



Selective oxidation of alcohols in the presence of an Os/O₂-system[†]

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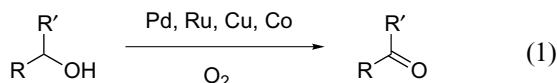
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Abstract—The osmium-catalyzed oxidation of alcohols with molecular oxygen to give aldehydes in good to excellent yields has been developed. Best results are obtained by using a buffered two-phase system with a constant pH of 10.4. Under optimized reaction conditions a remarkable catalyst productivity (TON up to 16600) is observed. © 2001 Published by Elsevier Science Ltd.

The selective oxidation of alcohols to give aldehydes is an important synthetic tool both for natural product synthesis as well as for fine chemical production. Although a number of catalytic procedures are known to achieve this transformation,¹ there is a general interest to improve existing procedures or to develop new methods. When developing new procedures for the oxidation of alcohols, environmentally benign oxidants, e.g. air or hydrogen peroxide, should be applied. In addition, only small amounts of expensive transition metal catalysts should be used. So far the oxidation of alcohols to aldehydes with air or molecular oxygen has been performed in the presence of relatively large amounts of Pd,² Ru,³ Cu⁴ and Co complexes⁵ (Eq. (1)).



R = aryl, alkyl; R' = H, alkyl

Recently, we reported that the osmium-catalyzed dihydroxylation of aliphatic and aromatic olefins proceeds efficiently in the presence of dioxygen at ambient conditions.⁶ While studying this reaction in detail, we noticed that at reaction temperatures above 60°C further oxida-

tion of 1,2-diols takes place. In this respect it is interesting to note that Osborn and co-workers described very recently the oxidation of benzylic alcohols to give benzaldehydes in the presence of a bimetallic Os/Cu system in good to excellent yields.⁷ We wondered whether this oxidation could be performed simply with an osmium catalyst under the conditions of our dihydroxylation procedure. Initially, we studied the oxidation of benzyl alcohol and 1-phenylethanol in the presence of K₂[OsO₂(OH)₄] as model reactions (Table 1).

Applying our previously optimized conditions⁶ (2 mmol alcohol, 1 bar molecular dioxygen, 35 ml H₂O/*t*-BuOH (2.5:1), 0.5 mol% K₂[OsO₂(OH)₄], 3 mol% DABCO, 50°C), we observed the smooth formation of acetophenone and benzaldehyde in 95 and 92% yield, respectively (Table 1, entries 2 and 12). Without osmium catalyst no oxidation is observed under these conditions. Due to the importance of the pH value of the reaction mixture for the reoxidation of the osmium(VI) to the active Os(VIII)⁸ the reaction of 1-phenylethanol was studied at pH 9.5, 11.2 and 12.0 (Table 1, entries 3–5). Excellent yields are obtained in between pH 9.5 and 11.2. At higher pH the conversion is significantly decreased. The highest reaction rate is observed at pH 10.4. Hence, all further experiments were performed at this pH value.⁹

Obviously, air is the most economical as well as environmentally friendly oxidation reagent known. With regard to the price and safety issues it is significantly more advantageous to use air than pure dioxygen gas.

Keywords: oxidation; alcohols; aldehydes; oxygen; osmium.

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[†] Dedicated to Professor Bernhard Lücke on the occasion of his 65th birthday.

Table 1. Osmium catalyzed oxidation of benzyl alcohol and 1-phenylethanol^a

		$\begin{array}{c} \text{R}' \\ \\ \text{R}-\text{C}-\text{OH} \end{array} \xrightarrow[\text{O}_2, \text{H}_2\text{O} / \text{tBuOH}]{\text{K}_2[\text{OsO}_2(\text{OH})_4]} \begin{array}{c} \text{R}' \\ \\ \text{R}-\text{C} \end{array}$								
Alcohol	Osmium (mol%)	Oxidant	pH ^b	T (°C)	DABCO (L:Os)	t (h)	Conversion	Yield ^c		
1	0.5	1 bar O ₂	10.4	50	–	12	100	95		
2	0.5	1 bar O ₂	10.4	50	3:1	12	100	95		
3	0.5	1 bar O ₂	9.5	50	3:1	24	100	93		
4	0.5	1 bar O ₂	11.2	50	3:1	14	100	95		
5	0.5	1 bar O ₂	12.0	50	3:1	24	79	74		
6 ^d	0.02	20 bar air	10.4	80	3:1	24	100	94		
7 ^d	0.01	20 bar air	10.4	80	3:1	24	91	85		
8 ^d	0.005	40 bar air	10.4	80	3:1	24	70	66		
9 ^d	0.005	40 bar air	10.4	100	3:1	24	82	76		
10 ^d	–	40 bar air	10.4	100	–	24	6	5		
11	–	1 bar O ₂	10.4	80	–	24	–	–		
12	0.5	1 bar O ₂	10.4	50	3:1	16	100	92		
13 ^d	0.02	20 bar air	10.4	50	3:1	24	88	82		
14 ^d	0.02	20 bar air	10.4	80	3:1	24	100	92		
15 ^d	0.005	40 bar air	10.4	80	3:1	24	80	74		
16 ^d	0.005	40 bar air	10.4	100	3:1	24	90	83		
17 ^d	–	20 bar air	10.4	80	–	24	5	4		

^a General conditions: 2 mmol alcohol, K₂[OsO₂(OH)₄], 35 ml H₂O/tBuOH (2.5:1).

^b The given value is the pH value of the water phase.

^c GC yield of benzaldehyde or acetophenone.

^d 4 mmol alcohol.

Hence, we investigated the influence of air on the oxidation of alcohols (Table 1, entries 6–10 and 13–17). Increasing the pressure and the temperature leads to a much faster reaction. Thus, it is possible to decrease the amount of the expensive osmium catalyst up to 0.005 mol%. Despite this low amount of catalyst acetophenone and benzaldehyde are produced in 83 and 76% yields, respectively. In the case of acetophenone this corresponds to a catalyst turnover number (TON) of 16600 and catalyst activity (TOF) of ca. 700 h⁻¹.

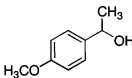
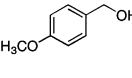
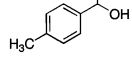
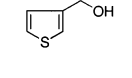
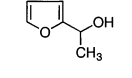
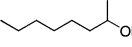

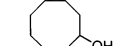
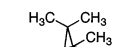
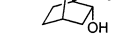
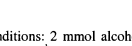

Next we applied the method to other alcohols. As shown in Table 2 the oxidation of different benzylic (aromatic and heteroaromatic) alcohols proceeds under mild conditions in excellent yields, even at 1 bar of molecular oxygen. However, secondary aliphatic alcohols need a larger amount of catalyst and/or higher reaction temperatures in order to obtain sufficient conversion. It should be noted that these reactions have not been optimized. Higher product yields can be expected most likely at higher pressure of air.

In conclusion, we have shown that the oxidation of benzylic and secondary aliphatic alcohols is possible with molecular oxygen or air in the presence of a commercially available osmium catalyst. Upon optimization a remarkable catalyst productivity and activity is observed.

Acknowledgements

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Table 2. Osmium-catalyzed oxidation of different alcohols^a

	Alcohol	T [°C]	t [h]	Conversion [%]	Yield [%]
1		50	21	100	92
2		“	22	100	92
3		“	12	100	93
4		80	19	100	80
5		50	24	93	85
6		“	“	33	41
7		80	“	54	49
8 ^b		“ ^b	“	63	59
9		50	“	41	37
10		80	“	77	71
11 ^b		“ ^b	“	85	79
12		50	20	100	98

^a General conditions: 2 mmol alcohol, 1 bar O₂, 0.5 mol% K₂[OsO₂(OH)₄], 1.5 mol% DABCO, 35 ml H₂O/tBuOH (2.5:1). ^b 1 mol% K₂[OsO₂(OH)₄], 3 mol% DABCO. GC yield of the corresponding aldehyde or ketone.

of Mecklenburg-Western Pomerania and the Bayer AG.

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9. General procedure: (a) Oxidation of alcohols under atmospheric dioxygen pressure: In a 100 ml Schlenk tube, $K_2[OsO_2(OH)_4]$ and DABCO were dissolved in 25 ml aqueous buffer solution and 10 ml *tert*-BuOH. The Schlenk tube was purged with oxygen and the biphasic mixture was heated to the reaction temperature. Then the alcohol was added in one portion by a syringe and the tube connected to a graduated gas burette filled with oxygen. The reaction mixture was stirred vigorously with a magnetic stirring bar. After 12–24 h a little amount of Na_2SO_3 was added and the mixture was cooled to room temperature under stirring. The mixture was then extracted twice with 20 ml portions of ethyl acetate. The combined organic layers were dried over $MgSO_4$ and submitted for GC analysis after addition of 100 μ l of diethyleneglycol di-*n*-butyl ether as an internal GC standard. (b) Oxidation under elevated pressure: In a 100 ml steel autoclave (Parr Instruments), equipped with a magnetic stirrer and a glass inline, $K_2[OsO_2(OH)_4]$ and DABCO were dissolved in 25 ml aqueous buffer solution and 10 ml *tert*-BuOH. After addition of alcohol the autoclave was closed, pressurized with air and heated to the reaction temperature. After 12–24 h, the reaction mixture was worked up as described.