Tetrahedron Letters 55 (2014) 4452–4454

Contents lists available at ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Magtrieve™: a convenient catalyst for the oxidation of alcohols

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ARTICLE INFO

Article history:
Received 15 April 2014
Revised 10 June 2014
Accepted 13 June 2014
Available online 21 June 2014

Keywords:
Oxidation
Alcohol
Chromium
Hypervalent iodine
Catalysis

ABSTRACT

We find that Magtrieve™ (CrO_2) catalyzes the oxidation of a wide variety of alcohols with periodic acid as the terminal oxidant. Mild conditions, short reaction times, and facile aqueous work-up make this a most attractive method. Olefins are not oxidized under these conditions; thus alcohols react selectively in the presence of alkenes. Conditions have been optimized with respect to catalyst loading, solvent, and co-oxidant; and the scope of the reaction includes primary and secondary benzylic, allylic, and aliphatic alcohols.

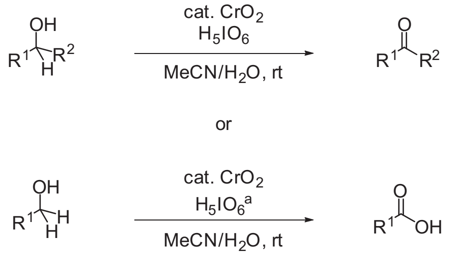
Introduction

We offer a new and convenient oxidation method for alcohols using Magtrieve™ (CrO_2) as a catalyst and periodic acid as the terminal oxidant. Magtrieve™ is a cheap ($1/g), nontoxic, easily disposed chromium(IV) oxide that can be readily removed from the reaction due to its heterogeneous nature and ferromagnetic properties.[1,2] Due to its ability to be regenerated by heating in air,[1] we wondered if Magtrieve™ could be regenerated in situ by a suitable co-oxidant, thereby catalyzing the oxidation of a substrate.

Alcohol oxidation chemistry is not new. Many stoichiometric methods have been reported over the years; some of the most notable being pyridinium chlorochromate (PCC), Swern type oxidations, Dess–Martin Periodinane, and Oppenauer type oxidations.[3] In an effort to minimize the economic and environmental cost associated with the above methods, more recent work has focused on catalysis.[4]

Although these methods are feasible, we find that Magtrieve catalysis is much simpler to perform. Our strategy does not require anhydrous conditions, meaning it can be carried out open to air at room temperature. The reaction is complete in a matter of minutes in most cases. Inorganic byproducts are easily removed from the carbonyl products by aqueous work-up.

This study reports the oxidation of primary and secondary alcohols to the respective carbonyl compounds using Magtrieve™ in catalytic amounts with periodic acid as the terminal oxidant. Reaction conditions were optimized for the conversion of benzyl alcohol to benzaldehyde, and the scope of the reaction was studied by oxidizing various substituted benzyl alcohols, as well as primary and secondary aliphatic alcohols, using the optimized conditions (Scheme 1). Thus we present a rapid and cheap oxidation method with an easy work-up.



Scheme 1. R^1 = Aryl, Alkyl. R^2 = H, Alkyl, Aryl. [a]Different molar ratios of H_5IO_6 to alcohol were used depending on the target carbonyl. Representative oxidation of alcohols was carried by Magtrieve™ with periodic acid as oxidant. Eight examples are reported here, though many other possibilities exist.

Results and discussion

Optimization

The key to success has been understanding the proper reaction conditions, which were investigated using benzyl alcohol (**1a**) as a

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http://dx.doi.org/10.1016/j.tetlet.2014.06.055
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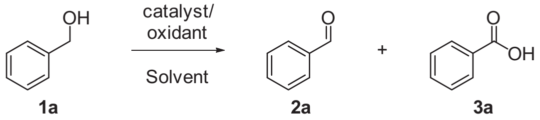
Table 1
Optimization of reaction conditions for room temperature oxidation of benzyl alcohol (5.0 mmol)



Entry	Solvent	Oxidant	Catalyst	Time	**1**	**2**	**3**
1	CH_3CN	H_5IO_6 (7.5 mmol)	None	36 h	76	23	<1
2	CH_3CN	H_5IO_6 (7.5 mmol)	CrO_2 (0.05 mmol)	36 h	65	34	<1
3	CH_3CN	H_5IO_6 (7.5 mmol)	CrO_2 (0.25 mmol)	1 h	20	79	<1
4	CH_3CN	H_5IO_6 (7.5 mmol)	CrO_2 (0.5 mmol)	1 h	ND[a]	>99	<1
5	CH_3CN	H_5IO_6 (7.5 mmol)	CrO_2 (1.0 mmol)	15 min	ND	>99	ND
6	CH_3CN	H_5IO_6 (7.5 mmol)	CrO_2 (0.5 mmol)[b]	30 min	ND	>99	ND
7	CH_3CN	H_5IO_6 (5.5 mmol)	CrO_2 (0.5 mmol)	20 min	ND	>99	ND
8	CH_3CN	Air	CrO_2 (0.5 mmol)	3.5 h	93	>6	ND
9	DCM	H_5IO_6 (7.5 mmol)	CrO_2 (0.5 mmol)	16 h	22	78	ND
10	Toluene	H_5IO_6 (7.5 mmol)	CrO_2 (0.5 mmol)	16 h	37	44	19
11	92:8 CH_3CN/H_2O	H_5IO_6 (5.5 mmol)	CrO_2 (0.5 mmol)	1 h	2[c]	94[c]	4[c]
12	60:40 CH_3CN/H_2O	H_5IO_6 (5.5 mmol)	CrO_2 (0.5 mmol)	1 h	12[c]	87[c]	<1[c]
13	80:20 CH_3CN/H_2O	H_5IO_6 (7.5 mmol)	CrO_2 (0.5 mmol)	1 h	6.5[c]	90[c]	3.5[c]

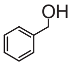
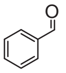
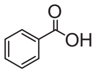
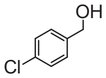
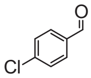
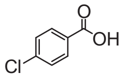
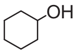
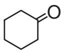
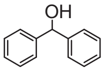
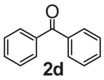
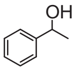
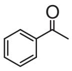
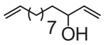
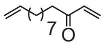
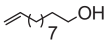
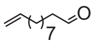
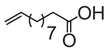
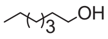
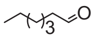
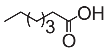
Crude ratios determined by GC–MS peak integration ratios unless noted otherwise.

[a] ND = Not detected.

[b] 0.5 mmol hydroquinone was added to the reaction.

[c] Percent of crude as determined by GC–FID peak integration.

Table 2
Substrate scope

Entry	**1**	**2**	**3**	H_5IO_6 (equiv)	Time	**1**	**2**	**3**
1	 **1a**	 **2a**	 **3a**	1.5	1 h	6.5	90	3.5
2	 **1b**	 **2b**	 **3b**	1.1	15 min	28.5	69.5	2
3	**1b**	**2b**	**3b**	2.2	5 h	ND[a]	12	88
4	 **1c**	 **2c**	NA[b]	1.5	1 h	3.5	96.5	NA
5	 **1d**	 **2d**	NA	1.5	15 min	3	97	NA
6	 **1e**	 **2e**	NA	1.1	1 h	5	95	NA
7[c]	 **1f**	 **2f**	NA	1.5	1 h	3.5	96.5	NA
8	 **1g**	 **2g**	 **3g**	2.2	1 h	4[d]	4[d]	92[d]
9	 **1h**	 **2h**	 **3h**	3.0	1 h	1.5	1.5	97

Five mmol alcohol and 80:20 CH_3CN/H_2O used unless noted otherwise. Crude ratio determined by GC–FID peak integration ratios unless noted otherwise. Product identities verified according to retention times of pure standards or by ^1H and ^{13}C NMR analysis of the crude product.

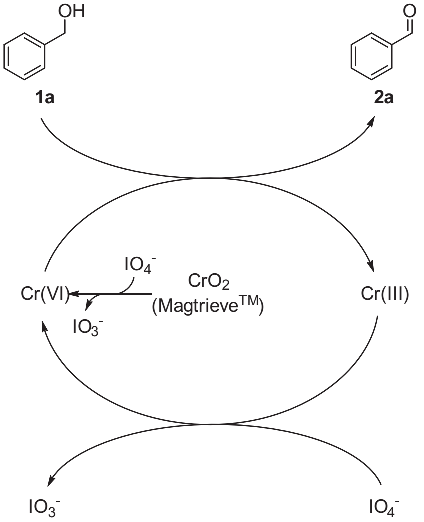
[a] ND = Not detected.

[b] NA = Not applicable.

[c] Used 2.4 mmol starting alcohol.

[d] Calculated from ^1H NMR peak integration.

test substrate (Table 1). We found that **1a** converts to benzaldehyde (**2a**) using 1.5 equiv of periodic acid and 10 mol % Magtrieve™ in an 80:20 acetonitrile/water solution. Completion of this transformation was reached in less than 1 h (Table 1, entry 13 and Table 2, entry 1) while the control experiment (without catalyst) yielded only 23% conversion after 36 h (Table 1, entry 1).



Scheme 2. Proposed catalytic cycle for the oxidation of benzyl alcohol (**1a**) to benzaldehyde (**2a**).

When 20 mol % Magtrieve™ was used, **1a** was completely converted after 15 min, but over-oxidation to benzoic acid (**3a**) began to take place after an hour (Table 1, entry 5). Over-oxidation also occurred using 10 mol % Magtrieve™ but only after 12 h. Approximately 80% conversion to **2a** occurred after 1 h when 5 mol % Magtrieve™ was used (Table 1, entry 3), but 1 mol % proved ineffective toward the oxidation of **1a** (Table 1, entry 2). A catalyst loading of 10 mol % was used in subsequent oxidations.

Solvent choice is an important. In fact, a combination of water and acetonitrile (ACN) leads to the best result. We attempted oxidations in toluene and dichloromethane (DCM), but achieved the highest conversion in the least time using acetonitrile (see Table 1, entries 9 and 10). To maximize periodic acid solubility and avoid the precipitation of $Cr(IO_3)_3$, we added water to the reaction mixture.[5,6]

Formation of insoluble $Cr(IO_3)_3(s)$ effectively blocks the alcohol oxidation by periodate,[6] and was avoided using 80:20 ACN/H_2O (Table 2, entry 1). Decreasing the water content to 8% resulted in precipitate formation (Table 1, entry 11). The oxidation of **1a** proceeded well in 60:40 ACN/H_2O (Table 1, entry 12), but to ensure solubility of less polar substrates, 80:20 ACN/H_2O was used for the remaining studies.

Hydroquinone was added in catalytic amounts (10 mol %) to study its effect on over-oxidation, but it had no noticeable effect on the reaction (Table 1, entry 6). An attempt to use air as the co-oxidant failed (Table 1, entry 8), as the reaction was sluggish for the first 3 h with air bubbling through the reaction mixture, and when allowed to bubble overnight, the solvent had evaporated by the next morning.

Mechanistic considerations

To gain insight into an aspect of the mechanism, Magtrieve™ was reacted with excess periodic acid in water. A yellow solution formed, and microchemical tests with Ag(I) suggested the presence of CrO_4^{2-}. Thus, it seems that CrO_2 is initially oxidized to Cr(VI), which accepts electrons from the alcohol to form Cr(III). The Cr(III) must be reoxidized by the periodic acid to complete the catalytic cycle (Scheme 2).

Substrate scope

Results of the oxidation of several alcohols can be found in Table 2. Except in one case, high conversion percentages were achieved within one hour at room temperature and open to air. In addition to very effectively oxidizing primary benzylic alcohols to the benzaldehydes (Table 2, entries 1–3), our method converts secondary alcohols—aliphatic, benzylic, and allylic—cleanly and quickly to the corresponding ketones (Table 2, entries 4–7). As mentioned above, olefins remain unreacted during alcohol oxidations (Table 2, entries 7–8). Also, primary aliphatic alcohols are converted to the carboxylic acids (Table 2, entries 8 and 9). To convert 4-chlorobenzyl alcohol (**1b**, Table 2, entries 2 and 3) to 4-chlorobenzoic acid (**3b**), 2.2 equiv of periodic acid and a 5 h reaction time were used, indicating that the extent of oxidation can be controlled. Product identification was confirmed either by GC retention time compared to purchased compounds or by ^1H and ^{13}C NMR compared to literature values.[7]

Conclusions

Magtrieve™ is an inexpensive catalyst for oxidations of alcohols to the corresponding aldehydes, carboxylic acids, or ketones. Reactions are generally complete within one hour at room temperature exposed to air, and are selective for the oxidation of alcohols in the presence of olefins. We believe this oxidation method surpasses previous methods due to its convenience, chemoselectivity, time to completion, and ease of work-up.

Acknowledgments

This material is based upon work supported by the United States National Science Foundation under Grant No. DMR-0703261. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the United States National Science Foundation. The authors would also like to thank Dr. Jon Stewart from the University of Florida Department of Chemistry for the use of GC–MS.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tetlet.2014.06.055.

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