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New vanadium oxazoline catalysts for epoxidation of allylic alcohols

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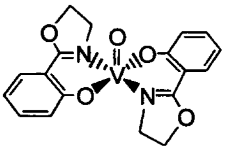
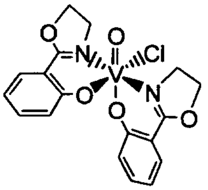
Abstract

The new vanadium complexes, VO(hoz)$_2$ **1** and VO(hoz)$_2$Cl **2** (hoz=2-(2′-hydroxyphenyl)-2-oxazoline), catalyze the epoxidation of allylic alcohols with *tert*-butylhydroperoxide. Catalyst **2** with the oxidation state (V) exhibits superior activity in comparison to **1**, producing yields from 88 to >99% under mild conditions, 60°C and non-dry solvent. © 1999 Elsevier Science Ltd. All rights reserved.

Metal-catalyzed reactions with alkyl hydroperoxides have been employed extensively in constructing epoxides from olefins.[1] The development of new vanadium-based catalysts for oxidation of alkenes is a subject that has attracted intensive research recently.[2] VO(acac)$_2$ (acac=acetylacetonate) is the catalyst of choice for stereoselective epoxidation of allylic alcohols.[3–6] However, epoxidations with VO(acac)$_2$ require high temperatures and dry solvent. Our intention was to develop new vanadium catalysts that could be utilized under mild conditions. We report herein on the synthesis of two new vanadium complexes, **1** and **2**, and on their catalytic activity in epoxidation of various allylic alcohols.



1



2

Compound **1**[7] was synthesized by reacting VO(acac)$_2$ with 2 molar equivalents of oxazoline ligand[8] in CH$_2$Cl$_2$ at room temperature.[9a] Complex **2** was prepared from VOCl$_3$ and 2 molar equivalents of ligand in dry CH$_2$Cl$_2$ at room temperature.[9b]

We initially tested the epoxidation of cinnamyl alcohol as a model substrate under various reaction conditions (Table 1). Catalyst **2** with *tert*-butylhydroperoxide at 60°C afforded the highest yield of

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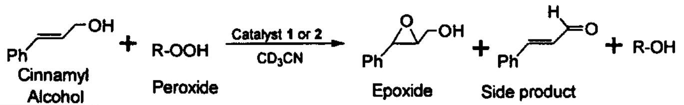
Table 1
Summary of the epoxidation reactions of cinnamyl alcohol under different conditions[a]



Entry	Peroxide (alkene:ROOH)	Catalyst	Temp. (°C)	Reaction Time (hrs.)	Epoxide yield (%)[b]	Side product yield[b,c] (%)
1	H_2O_2 (1:5)	**2**	RT	2	30	30
2	H_2O_2 (1:2)	**2**	RT	2	16	13
3	H_2O_2 (1:2)	**1**	RT	3	No	Reaction
4	TBHP[d] (1:2)	**1**	RT	3	No	Reaction
5	TBHP (1:2)	**2**	RT	3	53	32
6	TBHP (1:2)	**2**	60	2	90	10
7	H_2O_2 (1:2)	**2**	60	2	16	13

a) NMR scale reactions in CD_3CN with 5 mol % catalyst. b) Analyzed by ^{1}H-NMR. c) In addition to the aldehyde shown in the above equation, benzaldehyde was also detected. d) TBHP = *tert*-butylhydroperoxide.

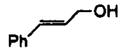
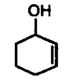
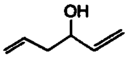
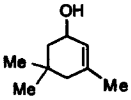
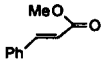
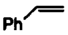
epoxide (90%) with only 10% aldehyde after 2 h (entry 6). The epoxidation rate is highly dependent on the stoichiometric oxidant (H_2O_2 versus TBHP), temperature, and the oxidation state of vanadium. In order to exclude deleterious effects due to chloride, which is present in **2** but not **1**, epoxidation of cinnamyl alcohol with 2 equivalents of TBHP at room temperature in the presence of catalyst **1** and $[Bu_4N]Cl$ was carried out. The additive chloride had no effect on the catalytic reaction, since no epoxide was observed. In contrast, when **2** was employed under identical conditions, 53% epoxide was produced (entries 4 and 5 in Table 1). Thus, the higher oxidation state (V) on vanadium might facilitate clean and rapid generation of the active species.[10]

To further explore the potential of the new catalyst **2**, we examined epoxidation of various allylic alcohols and unfunctionalized alkenes under the optimized conditions in Table 1;[11] these results are summarized in Table 2. The epoxidation of allylic alcohol substrates proceeds smoothly with high yields comparable to and in some instances better than those observed with $VO(acac)_2$.[4,5,12,13] The epoxides formed from cyclic allylic alcohols (entries 2 and 4) were found to be principally *cis* to the -OH functional group: entry 2 with >99% *cis* and entry 4 with 70% *cis*. The stereoselectivity found here is in agreement with previous literature reports.[5,6,12,13] On the other hand, catalyst **2** displayed lower regioselectivity than $VO(acac)_2$ in *trans,trans*-1,5-hexadien-3-ol (entry 3).[14] The allylic alcohol with conjugated diene (entry 6) produced 75% 2,4-hexadienal with no epoxide. The -OH group, which is activated by the conjugated diene, undergoes oxidation more readily than the C=C double bond.[15]

Unfunctionalized olefins (entries 5 and 7) that lack the -OH functional group exhibit lower activity and selectivity towards epoxide formation. Methyl *trans*-cinnamate (entry 5), which has an electron withdrawing ester, did not react with the **2**/TBHP oxidant. Also, styrene (entry 7) has undergone only 30% conversion: no epoxide, 20% diol, and 10% benzaldehyde. It is evident that the coordinating and electron donating -OH group is necessary for effective catalysis with $VO(hoz)_2Cl$.[16]

In conclusion, the new vanadium complexes **1** and **2** were synthesized and tested as catalysts for epoxidation of allylic alcohols with H_2O_2 and TBHP. $VO(hoz)_2Cl$ **2** was found to be the superior catalyst, and TBHP exhibited higher activity and selectivity in the epoxidation of allylic alcohols. Epoxide yields ranging from 88 to >99% were achieved with various allylic alcohols. However, conjugated allylic alcohols exclusively gave aldehyde as the oxidation product. Detailed mechanistic studies and efforts to extend the scope of this reaction to include asymmetric epoxidation are in progress.

Table 2
Epoxidation of allylic alcohols with TBHP and catalyst **2** at 60°C[a]

entry	Allylic alcohol	Time (hours)	Mass balance (%)	Epoxide yield (%)[b,c]	Side product yield (%)[c,d]	Ratio of *cis:trans*[c]
1		2	>97	90	10	--
2		3	>97	88	12	>99% *cis*
3		2	>99	>99[e]	~0	--
4		4	>95	>99	~0	7:3
5[f]		2	No Reaction			
6[f]		4	--	0	75	--
7[f]		2	--	0	30[g]	--

a) Unless otherwise stated, reactions were carried out in 15 mL CH_3CN with molar ratio of allylic alcohol: peroxide: catalyst = 1: 2: 0.05. b) Yield of the crude product. c) Analyzed by ^1H-NMR and GC/MS. d) Aldehyde or ketone from corresponding allylic alcohol via –OH oxidation. e) 1,2-epoxy-5-hexen-3-ol : 1,2-epoxy-5-hexen-4-ol = 2 : 1. f) NMR scale reaction in CD_3CN. g) 10 % benzaldehyde and 20 % diol.

Acknowledgements

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8. The oxazoline ligand was prepared from benzonitrile and aminoethyl alcohol according to literature protocols: Cozzi, P. G.; Floriani, C.; Chiesi-Villa, A.; Rizzoli, C. *Inorg. Chem.* **1995**, *34*, 2921.
9. (a) 0.50 g (1.9 mmol) of $VO(acac)_2$ was dissolved in 200 mL CH_2Cl_2 and a solution of 0.62 g (3.8 mmol) of oxazoline ligand in 50 mL of CH_2Cl_2 was added. The reaction was stirred for 48 h at room temperature, filtered, and the solvent was removed in vacuo to afford 0.49 g of a blue solid $VO(hoz)_2$ (67% yield). The product was analyzed spectroscopically by

FAB/MS (NBA matrix): M^+=391, and UV–vis, which was identical to that reported in Ref. 7 above. (b) 0.65 g (4 mmol) of oxazoline ligand was loaded into a 100 mL Schlenk flask and filled with 20 mL dry CH_2Cl_2. To this stirring solution, 0.20 mL (0.35 g; 2 mmol; *d*=1.84) of $VOCl_3$ was added via syringe. After stirring under argon at room temperature for 2 h, the solvent was removed under vacuum, yielding 0.64 g of blue/black powder $VO(hoz)_2Cl$ (75% yield). The product was analyzed spectroscopically by FAB/MS (NBA matrix): M^+=427, $(M-Cl)^+$=391, and ^1H NMR (δ in CD_3OD): 4.27 (*dd*, 4H), 5.07 (*dd*, 4H), 6.90 (*d*, 2H), 7.12 (*m*, 2H), 7.68 (*m*, 2H), 7.93 (*d*, 2H).

10. Similar observations have been reported recently in which a V(V) starting complex results in a more active epoxidation catalyst than V(IV) in the presence of TrOOH, see Ref. 2(d) above.
11. General experimental procedure for epoxidation of allylic alcohols is as follows: To a 100 mL round bottom flask equipped with a condenser and a magnetic stirring bar, 1.5 mmol of allylic alcohol, 32 mg (0.075 mmol) of $VO(hoz)_2Cl$, and 15 mL of CH_3CN were added. Then 334 μL (3.0 mmol) of *tert*-butylhydroperoxide (~5.0 M in decane) were added to the mixture, and the reaction flask was put in a water bath at a constant temperature of 60°C. Reaction progress was followed by TLC. After completion of the reaction, CH_3CN was removed by rotovap and 15 mL of CH_2Cl_2 was added. The mixture was extracted three times with 30 mL of saturated potassium carbonate, and the organic phase was collected. After removal of CH_2Cl_2 under vacuum, the oily crude products were analyzed by ^1H NMR and GC/MS.
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15. Conjugated allylic alcohols are notorious for oxidizing to aldehydes rather than epoxides: March, J. *Advanced Organic Chemistry*, 4th ed.; John Wiley & Sons: New York, 1992.
16. When TBHP is added to **2**, the resulting V(V) peroxo complex has coordinated oxazoline ligand as evidenced by ^1H NMR. However, when an allylic alcohol is present, one of the two oxazoline ligands is displaced. See, for example: (a) Mimoun, H. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 734. (b) Di Furia, F.; Modena, G. *Rev. Chem. Intermed.* **1985**, *6*, 51.