COMMUNICATION www.rsc.org/chemcomm | ChemComm

Polymer-supported nitroxyl radical catalyst for selective aerobic oxidation of primary alcohols to aldehydes

Michelle Gilhespy, Martin Lok and Xavier Baucherel*

Received (in Cambridge, UK) 14th October 2004, Accepted 24th November 2004
First published as an Advance Article on the web 12th January 2005
DOI: 10.1039/b415902k

PS-TEMPO, a polymer-supported 2,2,6,6-tetramethylpiperidine-*N*-oxyl (TEMPO), was successfully applied as a recyclable, active and selective catalyst for the oxidation of primary aliphatic and benzylic alcohols to aldehydes by molecular oxygen in the presence of $Co(NO_3)_2$ and $Mn(NO_3)_2$ as co-catalysts.

The oxidation of alcohols is one of the most important transformations in organic chemistry both on the laboratory and on the industrial scale.[1] Especially the catalytic conversion of unactivated primary alcohols to aldehydes remains a challenging process for academic research and is crucial for the synthesis of fine chemicals such as fragrances or food additives.[2] The systems involving both 2,2,6,6-tetramethylpiperidine-*N*-oxyl (TEMPO) and sodium hypochlorite[3] or molecular oxygen in the presence of a co-catalyst[4] are of particular interest in this area. The immobilisation of TEMPO on various supports has been reported in the literature.[5,6] However, very few catalytic systems[6] combine the advantages of using oxygen as terminal oxidant under non-chlorinated conditions with the possibility to recover and recycle the *N*-oxyl radical catalyst.

We report herein the use of a polymer supported TEMPO for the aerobic oxidation of alcohols. The catalyst was prepared by coupling 4-hydroxy-TEMPO onto a carboxylic acid functionalised polymer, FibreCat®.[7] FibreCat® consists of a polymer fibre functionalised *via* graft copolymerisation, which results in a high density of active functional sites being generated on the polymer (6.5 mmol g^{-1}). Furthermore, the open structure of the polymer and its good functional group accessibility are the reason it achieves high catalyst loading (2.3 mmol g^{-1} of nitroxyl radical).

This new immobilised TEMPO, subsequently referred to as PS-TEMPO, proved to be an efficient heterogeneous catalyst for the oxidation of alcohols using molecular oxygen under the conditions developed by Minisci.[4] 1-Octanol was converted into octanal with full conversion and 99% selectivity after 2.5 hours of reaction (Run 1).

Primary aliphatic and benzylic alcohols were readily oxidised with complete conversion and high selectivity to the corresponding aldehydes (Runs 1–4). To our knowledge this represents the first example of a truly heterogeneous TEMPO catalyst active and selective for the difficult conversion of unreactive aliphatic primary alcohols into aldehydes using molecular oxygen as terminal oxidant.

The oxidation of secondary aliphatic alcohols proved more challenging for this system. A longer reaction time was required for the oxidation of 2-octanol (24 h, 99% conversion at 95% selectivity, Run 5, Table 1). In a competitive experiment, with a lower catalyst loading, PS-TEMPO showed a marked preference for primary

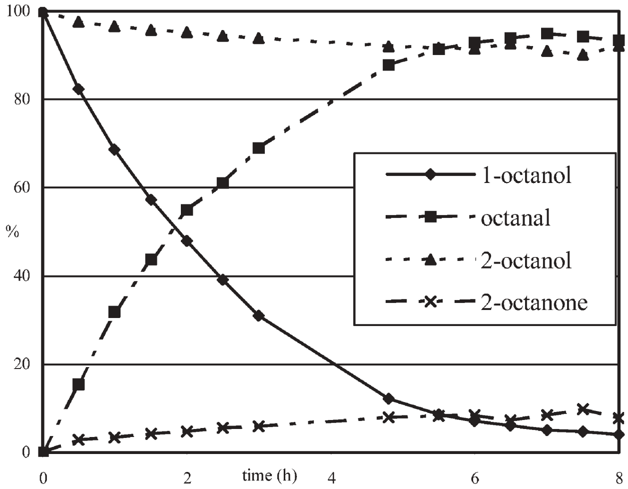

Fig. 1 Competitive oxidation of 1-octanol and 2-octanol. Substrate 10 mmol, PS-TEMPO 200 mg, AcOH 10 ml, $Mn(NO_3)_2{\cdot}6H_2O$ 58 mg (2 mol%), $Co(NO_3)_2{\cdot}6H_2O$ 58 mg (2 mol%), 40 °C, O_2 1 atm. Conversion and selectivity determined by GLC using *p*-methoxyacetophenone as internal standard.

Table 1 PS-TEMPO oxidation of alcohols[a]

Run	Substrate	Product	Time (h)	Conv. (%)	Sel. (%)
1	1-octanol	octanal	2.5	> 99	> 99
2	1-undecanol	undecanal	3	> 99	> 99
3	3-phenyl-1-propanol	3-phenylpropionaldehyde	2.5	95	94
4	benzyl alcohol	benzaldehyde	1	> 99	> 99
5	2-octanol	2-octanone	24	> 99	95

[a] Substrate 10 mmol, PS-TEMPO 500 mg, AcOH 10 ml, $Mn(NO_3)_2{\cdot}6H_2O$ 58 mg (2 mol%), $Co(NO_3)_2{\cdot}6H_2O$ 58 mg (2 mol%), 40 °C, O_2 1 atm. Conversion and selectivity determined by GLC using *p*-methoxyacetophenone as internal standard.

---

*xavier.baucherel@matthey.com

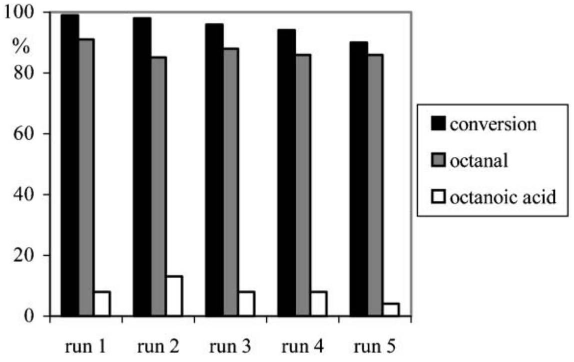

Fig. 2 Conversion and yields obtained in the oxidation of 1-octanol. Substrate 10 mmol, PS-TEMPO 500 mg, AcOH 10 ml, $Mn(NO_3)_2 \cdot 6H_2O$ 58 mg (2 mol%), $Co(NO_3)_2 \cdot 6H_2O$ 58 mg (2 mol%), 40 °C, 3 hours, O_2 1 atm. Conversion and selectivity determined by GLC using *p*-methoxyacetophenone as internal standard.

alcohols (Fig. 1). While over 90% of 1-octanol was selectively converted into octanal, less than 10% of 2-octanol was consumed to give 2-octanone, confirming the marked preference of the catalyst for the oxidation of primary hydroxyl groups.

Finally, we investigated the recyclability of the catalyst. PS-TEMPO was recovered by filtration after 3 hours of reaction and re-used, without any further reactivation process, in a sequence of oxidations using 1-octanol as substrate. Fresh $Mn(NO_3)_2$ and $Co(NO_3)_2$ were added to each successive run. The results presented in Fig. 2 show that even after 5 subsequent runs the catalyst activity and selectivity remained high, proving the high efficiency of the catalyst recovery. The slight decrease in the conversion of 1-octanol observed during the successive runs could be due to loss of some catalyst during filtration of the small amount of catalyst; no addition of any fresh PS-TEMPO catalyst to keep the amount of catalyst used constant was performed.

In conclusion we have demonstrated that PS-TEMPO, a polymer-supported TEMPO, is an excellent catalyst for the oxidation of alcohols. Especially it shows high activity and selectivity for the more difficult conversion of non-activated primary aliphatic alcohols affording the corresponding aldehydes in high yields. The catalyst was also shown to be easy to recycle by filtration without significant loss of activity.†‡

Michelle Gilhespy, Martin Lok and Xavier Baucherel*
Johnson Matthey Catalysts, PO Box 1, Belasis Avenue, Billingham, Cleveland, UK TS23 1LB. E-mail: xavier.baucherel@matthey.com

Notes and references

† *General procedure*. All alcohols and solvents were used as received without any further purification. The oxidation of alcohols using PS-TEMPO as catalyst was carried out in a two-necked round bottomed flask equipped with a condenser attached to a gas burette. The flask was charged with PS-TEMPO 500 mg (1.15 mmol based on 2.3 mmol g^{-1} loading), $Mn(NO_3)_2 \cdot 6H_2O$ 58 mg (2 mol%), $Co(NO_3)_2 \cdot 6H_2O$ 58 mg (2 mol%) and *p*-methoxyacetophenone 500 mg as internal standard. Glacial acetic acid (10 ml) was added followed by the alcohol (10 mmol). The reaction mixture was stirred at 40 °C under an atmosphere of molecular oxygen. Samples of the reaction mixture were taken out regularly to monitor the reaction by GLC. The products of the reaction were determined by comparison with the commercially available carbonyl compounds.

‡ *Procedure* for the preparation of PS-TEMPO. The technique used for immobilisation of 4-hydroxy-TEMPO involved suspending Smopex-102pp (30 g) in anhydrous dichloromethane (300 ml) before addition of diisopropylcarbodiimide (65 ml) and dimethylaminopyridine (2.48 g). 4-Hydroxy-TEMPO (35 g) dissolved in anhydrous dichloromethane (60 ml) was then added followed by triethylamine (57 ml). The reaction mixture was stirred at room temperature under an atmosphere of nitrogen for 16 hours. The solid catalyst was collected by filtration and successively washed using dimethylformamide, methanol and dichloromethane. The solid was air-dried before being soxhlet-extracted using dichloromethane to remove any non-reacted 4-hydroxy-TEMPO. Finally the polymer-supported TEMPO was dried under vacuum (40 °C) for 16 hours. This method achieved an average TEMPO loading of 2.3 mmol g^{-1} (as determined by recovered 4-hydroxy-TEMPO).

1 M. Hudlicky, *Oxidations in Organic Chemistry*; American Chemical Society: Washington, DC, 1990.

2 R. A. Sheldon, I. W. C. E. Arends and A. Dijksman, *Catal. Today*, 2000, **57**, 157–166; T. Mallat and A. Baiker, *Catal. Today*, 1994, **19**, 247–283.

3 A. E. J. de Nooy, A. C. Besemer and H. van Bekkum, *Synthesis*, 1996, 1153–1174; P. L. Anelli, C. Biffi, F. Montanari and S. Quici, *J. Org. Chem.*, 1987, **52**, 2559–2562.

4 R. Liu, X. Liang, C. Dong and S. Hu, *J. Am. Chem. Soc.*, 2004, **126**, 4112–4113; P. Gamez, I. W. C. E. Arends, J. Reedijk and R. A. Sheldon, *Chem. Commun.*, 2003, 2414–2415; R. Ben-Daniel, P. Alsters and R. Neumann, *J. Org. Chem.*, 2001, **66**, 8650–8653; A. Dijksman, A. Marino-Gonzalez, A. Mairata i Payeras, I. W. C. E. Arends and R. A. Sheldon, *J. Am. Chem. Soc.*, 2001, **123**, 6826–6833; A. Cecchetto, F. Fontana, F. Minisci and F. Recupero, *Tetrahedron Lett.*, 2001, **42**, 6651–6653; M. F. Semmelhack, C. R. Schmid, D. A. Cortés and C. S. Chou, *J. Am. Chem. Soc.*, 1984, **106**, 3374–3376.

5 G. Pozzi, M. Cavazzini, S. Quici, M. Benaglia and G. Dell'Anna, *Org. Lett.*, 2004, **6**, 441–443; P. Ferreira, W. Hayes, E. Phillips, D. Rippon and S. Chi Tsang, *Green Chem.*, 2004, **6**, 310–312; C. Tanyeli and A. Gümüs, *Tetrahedron Lett.*, 2003, **44**, 1639–1642; R. Ciriminna, C. Bolm, T. Fey and M. Pagliaro, *Adv. Synth. Catal.*, 2002, **344**, 159–163; T. Fey, H. Fischer, S. Bachmann, K. Albert and C. Bolm, *J. Org. Chem.*, 2001, **66**, 8154–8159; A. Dijksman, I. W. C. E. Arends and R. A. Sheldon, *Chem. Commun.*, 2000, 271–272; C. Bolm and T. Fey, *Chem. Commun.*, 1999, 1795–1796.

6 F. Minisci, F. Recupero, M. Rodinò, M. Sala and A. Schneider, *Org. Proc. Res. Dev.*, 2003, **7**, 794–798; D. Brunel, F. Fajula, J. B. Nagy, B. Deroide, M. J. Verhoef, L. Veum, J. A. Peters and H. van Bekkum, *Appl. Catal. A: Gen.*, 2001, **213**, 73–82.

7 S. Collard, C. F. J. Barnard, S. Bennett, S. H. Elgafi, G. R. Henderson, G. Sweeney and M. Sundell, *Catalysis for Organic Reactions*, (Proceedings 19th ORCS Conference), Marcel Dekker, New York, 2002, pp. 49–60; S. Buckley, *Speciality Chemicals*, October 2002, pp. 12–13; J.-A. A. Nasman and R. T. Peltonen, *EP629441*.