JOC Article

Oxovanadium Complex-Catalyzed Aerobic Oxidation of Propargylic Alcohols

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A catalytic system consisting of vanadium oxyacetylacetonate [$VO(acac)_2$] and 3 Å molecular sieves (MS3A) in acetonitrile works effectively for the aerobic oxidation of propargylic alcohols [$R^1CH(OH)C{\equiv}CR^2$] to the corresponding carbonyl compounds under an atmospheric pressure of molecular oxygen. Although the reactivity of α-acetylenic alkanols (R^1 = alkyl) is lower compared to that of the alcohols of R^1 = aryl, alkenyl, and alkynyl, the use of $VO(hfac)_2$ as a catalyst and the addition of hexafluoroacetylacetone improve the product yield in these cases. A catalytic cycle involving a vanadium(V) alcoholate species and *β*-hydrogen elimination from it has been proposed for this oxidation.

Introduction

Transition metal-catalyzed oxidation of alcohols with various organic and inorganic oxidants has been established in recent years.[1] Although their methods are useful, they require stoichiometric oxidants, in which sometimes toxic wastes are produced. In view of green and sustainable chemistry, the use of a cleaner oxidant, especially molecular oxygen, is particularly attractive and many methods for the aerobic oxidation of alcohols with a transition metal catalyst such as Ru,[2] Pd,[3] Co,[4] Cu,[5] V,[6] Os,[7] and Ni[8] have been developed. However, some limitations for the substrate to be oxidized still exist, because of the instability of the produced carbonyl compounds in the reaction system, the catalyst deactivation by the formation of metallic polymer, and the

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(1) For example, see: (a) Sheldon, R. A.; Kochi, J. K. *Metal-Catalyzed Oxidations of Organic Compounds*; Academic Press: New York, 1981. (b) Hudlicky, M. *Oxidations in Organic Chemistry*; ACS Monograph Series; American Chemical Society: Washington, DC, 1990. (c) Mancuso, A. J.; Swern, D. *Synthesis* **1981**, 165. (d) Dess, D. B.; Martin, J. C. *J. Org. Chem.* **1983**, *48*, 4155. (e) Cainelli, G.; Cardillo, G. In *Chromium Oxidations in Organic Chemistry*; Springer-Verlag: Berlin, Germany, 1984. (f) Ley, S. V.; Madin, A. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1991; Vol. 7, p 251. (g) Lee, T. V. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1991; Vol. 7, p 291. (h) Procter, G. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1991; Vol. 7, p 305. (i) Sheldon, R. A.; Arends, I. W. C. E.; Dijksman, A. *Catal. Today* **2000**, *57*, 157.

(2) (a) Hanyu, A.; Takezawa, E.; Sakaguchi, S.; Ishii, Y. *Tetrahedron Lett.* **1998**, *39*, 5557. (b) Hinzen, B.; Lenz, R.; Ley, S. V. *Synthesis* **1998**, 977. (c) Kaneda, K.; Yamashita, T.; Matsushita, T.; Ebitani, K. *J. Org. Chem.* **1998**, *63*, 1750. (d) Coleman, K. S.; Lorber C. Y.; Osborn, J. A. *Eur. J. Inorg. Chem.* **1998**, 1673. (e) Vocanson, F.; Guo, Y. P.; Namy, J. L.; Kagan, H. B. *Synth. Commun.* **1998**, *28*, 2577. (f) Matsushita, T.; Ebitani, K.; Kaneda, K. *Chem. Commun.* **1999**, 265. (g) Dijksman, A.; Arends, I. W. C. E.; Sheldon, R. A. *Chem. Commun.* **1999**, 1591. (h) Bleloch, A.; Johnson, B. F. G.; Ley, S. V.; Price, A. J.; Shephard, D. S.; Thomas, A. W. *Chem. Commun.* **1999**, 1907. (i) Matsutani, K.; Uchida, T.; Irie, R.; Katsuki, T. *Tetrahedron Lett.* **2000**, *41*, 5119. (j) Yamaguchi, K.; Mori, K.; Mizugaki, T.; Ebitani, K.; Kaneda, K. *J. Am. Chem. Soc.* **2000**, *122*, 7144. (k) Friedrich, H. B.; Khan, F.; Singh N.; van Staden, M. *Synlett* **2001**, 869. (l) Dijksman, A.; Marino-González, A.; Payeras, A. M. i.; Arends, I. W. C. E.; Sheldon, R. A. *J. Am. Chem. Soc.* **2001**, *123*, 6826. (m) Miyata, A.; Murakami, M.; Irie, R.; Katsuki, T. *Tetrahedron Lett.* **2001**, *42*, 7067. (n) Csjernyik, G.; Éll, A. H.; Fadini, L.; Pugin, B.; Bäckvall, J.-E. *J. Org. Chem.* **2002**, *67*, 1657. (o) Hasan, M.; Musawir, M.; Dabey, P. N.; Kozhevnikov, I. V. *J. Mol. Catal. A* **2002**, *180*, 77.

(3) (a) Peterson, K. P.; Larock, R. C. *J. Org. Chem.* **1998**, *63*, 3185. (b) Ebitani, K.; Fujie, Y.; Kaneda, K. *Langmuir* **1999**, *15*, 3557. (c) Nagata, H.; Ogasawara, K. *Tetrahedron Lett.* **1999**, *40*, 6617. (d) ten Brink, G.-J.; Arends, I. W. C. E.; Sheldon, R. A. *Science* **2000**, *287*, 1636. (e) Besson, M.; Callezot, P. *Catal. Today* **2000**, *57*, 127 and references therein. (f) Jensen, D. R.; Pugsley, J. S.; Sigman, M. S. *J. Am. Chem. Soc.* **2001**, *123*, 7475. (g) Ferreira, E. M.; Stoltz, B. M. *J. Am. Chem. Soc.* **2001**, *123*, 7725.

(4) (a) Iwahama, T.; Yosino, Y.; Keitoku, T.; Sakaguchi, S.; Ishii, Y. *J. Org. Chem.* **2000**, *65*, 6502. (b) Fernández, I.; Pedro, J. R.; Roselló, A. L.; Ruiz, R.; Castro, I.; Ottenwaelder, X.; Journaux, Y. *Eur. J. Org. Chem.* **2001**, 1235.

(5) (a) Markó, I. E.; Tsukazaki, M.; Giles, P. R.; Brown, S. M.; Urch, C. J. *Angew. Chem., Int. Ed.* **1997**, *36*, 2208. (b) Wang, Y.; DuBois, J. L.; Hedman, B.; Hodgson, K. O.; Stack, T. D. P. *Science* **1998**, *279*, 537. (c) Chaudhuri, P.; Hess, M.; Flörke, U.; Wieghardt, K. *Angew. Chem., Int. Ed.* **1998**, *37*, 2217. (d) Markó, I. E.; Gautier, A.; Chellé-Regnaut, I.; Giles, P. R.; Tsukazaki, M.; Urch C. J.; Brown, S. M. *J. Org. Chem.* **1998**, *63*, 7576. (e) Markó, I. E.; Giles, P. R.; Tsukazaki, M.; Chellé-Regnaut, I.; Gautier, A.; Brown, S. M.; Urch, C. J. *J. Org. Chem.* **1999**, *64*, 2433. (f) Markó, I. E.; Gautier, A.; Mutonkole, J.-L.; Dumeunier, R.; Ates, A.; Urch, C. J.; Brown, S. M. *J. Organomet. Chem.* **2001**, *624*, 344. (g) Betzemeier, B.; Cavazzini, M.; Quici, S.; Knochel, P. *Tetrahedron Lett.* **2000**, *41*, 4343.

(6) (a) Matsumoto, M.; Watanabe, N. Japanese Patent 59157043; *Chem. Abstr.* **1985**, *102*, 79177. (b) Kirihara, M.; Ochiai, Y.; Takizawa, S.; Takahata, H.; Nemoto, H. *Chem. Commun.* **1999**, 1387. (c) Bonchio, M.; Bortolini, O.; Conte, V.; Primon, S. *J. Chem. Soc., Perkin Trans. 2* **2001**, 763.

(7) (a) Coleman, K. S.; Coppe, M.; Thomas, C.; Osborn, J. A. *Tetrahedron Lett.* **1999**, *40*, 3723. (b) Shapley, P. A.; Zhang, N.; Allen, J. L.; Pool, D. H.; Liang, H.-C. *J. Am. Chem. Soc.* **2000**, *122*, 1079. (c) Muldoon, J.; Brown, S. N. *Org. Lett.* **2002**, *4*, 1043.

(8) Choudary, B. M.; Kantam, M. L.; Rahman, A.; Reddy, C. V.; Rao, K. K. *Angew. Chem., Int. Ed.* **2001**, *40*, 763.

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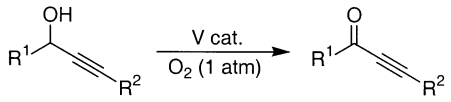
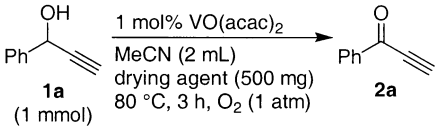
SCHEME 1



formation of stable complexes between metal salts and some electron donors on the starting alcohols such as heteroatoms and unsaturated carbon−carbon bonds. Propargylic alcohols are one type of target substrates for oxidation, because α,β-acetylenic carbonyl compounds (ynones) are useful precursors for various heterocycles, and important frameworks in DNA cleavage agents.[9] Although there are some useful oxidation procedures for these alcohols with stoichiometric oxidants such as MnO_2, chromium salts, a combination of dimethyl sulfoxide and oxalyl chloride (Swern oxidation), Dess−Martin reagent, etc.,[1,10] the catalytic and aerobic oxidation methods are quite limited.[2i,11]

In our recent works on the aerobic oxidation of alcohols with palladium(II) catalyst,[12] the oxidation of propargylic alcohols failed due to the formation of inactive metallic palladium, resulting in the formation of unidentified tarry compounds. To overcome such limitations, we have continued to search the efficient catalytic system for aerobic oxidation of such alcohols, and recently found that some oxovanadium compounds worked as effective catalysts for the aerobic oxidation of propargylic alcohols under an atmospheric pressure of oxygen (Scheme 1).[13,14] We report herein the scope and limitations and some mechanistic aspects of this catalytic reaction.

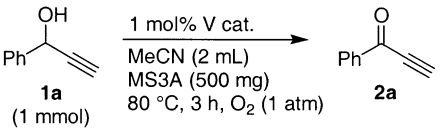
TABLE 1. Effect of Drying Agents



entry	drying agent	conv of **1a** (%)	GLC yield of **2a** (%)[a]
1[b]	MS3A	95	95
2[b,c]	MS3A	79	79
3[b,d]	MS3A	48	48
4	MS3A	100	quant.
5	MS4A	20	18
6	K_2CO_3	0	
7	$CaSO_4$	6	6
8	Na_2SO_4	11	8

[a] Based on alcohol employed. [b] 5 mol % of catalyst and 5 mL of MeCN. [c] MS3A (250 mg). [d] MS3A (100 mg).

TABLE 2. Oxovanadium Complex-Catalyzed Oxidation of 1a to 2a under Molecular Oxygen



entry	V cat.	conv of **1a** (%)	GLC yield of **2a** (%)[a]
1	$VO(acac)_2$	100	quant.
2	$VOCl_3$	100	quant.
3	$VO(OEt)_3$	100	quant.
4	$VO(tfac)_2$	94	94
5	$VO(hpfdm)_2$	99	99
6	$VO(hfac)_2$	97	97
7	V_2O_5	<1	<1

[a] Based on alcohol employed.

Results and Discussion

On the basis of our previous studies, oxidation of propargylic alcohols (1.0 mmol) under molecular oxygen was generally carried out in the presence of a catalytic amount of $VO(acac)_2$ (1 mol %) and MS3A (500 mg) in acetonitrile (2 mL) under stirring at 80 °C for 3 h (a standard condition for the oxidation). It was noteworthy that the product yield was much affected by the amount of MS3A and the kind of drying agents. When the amount of MS3A was reduced in the oxidation of 1-phenyl-2-propyn-1-ol (**1a**) with 5 mol % of $VO(acac)_2$ as a catalyst, the yield of 1-phenyl-2-propyn-1-one (**2a**) decreased (Table 1, entries 1−3). The use of MS4A instead of MS3A dramatically diminished the yield of **2a** (entry 5: compare to entry 4). Further, the use of other drying agents such as K_2CO_3, $CaSO_4$, and Na_2SO_4 was ineffective for this oxidation (entries 6−8).[15] In other solvents such as benzonitrile, toluene, THF, and 1,2-dichloroethane, the yield of **2a** decreased. Other oxovanadium compounds such as $VOCl_3$, $VO(OEt)_3$, $VO(tfac)_2$ (tfac = 1,1,1-trifluoroactylacetonate), $VO(hfac)_2$ (hfac = hexafluoroacetylacetonate), and $VO(hpfdm)_2$ (hpfdm = 6,6,7,7,8,8,8-hep-

(9) (a) Adlington, R. M.; Baldwin, J. E.; Pritchard, G. J.; Spencer, K. C. *Tetrahedron Lett.* **2000**, *41*, 575. (b) Basak, A.; Bdour, H. M.; Shain, J. C.; Mandal, S.; Rudra, K. R.; Nag, S. *Bioorg. Med. Chem. Lett.* **2000**, *10*, 1321. (c) Cabarrocas, G.; Ventura, M.; Maestro, M.; Mahía, J.; Villalgordo, J. M. *Tetrahedron*: *Asymmetry* **2000**, *11*, 2483. (d) Wei, H.-X.; Kim, S. H.; Caputo, T. D.; Purkiss, D. W.; Li, G. *Tetrahedron* **2000**, *56*, 2397. (e) Wender, P. A.; Bi, F. C.; Brodney, M. A.; Gosselin, F. *Org. Lett.* **2001**, *3*, 2105. (f) Li, P.; Fong, W. M.; Chao, L. C. F.; Fung, S. H. C.; Williams, I. D. *J. Org. Chem.* **2001**, *66*, 4087 and references therein.

(10) (a) Carreira, E. M.; Bois, J. D. *J. Am. Chem. Soc.* **1995**, *117*, 8106. (b) Han, Z.; Shinokubo, H.; Oshima, K. *Synlett* **2001**, 1421. (c) Luca, L. D.; Giacomelli, G.; Porcheddu, A. *J. Org. Chem.* **2001**, *66*, 7907. (d) Matsuto, J.; Iida, D.; Tatani K.; Mukaiyama, T. *Bull. Chem. Soc. Jpn.* **2002**, *75*, 223.

(11) Sakaguchi, S.; Takase, T.; Iwahara, T.; Ishii, Y. *Chem. Commun.* **1998**, 2037.

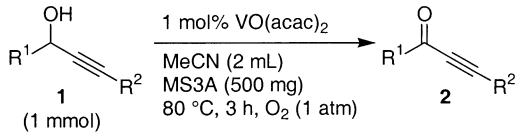
(12) (a) Nishimura, T.; Onoue, T.; Ohe, K.; Uemura, S. *Tetrahedron Lett.* **1998**, *39*, 6011. (b) Nishimura, T.; Onoue, T.; Ohe, K.; Uemura, S. *J. Org. Chem.* **1999**, *64*, 6750. (c) Nishimura, T.; Kakiuchi, N.; Inoue, M.; Uemura, S. *Chem. Commun.* **2000**, 1245. (d) Nishimura, T.; Maeda, Y.; Kakiuchi, N.; Uemura, S. *J. Chem. Soc., Perkin Trans. 1* **2000**, 4301. (e) Kakiuchi, N.; Nishimura, T.; Inoue, M.; Uemura, S. *Bull. Chem. Soc. Jpn.* **2001**, *74*, 165. (f) Kakiuchi, N.; Maeda, Y.; Nishimura, T.; Uemura, S. *J. Org. Chem.* **2001**, *66*, 6620.

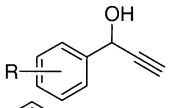
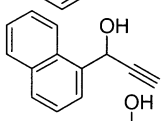
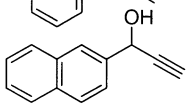
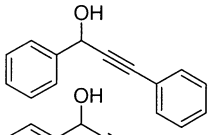
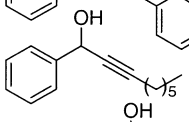
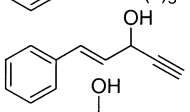
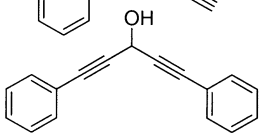
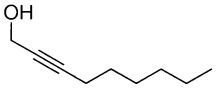
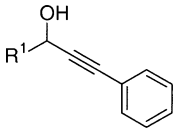
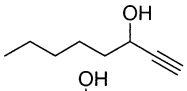
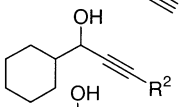
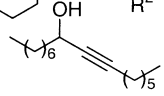
(13) Maeda, Y.; Kakiuchi, N.; Matsumura, S.; Nishimura, T.; Uemura, S. *Tetrahedron Lett.* **2001**, *42*, 8877.

(14) For recent advances in the aerobic oxidation forming epoxides, biaryls, and so on catalyzed by oxovanadium complexes, see: (a) Takai, T.; Yamada, T.; Mukaiyama, T. *Chem. Lett.* **1990**, 1657. (b) Inoki, S.; Takai, T.; Yamada, T.; Mukaiyama, T. *Chem. Lett.* **1991**, 941. (c) Mukaiyama, T.; Takai, T. Japanese Patent 03227952; *Chem. Abstr.* **1992**, *116*, 20776. (d) Mukaiyama, T.; Takai, T. Japanese Patent 03227951; *Chem. Abstr.* **1992**, *116*, 58959. (e) Hirao, T. *Chem. Rev.* **1997**, *97*, 2707. (f) Kirihara, M.; Takizawa, S.; Momose, T. *J. Chem. Soc., Perkin Trans. 1* **1998**, 7. (g) Kirihara, M.; Ichinose, M.; Takizawa, S.; Momose, T. *Chem. Commun.* **1998**, 1691. (h) Kirihara, M.; Ochiai, Y.; Arai, N.; Takizawa, S.; Momose, T.; Nemoto, H. *Tetrahedron Lett.* **1999**, *40*, 9055. (i) Ishii, Y.; Matsunaka, K.; Sakaguchi, S. *J. Am. Chem. Soc.* **2000**, *122*, 7390. (j) Chu, C.-Y.; Hwang, D.-R.; Wang, S.-K.; Uang, B.-J. *Chem. Commun.* **2001**, 980. (k) Hirao, T.; Morimoto, C.; Takada, T.; Sakurai, H. *Tetrahedron* **2001**, *57*, 5073. (l) Barhate, N. B.; Chen, C.-T. *Org. Lett.* **2002**, *4*, 2529.

(15) Molecular sieves can work to remove water formed during the oxidation. Such positive effect has been known. See, for example: (a) Reference 14b. See also: (b) Kato, K.; Yamada, T.; Takai, T.; Inoki, S.; Isayama, S. *Bull. Chem. Soc. Jpn.* **1990**, *63*, 179 and references therein.

TABLE 3. Oxidation of Propargylic Alcohols under Molecular Oxygen



entry	substrate **1**		conversion of **1** (%)	isolated yield of **2** (%)[a]
1		**1a** R = H	100	quant.[b]
2		**1b** R = 2-Cl	84	65
3		**1c** R = 4-Me	98	70
4		**1d**	80	70
5		**1e**	98	86
6		**1f**	96	81
7		**1g**	99	98
8		**1h**	90	65
9		**1i**	83	76
10		**1j**	36	25
11[c]		**1j**	91	62
12		**1k** R^1 = Me	33	33
13		**1l** R^1 = *t*-Bu	54	44
14		**1m**	68	52[b]
15[d]		**1m**	59	59[b]
16[c,e]		**1m**	90	65[b]
17		**1n** R^2 = H	71	41
18		**1o** R^2 = *n*-C_4H_9	90	62
19		**1p** R^2 = *n*-C_6H_{13}	83	60
20		**1q**	52	44

[a] Based on alcohol employed. [b] GLC yield. [c] 5 mol % of catalyst. [d] For 12 h. [e] At 60 °C for 36 h.

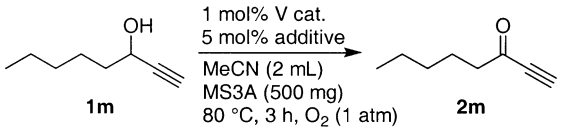
tafluoro-2,2-dimethyl-3,5-octanedionate), except for V_2O_5, could be used as effective catalysts for this oxidation (Table 2). However, $VO(acac)_2$ was chosen as a suitable catalyst, considering the ease of handling and low cost.

First, the oxidation of propargylic alcohols having an arylic, vinylic, or acetylenic substituent at the α-position was examined. Typical results are listed in Table 3. Propargylic alcohols having an arylic substituent at the α-position (**1a**−**g**) were converted to the corresponding carbonyl compounds in high yields (entries 1−7). Similarly, propargylic alcohols having a vinylic substituent (**1h**) and an acetylenic substituent (**1i**) gave the corresponding carbonyl compounds in good yields (entries 8 and 9).

Next, the alcohols having an alkyl substituent or only hydrogens at the α-position were examined. The alcohol having only hydrogens at the α-position (**1j**) was converted to the corresponding aldehyde (**2j**) in low yield (Table 3, entry 10), but when the oxidation was performed with 5 mol % of $VO(acac)_2$, the yield of **2j** improved (entry 11). The alcohols having an alkyl substituent at the α-position (α-acetylenic alkanols) (**1k**−**q**) gave the corresponding ketones in moderate yields (entries 12−20) and longer reaction time did not improve much the product yield.

To obtain a more effective reaction condition of oxovanadium complex catalyzed oxidation of α-acetylenic alkanols such as **1j**−**q**, the effect of some additives was

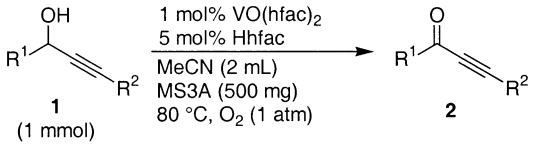
TABLE 4. Effect of Additives



entry	V cat.	additive	conv of **1m** (%)	GLC yield of **2m** (%)[a]
1	$VO(acac)_2$		68	52
2	$VO(acac)_2$	pyridine	7	5
3	$VO(acac)_2$	Hacac	56	45
4[b]	$V(acac)_3$		79	70
5[b]	$VO(hpfdm)_2$		65	57
6[b]	$VO(hfac)_2$		65	55
7[b]	$VO(hfac)_2$	Hhfac	83	71

[a] Based on alcohol employed. [b] For 12 h.

TABLE 5. $VO(hfac)_2$-Catalyzed Oxidation of α-Acetylenic Alkanols under Molecular Oxygen



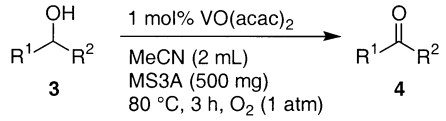
entry	substrate	time (h)	conv of **1** (%)	isolated yield of **2** (%)[a]
1	**1j**	12	60	**2j**, 39
2	**1k**	3	49	**2k**, 45
3	**1k**	12	67	**2k**, 67
4	**1m**	12	83	**2m**, 71[b]
5	**1p**	12	77	**2p**, 50
6	**1q**	12	84	**2q**, 57

[a] Based on alcohol employed. [b] GLC yield.

investigated with **1m** as a substrate. The presence of a base such as pyridine inhibited the reaction (Table 4, entry 2). The addition of acetylacetone did not affect the yield of **2m** (entry 3). With use of $V(acac)_3$ as a catalyst, **2m** was obtained in good yield (entry 4). $VO(hpfdm)_2$ and $VO(hfac)_2$ also worked well as a catalyst (entries 5 and 6). Since the addition of hexafluoroacetylacetone in the system with $VO(hfac)_2$ as a catalyst gave a better yield of **2m** (71% yield, entry 7), this improved catalytic system was applied to other α-acetylenic alkanols, the results being listed in Table 5. The improvement of the yield of the corresponding carbonyl compounds was observed in the oxidation of alcohols **1k**, **1m**, and **1q** compared with the results in the case of using $VO(acac)_2$ as a catalyst (entries 2−4 and 6; compare also with entries 12, 14, and 20 in Table 3).

Next, the oxidation of benzylic, allylic, and aliphatic alcohols with $VO(acac)_2$ as a catalyst was examined (Table 6). Benzyl alcohol (**3a**) was converted to benzaldehyde (**4a**) in low yield (entry 1). When the oxidation was performed with 5 mol % of $VO(acac)_2$, the yield of **4a** increased (entry 2). 1-Phenylethyl alcohol (**3b**) and diphenylmethanol (**3c**) were converted to the corresponding ketones in moderate yields (entries 3 and 4). Primary and secondary aliphatic alcohols (**3d** and **3e**) and cinnamyl alcohol (**3f**) gave the corresponding carbonyl compounds in low yields (entries 5−7). Allylic alcohols

TABLE 6. $VO(acac)_2$-Catalyzed Oxidation of Alcohols under Molecular Oxygen



entry	substrate	R^1	R^2	conv of **3** (%)	isolated yield of **4** (%)[a]
1	**3a**	Ph	H	25	**4a**, 11[b]
2[c]	**3a**	Ph	H	65	**4a**, 62[b]
3	**3b**	Ph	Me	50	**4b**, 50[b]
4	**3c**	Ph	Ph	45	**4c**, 45
5	**3d**	n-$C_{11}H_{23}$	H	19	**4d**, 13
6	**3e**	n-$C_{10}H_{21}$	Me	15	**4e**, 11
7	**3f**	(*E*)-PhCH=CH	H	20	**4f**, 15
8	**3g**	(*E*)-HC≡CC(CH_3)=CH	H	99	**4g**, 54
9	**3h**	(*E*)-PhC≡CCH=CH	H	91	**4h**, 51[d]
10	**3i**	(*Z*)-PhC≡CCH=CH	H	99	**4i**, 60[d]

[a] Based on alcohol employed. [b] GLC yield. [c] 5 mol % of catalyst at 50 °C for 14 h. [d] Several unidentified compounds were present.

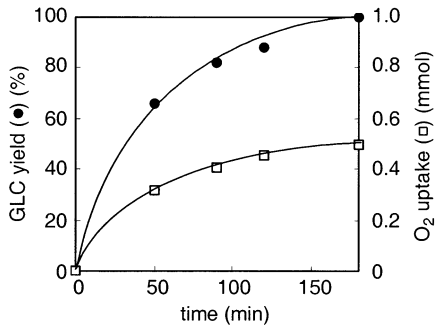
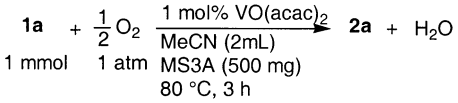


FIGURE 1. Plots of yield of **2a** vs O_2 uptake.

SCHEME 2



having alkynic substituents (**3g**−**i**) were converted to the corresponding aldehydes in moderate yields (entries 8−10).

The measurement of O_2 uptake during the reaction was performed with **1a** as a substrate to obtain some information about the reaction pathway. As a result, it was observed that a half molar amount of O_2 was absorbed relative to the yield of **2a**, showing the stoichiometry of the oxidation to be that shown in Scheme 2 (Figure 1).

Next, the oxidation of **1a** to **2a** in the presence or absence of a radical inhibitor such as 2,6-di-*tert*-butylphenol and garvinoxyl (Scheme 3) was examined, the time profile of the product yield being shown in Figure 2. It was revealed that the addition of the inhibitor did not affect the reaction rate as well as the product yield, suggesting that the main reaction course may be an ionic one.

Further, the stoichiometric reaction under a nitrogen atmosphere was examined. Treatment of **1a** (0.1 mmol) in the presence of $VO(acac)_2$ (0.1 mmol) and MS3A (500 mg) in acetonitrile (20 mL) under N_2 at 80 °C did not give the corresponding carbonyl compound at all even

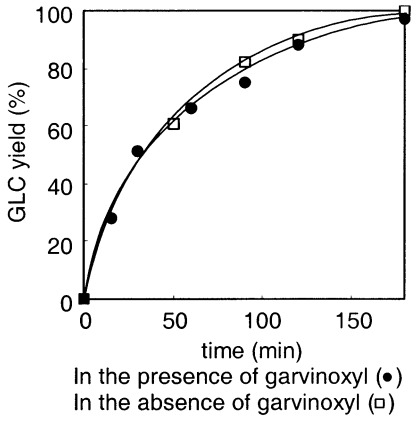
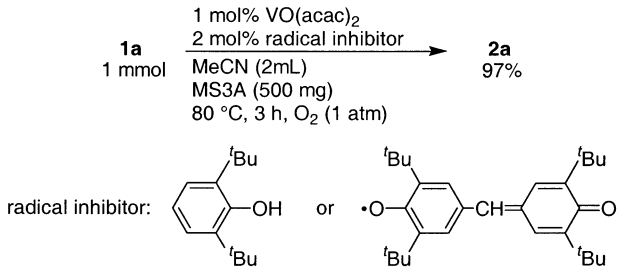


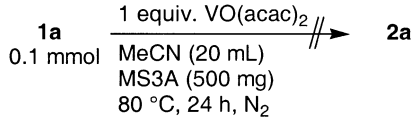
FIGURE 2. Time profile of the oxidation of **1a** in the presence or absence of garvinoxyl.

SCHEME 3



after 24 h (Scheme 4). This result suggests that the presence of oxygen is indispensable for the formation of an active species for this oxidation.

SCHEME 4



As the electron spin resonance (ESR) study of VO(acac)$_2$ has been throughly carried out to disclose the characteristic spectrum due to vanadium(IV),[16] the measurement of the ESR spectrum of a vanadium species in our reaction system was tried under various conditions to obtain some information on the reaction pathway. First, the spectrum of VO(acac)$_2$ was measured in acetonitrile (0.5 M) in the presence or absence of MS3A under argon at room temperature. Nearly the same spectrum was obtained in both cases (a(V) = 10.5 mT, g = 1.964), which was in accord with the literature values[16a] (a(V) = 10.5 mT, g = 1.969). The coexistence of suspended MS3A powder did not induce any abnormal line-width phenomenon, showing that the vanadium(IV) complex is not adsorbed on the MS3A powder. These results suggest that there is no favorable interaction between VO(acac)$_2$ and MS3A. Next, to investigate whether VO(acac)$_2$ changes to a higher valent vanadium species in the presence of molecular oxygen, its spectrum was measured in acetonitrile (0.5 M) in the presence of MS3A under 1 atm of O_2. The spectrum was the same as that of VO(acac)$_2$ even measured at 75 °C, showing that the oxidation state of the vanadium did not change even in the presence of oxygen. When the ESR measurement was carried out with the sample containing **1a**, oxygen, MS3A, and acetonitrile at room temperature, almost the same spectrum as above was obtained, but when the sample was heated to 65 °C, the color of the green mixture turned yellow to brown and the spectrum due to VO(acac)$_2$ disappeared completely. This result shows that a higher vanadium(V) species might be produced and, for its formation, the presence of both propargylic alcohol and molecular oxygen is necessary.

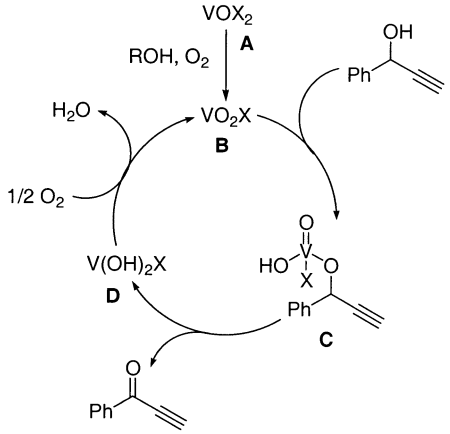


FIGURE 3. Plausible reaction pathway.

On the basis of these results, a plausible reaction pathway is shown in Figure 3.[1a,17] First, a vanadium(IV) species (**A**) reacts with both propargylic alcohol and molecular oxygen to form a vanadium(V) species (**B**). The species **B** further reacts with propargylic alcohol to afford a vanadium alcoholate (**C**). Next, the product carbonyl compound and a dihydroxyvanadium species (**D**) are formed via β-hydrogen elimination from species **C**. The subsequent dehydration of **D** by oxidation with oxygen reproduces species **B**.

Conclusion

We have disclosed that the oxidation of propargylic alcohols [R^{1}CH(OH)C≡CR^2] to the corresponding carbonyl compounds proceeded efficiently with VO(acac)$_2$ as a catalyst in the presence of MS3A in acetonitrile under an atmospheric pressure of molecular oxygen. Although the reactivity of α-acetylenic alkanols (R^1 = alkyl) was lower compared to that of the alcohols of R^1 = aryl, alkenyl, and alkynyl, the use of VO(hfac)$_2$ as a catalyst and the addition of hexafluoroacetylacetone improved the product yield in these cases.

Experimental Section

General Methods. ^{1}H NMR spectra were obtained in $CDCl_3$ at 300 or 400 MHz with Me_4Si as an internal standard. ^{13}C NMR spectra were obtained at 100 or 75.5 MHz. ESR spectra were recorded on a JEOL JES-TE200 spectrometer. Field sweep was monitored with an Echo Electronics EFM-2000 ^{1}H NMR gaussmeter. GLC analyses were performed on

(16) (a) Bernal, I.; Rieger, P. H. *Inorg. Chem.* **1962**, *2*, 256. (b) Kivelson, D.; Lee, S.-K. *J. Chem. Phys.* **1964**, *41*, 1896. (c) Walker, F. A.; Carlin, R. L.; Rieger, P. H. *J. Chem. Phys.* **1966**, *45*, 4181. (d) Guzy, C. M.; Raynol, J. B.; Symons, M. C. R. *J. Chem. Soc. (A)* **1969**, 2791.

(17) Itoh, T.; Jitsukawa, K.; Kaneda K.; Teratani, S. *J. Am. Chem. Soc.* **1979**, *101*, 159.

a Shimadzu GC-14A instrument (25 m × 0.33 mm, 5.0 mm film thickness, Shimadzu fused silica capillary column HiCap CBP10-S25-050) with a flame-ionization detector and helium as carrier gas. Analytical thin-layer chromatography (TLC) was performed with Merck silica gel 60 F-254 plates. Column chromatography was performed with Merck silica gel 60.

Materials. Commercially available organic and inorganic compounds were used without further purification except for the solvent, which was distilled by the usual method before use. $VO(tfac)_2$, $VO(hfac)_2$, and $VO(hpfdm)_2$ were synthesized by literature methods.[18] Commercial MS3A (powder) (Nacalai Tesque) was activated by calcination just before use. Alcohols **1a**, **1h**−**k**, **1m**, and **3a**−**g** were commercial products and purified by normal methods just before use. Alcohols **1b**−**g**, **1l,**and **1n**−**q** were prepared from the corresponding aldehydes and lithium acetylides or alkynylmagnesium bromides, purified by column chromatography on silica gel (eluent: hexane−ethyl acetate) and identified by ^{1}H NMR and ^{13}C NMR. All propargylic alcohols and the corresponding aldehydes and ketones except for **1q** are known compounds. Aldehydes and ketones **2f**, **2i**, **2k**, and **4a**−**f** are commercial products. Compounds **3h** and **3i** were prepared by the reported method.[19a] Compounds **3h**,[19a] **3i**,[19a] **4g**,[19b] **4h**,[19c] and **4i**[19c] were characterized by their spectral data. Some selected spectral data of alcohols and carbonyl compounds are shown below.

1-(*p*-Tolyl)-2-propyn-1-ol (1b, Table 3, entry 2). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.34 (s, 3H), 2.62 (dd, J = 2.2 0.5 Hz, 1H), 2.70 (br s, OH, 1H), 5.37 (s, 1H), 7.15 (d, J = 8.2 Hz, 2H), 7.39 (d, J = 8.2 Hz, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 21.1, 42.1, 74.5, 83.7, 126.5, 129.2, 137.2, 138.2.

1-(2-Chlorophenyl)-2-propyn-1-ol (1c, Table 3, entry 3). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.62 (d, J = 2.2 Hz, 1H), 3.30 (br s, OH, 1H), 5.79 (d, J = 2.2 Hz, 1H), 7.19−7.36 (m, 3H), 7.74 (dd, J = 7.3, 2.1 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 61.3, 74.6, 82.4, 127.1, 128.1, 129.5, 129.6, 132.5, 137.4.

1-(1-Naphthyl)-2-propyn-1-ol (1d, Table 3, entry 4). White solid, mp 57.7−58.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.44 (br s, OH, 1H), 2.72 (d, J = 1.0 Hz, 1H), 6.10 (d, J = 1.0 Hz, 1H), 7.43−7.56 (m, 3H), 7.82−7.88 (m, 3H), 8.25 (d, J = 8.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 62.7, 75.5, 83.2, 123.7, 124.5, 125.1, 125.9, 126.4, 128.7, 129.4, 130.3, 133.9, 134.9.

1-(2-Naphthyl)-2-propyn-1-ol (1e, Table 3, entry 5). White solid, mp 53.8−54.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (br s, OH, 1H), 2.71 (d, J = 2.2 Hz, 1H), 5.61 (d, J = 2.2 Hz, 1H), 7.47−7.51 (m, 2H), 7.64 (dd, J = 8.3, 1.5 Hz, 1H), 7.82−7.88 (m, 3H), 7.99, (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 64.5, 75.0, 83.5, 124.3, 125.4, 126.3, 126.3, 127.6, 128.1, 128.2, 128.5, 133.0, 137.2.

1,3-Diphenyl-2-propyn-1-ol (1f, Table 3, entry 6). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.10 (br s, OH, 1H), 5.64 (s, 1H), 7.22−7.46 (m, 8H), 7.56−7.59 (m, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 64.8, 86.4, 88.8, 122.3, 126.6, 126.7, 128.2, 128.2, 128.5, 131.6, 140.5.

1-Phenyl-2-nonyn-1-ol (1g, Table 3, entry 7). Yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.88 (t, J = 6.8 Hz, 3H), 1.23−1.40 (m, 6H), 1.50 (quint, J = 7.8 Hz, 2H), 1.56 (br s, OH, 1H), 2.22 (td, J = 7.3, 1.9 Hz, 2H), 5.38 (s, 1H), 7.23−7.39 (m, 3H), 7.49 (d, J = 7.3 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 18.7, 22.4, 31.2, 64.4, 64.4, 80.0, 87.2, 126.4, 127.7, 128.1, 141.1.

4,4-Dimethyl-1-phenyl-1-pentyn-3-ol (1l, Table 3, entry 13). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.06 (s, 9H), 2.16 (br s, OH, 1H), 4.23 (s, 1H), 7.25−7.31 (m, 3H), 7.39−7.44 (m, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 5.3, 36.1, 71.7, 85.6, 89.0, 122.8, 128.2, 128.2, 131.6.

1-Cyclohexyl-2-propyn-1-ol (1n, Table 3, entry 17). Yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.02−1.31 (m, 5H), 1.52−1.88 (m, 6H), 2.24 (br s, OH, 1H), 2.47 (d, J = 2.2 Hz, 1H), 4.16 (dd, J = 5.9, 2.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.8, 25.9, 26.3, 28.0, 28.4, 48.7, 66.9, 73.6, 83.9.

1-Cyclohexyl-2-heptyn-1-ol (1o, Table 3, entry 18). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.91 (t, J = 4.0 Hz, 3H), 1.02−1.86 (m, 15H), 2.22 (td, J = 6.6, 1.8 Hz, 2H), 4.13 (dt, J = 5.9, 1.8 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.5, 18.3, 21.8, 25.8, 25.9, 26.4, 28.0, 30.7, 44.2, 67.2, 80.1, 86.0.

1-Cyclohexyl-2-nonyn-1-ol (1p, Table 3, entry 19). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.89 (t, J = Hz, 3H), 1.02−1.85 (m, 19H), 2.10 (br s, OH, 1H), 2.20 (td, J = 7.0, 1.1 Hz, 2H), 4.13 (d, J = 7.7 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.9, 18.6, 22.5, 25.8 26.4, 28.0, 28.4, 28.5, 31.2, 44.2, 67.3, 80.1, 86.1.

9-Hexadecyn-8-ol (1q, Table 3, entry 20). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.88 (t, J = 7.0 Hz, 3H), 0.89 (t, J = 7.0 Hz, 3H), 1.29−1.68 (m, 23H), 2.20 (td, J = 6.8, 1.7 Hz, 2H), 4.35 (t, J = 6.4 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 14.0, 14.1, 18.8, 22.5, 22.6, 25.2, 28.5, 28.6, 29.2, 31.3, 31.8, 38.2, 62.8, 81.3, 85.6; IR (neat, cm^{-1}) 2932, 2856, 2211, 1709, 1671, 1450, 1243, 1165, 974, 894, 725. Anal. Calcd for $C_{16}H_{30}O$: C, 80.61; H, 12.68. Found C, 80.51; H, 12.40.

General Procedure for the Oxidation of Propargylic Alcohols with Molecular Oxygen. To a solution of $VO(acac)_2$ (2.65 mg, 0.01 mmol) in acetonitrile (1.5 mL) in a 10-mL two-necked round-bottomed flask was added MS3A (500 mg, powder). Next, a solution of propargylic alcohol (1 mmol) in acetonitrile (0.5 mL) was added and the resulting mixture was stirred. Oxygen gas was then introduced into the flask from an O_2 balloon under atmospheric pressure and then the mixture was stirred vigorously for 3 h at 80 °C under oxygen. The mixture was then cooled to room temperature and MS3A was separated by filtration through a glass filter. The amount of the product was determined by GLC analysis with bibenzyl or cyclododecane as an internal standard. For isolation of the product, the solvent was evaporated and the residue was purified by column chromatography (Merck silica gel 60; hexane−ethyl acetate as an eluent).

1-Phenyl-2-propyn-1-one (2a, Table 1 entry 1). Yellow solid, mp 42.5−43.5 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.45 (s, 1H), 7.49 (t, J = 7.4 Hz, 2H), 7.63 (t, J = 7.4 Hz, 1H), 8.16 (d, J = 7.4 Hz, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 80.1, 80.7, 128.4, 129.4, 134.3, 135.9, 177.1 (C═O).

1-(*p*-Tolyl)-2-propyn-1-one (2b, Table 3, entry 2). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.43 (s, 3H), 3.40 (s, 1H), 7.29 (d, J = 8.1 Hz, 2H), 8.05 (d, J = 8.1 Hz, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 21.8, 80.3, 80.4, 129.4, 129.8, 133.9, 145.7, 177.0 (C═O).

1-(2-Chlorophenyl)-2-propyn-1-one (2c, Table 3, entry 3). Pale yellow solid, mp 61.5−62.2 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.49 (s, 1H), 7.37−7.52 (m, 3H), 8.10 (ddd, J = 7.8, 1.6, 0.6 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 81.1, 81.3, 126.7, 131.7, 133.3, 133.8, 133.8, 134.5, 175.8 (C═O).

1-(1-Naphthyl)-2-propyn-1-one (2d, Table 3, entry 4). Yellow solid, mp 59.5−60.5 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.44 (s, 3H), 7.56 (m, 2H), 7.67 (t, J = 7.8 Hz, 1H), 7.89 (d, J = 7.8 Hz, 1H), 8.08 (d, J = 7.8 Hz, 1H), 8.60 (d, J = 7.8 Hz, 1H), 9.20 (d, J = 7.8 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 79.4 81.6, 124.4, 125.8, 126.9, 128.6, 129.2, 130.6, 131.8, 133.8. 135.5, 135.7, 178.8 (C═O).

1-(2-Naphthyl)-2-propyn-1-one (2e, Table 3, entry 5). Yellow solid, mp 102.0−102.9 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.50 (s, 1H), 7.56−7.68 (m, 2H), 7.88 (d, J = 8.6 Hz, 1H), 7.91 (d, J = 8.6 Hz, 1H), 8.02 (d, J = 8.6 Hz, 1H), 8.14 (dd, J = 8.6, 1.7 Hz, 1H), 8.75 (s, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 80.4, 80.7, 123.6, 127.1, 127.9, 128.6, 129.3, 129.9, 132.3, 133.3, 133.7, 136.2, 177.3 (C═O).

(18) (a) Su, C.-C.; Reed, J. W.; Gould, E. S. *Inorg. Chem*. **1973**, *12*, 337. (b) Pesiri, D. R.; Morita, D. K.; Walker, T.; Tumas, W. *Organometallics* **1999**, *18*, 4916.

(19) (a) Takeuchi, R.; Tanabe, K.; Tanaka, S. *J. Org. Chem*. **2000**, *65*, 1558. (b) Muller, B.; Férézou, J.-P.; Pancrazi, A.; Lallemand, J.-Y. *Bull. Soc. Chim. Fr*. **1997**, *134*, 13. (c) John, J. A.; Tour, J. M. *Tetrahedron* **1997**, *53*, 15515.

1-Phenyl-2-nonyn-1-one (2g, Table 3, entry 7). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.91 (t, J = 6.8 Hz, 3H), 1.31−1.35 (m, 4H), 1.43−1.53 (quint, J = 6.8 Hz, 2H), 1.68 (quint, J = 7.5 Hz, 2H), 2.50 (t, J = 7.2 Hz, 2H), 7.47 (t, J = 7.3 Hz, 1H), 7.48 (t, J = 6.9 Hz, 2H), 7.60 (tt, J = 7.3, 1.3 Hz, 1H), 8.12−8.15 (m, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.9, 19.1, 22.4, 27.7, 28.5, 31.1, 79.6, 96.8, 128.4, 129.4, 133.8, 136.8, 178.1 (C═O).

(*E*)-1-Phenyl-1-penten-4-yn-3-one (2h, Table 3, entry 8). Yellow solid, mp 51.2−52.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.32 (s, 1H), 6.81 (d, J = 16.1 Hz, 1H), 7.42−7.46 (m, 3H), 7.58−7.60 (m, 2H), 7.89 (d, J = 16.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 79.2, 79.9, 127.9, 128.7, 129.0, 131.3, 133.8, 149.5, 177.4 (C═O).

2-Nonynal (2j, Table 3, entry 10). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.90 (t, J = 6.8 Hz, 3H), 1.26−1.48 (m, 6H), 1.63 (quint, J = 7.2 Hz, 2H), 2.41 (t, J = 7.0 Hz, 2H), 9.18 (s, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.9, 18.7, 22.4, 27.3, 28.4, 31.2, 72.6. 92.5, 157.9 (C═O).

4,4-Dimethyl-1-phenyl-1-pentyn-3-one (2l, Table 3, entry 13). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.28 (s, 9H), 7.34−7.47 (m, 3H), 7.56−7.59 (m, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 26.1, 44.8, 85.9, 92.2, 120.1, 128.5, 130.5, 132.9 (C═O).

1-Octyn-3-one (2m, Table 3, entry 14). Yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.90 (t, J = 6.6 Hz, 3H), 1.31−1.33 (m, 4H), 1.69 (quint, J = 7.2 Hz, 2H), 2.58 (t, J = 7.6 Hz, 2H), 3.20 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 22.4, 23.5, 31.1, 45.4, 78.2, 81.4, 187.4(C═O).

1-Cyclohexyl-2-propyn-1-one (2n, Table 3, entry 17). Yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13−1.41 (m, 4H), 1.58−1.98 (m, 6H), 2.36 (tt, J = 10.8, 3.5 Hz, 1H), 3.18 (s, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 25.2, 25.6, 27.8, 52.1, 79.0, 80.7, 190.7 (C═O).

1-Cyclohexyl-2-heptyn-1-one (2o, Table 3, entry 18). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.93 (t, J = 7.2 Hz, 3H), 1.17−1.98 (m, 14H), 2.32−2.40 (m, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 13.4, 18.6, 21.9, 25.3, 25.7, 28.2, 29.7, 52.2, 80.1, 95.0, 191.8 (C═O).

1-Cyclohexyl-2-nonyn-1-one (2p, Table 3, entry 19). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.90 (t, J = 6.9 Hz, 3H), 1.18−1.98 (m, 18H), 2.31−2.44 (m, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 14.0, 22.4, 22.4, 25.4, 25.8, 27.7, 28.2, 28.5, 31.2, 52.3, 80.1, 95.0, 191.7 (C═O).

9-Hexadecyn-8-one (2q, Table 3, entry 20). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.89 (t, J = 6.8 Hz, 3H), 0.90 (t, J = 6.6 Hz, 3H), 1.28−1.68 (m, 18H), 2,36 (t, J = 7.0 Hz, 2H), 2.52 (t, J = 7.3 Hz, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 14.0, 14.0, 18.9, 22.6, 24.2, 27.7, 28.5, 28.9, 31.2, 31.6, 45.5, 80.9, 94.3, 188.6 (C═O).

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