

Cobalt phthalocyaninetetrasulphonamide catalyzed aerobic oxidation of α -hydroxyketones: an efficient and simple synthesis of α -diketones

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Abstract

A variety of α -hydroxyketones were efficiently oxidized to α -diketones in near quantitative yields with molecular oxygen, under alkaline conditions, using cobalt phthalocyaninetetrasulphonamide as catalyst. Acyloins in general were found to be less reactive than benzoin and required high pH for their oxidation. Among the benzoin, those substituted with electron donating groups were found to be more reactive and required lesser reaction time for their oxidation. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: α -Hydroxyketones; α -Diketones; Aerobic oxidation; Cobalt phthalocyaninetetrasulphonamide; Molecular oxygen

1. Introduction

α -Diketones are synthetically important building blocks [1] and are extensively used as substrates for benzylic acid rearrangement [2] and starting materials for the synthesis of heterocyclic compounds [3–6]. The oxidation of α -hydroxyketones is a simple and direct route for the synthesis of α -diketones and many stoichiometric reagents such as cupric sulphate [7], cupric acetate [8], ammonium nitrate [9], bismuth oxide [10], thallium nitrate [11] have been reported to be effective oxidants for this transformation. Owing to the growing environmental concerns surrounding the use of toxic and dangerous oxidants, oxidative catalytic-transformations of organic compounds with environmentally clean oxidants like molecular oxy-

gen has become an area of continued research and development in the recent years [12].

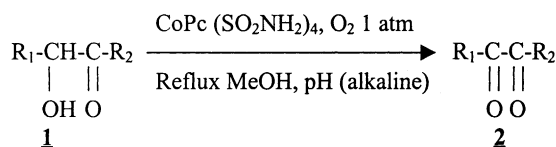
In this context, Dell' Anna et al. [13] reported the oxidation of α -hydroxyketones to α -diketones with molecular oxygen using Co(II) and Fe(II) complexes as catalyst and excess of aldehyde or aldoacetal as sacrificial agent. This method suffers from the drawback that 3.6 mmol of *i*-butyraldehyde or 6.0 mmol of propionaldehyde dimethyl acetal per mmol of α -hydroxyketone is required as sacrificial agent. Recently, Kirihara et al. [14] reported the aerobic oxidation of a variety of α -hydroxyketones to α -diketones using VOCl_3 as catalyst without the use of sacrificial aldehyde or aldoacetal. However, VOCl_3 is moisture-sensitive, hazardous material and is not easy to use in practice [15].

In continuation to our studies on oxidation using molecular oxygen as primary oxidant [16–18] herein, we report a simple and convenient method for the oxidation of α -hydroxyketones (**1**) to α -diketones (**2**)

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Scheme 1.

in near quantitative yields using molecular oxygen as the sole oxidant and cobalt phthalocyaninetetrasulphonamide as catalyst (Scheme 1).

2. Experimental

2.1. Materials

Benzoin was prepared by benzoin condensation of aldehydes in presence of cyanide ion. Acyloins were prepared by acyloin condensation of esters in the presence of sodium metal. Hydroxycamphor was prepared by the reduction of camphorquinone using zinc dust. Cobalt phthalocyaninetetrasulphonamide was prepared following the literature procedure reported by Agrawal et al. [19] and its structure was established by FAB mass spectral and elemental analysis.

2.2. Oxidation of α -hydroxyketones to α -diketones (general procedure)

α -Hydroxyketone (1 mmol), cobalt phthalocyaninetetrasulphonamide (0.02 mmol, 2 mol%) and methanol (15 ml) were taken in 50 ml double-necked round bottomed flask fitted with gas passing tube and reflux condenser. The solution was brought to the desired pH by adding 5% aqueous sodium carbonate (Na_2CO_3) solution. The mixture was then stirred and refluxed with oxygen gas bubbled in at slow rate. The reaction progress was monitored by TLC (SiO_2 gel) and after completion (Table 1) methanol was removed under reduced pressure. The residual mixture was then dissolved in toluene (20 ml) and organic layer was washed three times with distilled water (3×20 ml), followed by drying over anhydrous sodium sulphate and passing through a small column of silica gel. Removal of toluene yielded pure α -diketones, which were identified by comparing their physical and spectral data with those of authentic samples.

3. Results and discussion

Oxidation of a variety of α -hydroxyketones (**1**) with catalytic amount of cobalt phthalocyaninetetrasulphonamide in refluxing methanol under oxygen atmosphere provided α -diketones (**2**) in almost quantitative yields, without any evidence of the formation of any by-products which could arise due to cleavage of carbon–carbon bond of α -diketones [20,21]. These results are summarized in Table 1. Acyloins, in general were found to be less reactive than benzoin and required higher pH for their oxidation (Table 1, **1i–1k**). Benzoin containing electron donating groups were found to be more reactive and required lesser reaction time for their oxidation (Table 1, **1a–1f**).

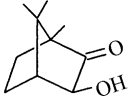
The reaction was found to be highly dependant upon the pH of the system. The results obtained on the oxidation of benzoin at different pH are summarized in Table 2. At neutral pH, the reaction was found to be very slow and the oxidation of benzoin to benzil did not complete even after 30 h. The reaction time decreased with the increase in pH and the reaction was completed within 2 h at pH 14.

The oxidation of benzoin to benzil was found to be very slow at room temperature (25°C) with the reactions requiring 3–4 days for their completion, while the same could be completed in 1–3 h in refluxing methanol.

The results obtained on the oxidation of benzoin (**1a**) using different solvents under similar conditions are summarized in Table 3. Among the solvents studied, methanol and ethanol were found to be good solvents for this reaction.

To evaluate the catalytic effect of cobalt phthalocyaninetetrasulphonamide, experiments were carried out with different catalyst concentrations and without any catalyst under identical conditions using 4-dimethylaminobenzoin (**1h**) as substrate. These results are presented in Table 4. In the absence of a catalyst, reaction was found to be very slow and did not complete even after 48 h. While, with the use of 0.5 mol% cobalt phthalocyaninetetrasulphonamide as catalyst the reaction got completed in 3 h. With the increase in catalyst concentration from 0.5 to 10 mol% there was marginal decrease in the reaction time from 3 to 1.25 h, indicating the effectiveness of the catalyst even at low concentration. The use of tetrasodium salt of cobalt tetrasulphophthalocynine [22] and cobalt

Table 1
Oxidation of α -hydroxyketones to α -diketones with molecular oxygen using cobalt phthalocyaninetetrasulphonamide as catalyst^a

Compound	α -Hydroxyketone	pH	Time (h)	Yield (%)
1a	R ₁ = R ₂ = C ₆ H ₅	11.72	3.00	96
1b	R ₁ = C ₆ H ₅ , R ₂ = 4-CH ₃ OC ₆ H ₄	11.74	1.75	97
1c	R ₁ = 4-CH ₃ OC ₆ H ₄ , R ₂ = 4-Me ₂ NC ₆ H ₄	11.00	1.00	95
1d	R ₁ = R ₂ = 4-CH ₃ C ₆ H ₄	11.68	1.75	96
1e	R ₁ = R ₂ = 4-CH ₃ OC ₆ H ₄	11.72	1.10	97
1f	R ₁ = 4-Me ₂ NC ₆ H ₄ , R ₂ = 2-ClC ₆ H ₄	11.72	1.25	90
1g	R ₁ = R ₂ = furan	11.72	0.50	97
1h	R ₁ = C ₆ H ₅ , R ₂ = 4-Me ₂ NC ₆ H ₄	11.72	2.50	96
1i	R ₁ = R ₂ = CH ₃ (CH ₂) ₁₂	14.00	6.00	85
1j	R ₁ = R ₂ = CH ₃ (CH ₂) ₁₄	14.00	8.00	85
1k		14.00	15.00	82

^a 1 mmol substrate, 2 mol% catalyst, 15 ml methanol (refluxing) atmospheric pressure of O₂.

Table 2
Effect of pH on the aerobic oxidation of benzoin (**1a**) using cobalt phthalocyaninetetrasulphonamide as catalyst^a

Compound	pH	Reaction time (h)	Conversion (%)
1a	7.00	30	75
1a	8.50	3.5	100
1a	11.70	3	100
1a	14.00	2	100

^a 1 mmol substrate, 2 mol% catalyst, 15 ml methanol (refluxing) under O₂ atmosphere.

phthalocyaninetetracarboxylic acid [23] as catalysts in place of cobalt phthalocyaninetetrasulphonamide gave comparable results.

Although mechanism of this reaction is not clear at this stage, probably the reaction proceeds through the

Table 3
Effect of the solvents on the aerobic oxidation of benzoin (**1a**) using cobalt phthalocyaninetetrasulphonamide as catalyst^a

Compound	Solvent	Reaction time (h)	Conversion (%)
1a	Methanol	3.0	100
1a	Ethanol	1.5	100
1a	Acetonitrile	12	80
1a	Acetone	24	40
1a	Acetonitrile + water (2:1)	32	Nil

^a 1 mmol substrate, 2 mol% catalyst, 15 ml solvent (refluxing), pH 11.72 under O₂ atmosphere.

Table 4
Effect of the catalyst concentration on the aerobic oxidation of 4-dimethylamino-benzoin (**1h**) using cobalt phthalocyaninetetrasulphonamide as catalyst^a

Compound	Catalyst concentration (mol%)	Reaction time (h)	Conversion (%)
1h	0.5	3.0	100
1h	2	2.5	100
1h	5	1.75	100
1h	10	1.25	100
1h	–	48.0	70

^a 1 mmol substrate, different catalyst concentration, 15 ml methanol (refluxing), pH 11.72 under O₂ atmosphere.

removal of a proton from the carbon attached to the hydroxyl group of α -hydroxyketone by hydroxide ion. As in the case of benzoin, this proton is more acidic in comparison to acylones, which require higher pH for their oxidation.

4. Conclusion

The simplicity of the system, nonhazardous nature of the catalyst and wide applicability make cobalt phthalocyaninetetrasulphonamide catalyzed oxidation an attractive, environmentally acceptable synthetic tool for the oxidation of α -hydroxyketones to α -diketones by molecular oxygen.

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