A new green tool for selective fi

Dr Sandra Grimaldi and Dr Jean-Luc Couturier of Arkema present a new oxidation catalyst, Oxynitrox S100

Growing demand for clean processes has made it necessary to develop high-performance catalysts that comply with the concepts of green chemistry or sustainable development, in terms of such issues as metal substitution, energy consumption, recycling and waste reduction.

Oxidation reactions are of great interest in fine chemistry, both at laboratory and at industrial scale. There are numerous applications using the conversion of primary alcohols into aldehydes.

Two particular types of reactions could fit in with this scheme: stoichiometric reactions involving the use of strong oxidising agents such as the complex chromium (VII) oxide/pyridine (the Collins or Sarret reagent), pyridinium chlorochromate (the Corey reagent), oxalyl chloride/DMSO (the Swern reagent), dimethyl sulphide/N-chlorosuccinimide (the Corey-Kim reagent), Dess-Martin periodinane, SO3/pyridine, KMnO4, MnO2, RuO4, etc. and catalytic dehydrogenation reactions with catalysts such as copper chromite, Raney nickel and palladium acetate.

However, not all of these reactions fit in perfectly with the Responsible Care approach, which is now a priority in all chemical reactions. They present a number of drawbacks, such as a high volume of metal waste, poor selectivity, safety issues in some cases or harsh reaction conditions.

A new family of green catalysts has appeared in the last few years. TEMPO, or 2,2,6,6-tetramethyl-1-piperidinyloxyl radical, is the most representative member of this family, and its efficiency in oxidation reactions is well documented.1,2

The oxidation of alcohols into aldehydes, ketones and carboxylic acids uses a catalytic amount of the nitroxyl radical and a stoichiometric amount of an oxidant, such as sodium hypochlorite, m-chloroperbenzoic acid, sodium bromite, sodium chlorite, trichloroisocyanuric acid, bis(2-carboxylato)iodobenzene, n-chlorosuccinimide or oxygen, in combination with CuCl2 or RuCl3(PPPh3)3.

The nitroxyl radical is converted into an active species, which is the corresponding oxoammonium ion, and is then able to oxidise various substrates (Figure 1).3 Among these, alcohols are converted into aldehydes, ketones or acids, diols into lactones, sulphones into sulphones, benzylic ethers into esters and β-hydroxy lactams into anhydrides.

Nevertheless, the TEMPO or hydroxyl-TEMPO structures present several drawbacks, such as poor thermal stability, strong volatility with a tendency to sublimation, high solubility in water, with ensuing difficulties in treating the aqueous wastes, significant toxicity and a complex synthesis route involving several reaction steps.

This is the reason why Arkema decided to develop a new nitroxyl catalyst for oxidation reactions. This catalyst is known under the proprietary trade name Oxynitrox S100 and is produced at pilot scale via an industrial process patented by Arkema.3

Characteristics & efficiency

Oxynitrox S100 is classified as a green catalyst, because it does not contain any metal. Additionally, it can efficiently replace classic metal catalysts, such as copper chromite, chromium derivatives and those based on ruthenium, molybdenum, silver, cerium, etc.

The catalyst belongs to the family of nitroxyl radicals. It features an oligomeric structure that contains several TEMPO moieties. Its high molecular weight (between 2,000 and 3,000 g/mol) makes it particularly suitable for possible recycling without losing any oxidation efficiency.

Oxynitrox S100 is generally used in homogeneous conditions, and its high molecular weight allows easy recovery of the end-products by simple distillation. Figure 2 shows its theoretical structure.

The conditions that are generally followed for the use of Oxynitrox S100 correspond to a biphasic medium. The general procedure uses sodium hypochlorite as the oxidant,
Oxytinox S100 as catalyst, dichloromethane, ethyl acetate or toluene as solvent and sodium bromide as co-oxidant. This co-catalyst leads to the in situ formation of NaOBr, which is a more efficient oxidant than NaOCl.

The degree of oxidation of the final product can be controlled by the amount of sodium hypochlorite. When using 1-1.5 NaOCl equivalents or 2 NaOCl equivalents, the primary alcohol is respectively converted into the corresponding aldehyde or acid.

The operating conditions are mild, and the reaction temperature can be adjusted from 0°C to room temperature. The reaction requires the control of the pH (around 8 to 9.5) using a buffer solution.

The reaction model that is mainly presented in this article is the conversion of n-octanol into n-octanal (Figure 3) and results under various conditions are shown in Table 1.

These demonstrate that only a small amount of Oxytinox S100 (0.5% wt in comparison with the amount of n-octanol) is required to produce highly satisfactory results. 1.1 sodium hypochlorite equivalent is enough to obtain the aldehyde form selectively; with the use of 2.5 equivalents of sodium hypochlorite, the acid is obtained as the main component of the reaction.

As co-oxidant, NaBr is necessary in order to obtain a good yield. The optimal reaction temperature in this case is 20°C, and the pH must be carefully controlled between 8 and 9. The best results are obtained by setting up the reaction in an appropriate solvent; data show that the use of dichloromethane can lead to a 93% yield in n-octanal after 1.5 hours.

As regards recycling benefits, in this example, n-octanal can easily be recovered by distillation. As a consequence, the distillation bottom, which contains Oxytinox S100, can be recycled. The octanal yield obtained by repeating the oxidation reaction was 85% after one cycle and 79% after two.

In addition to aliphatic alcohols, other alcohols were also efficiently oxidised. The use of Oxytinox S100 can also be extended to benzylic alcohols, cycloaliphatic alcohols or unsaturated alcohols and shows excellent yields and selectivities (Figure 4).

**Applications & conclusion**

Oxytinox S100 can be used in various nitroxide-mediating oxidation fields, mostly in the specialty chemicals industry, such as pharmaceuticals, flavours and fragrances, cosmetics, agrochemicals, or, more generally, in polysaccharide oxidation.

It is a versatile and high-performance catalyst for selective oxidation reactions, which makes its own contribution to the demands of modern chemistry where environmental protection is a high priority. High activities and selectivities are achieved for different types of alcohols and its use can extend to polyols or carbohydrates.

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**References:**
3. J. P. Gillet et al., EP patent 1 140807, 1999
6. G. Plos, WO patent 04/058331, 2004
7. C.M. Buchanan, WO patent 05/04297, 2005

**Table 1 - Experimental data on oxidation of n-octanol into n-octanal**

<table>
<thead>
<tr>
<th>Oxytinox % w/o</th>
<th>NaOCl eq/oL</th>
<th>NaBr %w/o</th>
<th>pH</th>
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<th>Temperature (°C)</th>
<th>Time (hours)</th>
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