahedron* 51 (1995) 6145.
- [8] J. Muzart, *Synthesis* (1995) 1325.
- [9] S. Ait-Mohand, A. Levina, J. Muzart, *Synth. Commun.* 25 (1995) 2051.
- [10] S. Ait-Mohand, A. Levina, S. Lunak, J. Muzart, *Inorg. Chim. Acta* 238 (1995) 183.
- [11] L. Zhang, P.A. Lay, *J. Am. Chem. Soc.* 118 (1996) 12624.
- [12] P.A. Lay, A. Levina, *Inorg. Chem.* 35 (1996) 7709, and cited references.
- [13] S. Maignien, S. Ait-Mohand, J. Muzart, *Synlett* (1996) 439.
- [14] D.T.C. Yang, Y.H. Cao, T.T. Evans, G.W. Kabalka, *Synth. Commun.* 26 (1996) 4275.
- [15] T. Takeda, S. Yamauchi, T. Fujiwara, *Synthesis* (1996) 600.