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Aziridination of styrene: comparison of [*N*-(*p*-tolylsulfonyl)imino]phenyliodinane and chloramine-T as nitrene donors

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Abstract

Chloramine-T and [*N*-(*p*-tolylsulfonyl)imino]phenyliodinane (PhI=NTs) are contrasted as nitrene donors for the aziridination of styrene using copper(II) triflate, and copper-exchanged zeolite Y (CuHY) as catalysts. For both catalysts, PhI=NTs is found to give significantly higher yields of the aziridine both in the presence and absence of a chiral bis(oxazoline) modifier. In addition, chloramine-T is found to induce leaching of most of the Cu from CuHY, and with this nitrene donor CuHY does not function as a heterogeneous catalyst. In contrast, PhI=NTs causes negligible leaching of Cu from CuHY and, consequently, for the heterogeneous CuHY catalyst, PhI=NTs is the preferred nitrene donor. With chloramine-T, the beneficial effects observed on addition of copper powder are shown to be due to the copper powder acting as a reservoir for Cu^{2+} in solution, since Cu^{2+} in solution is rapidly deactivated by toluenesulfonamide, a degradation product of the nitrene donor.

Keywords: Aziridination; Nitrene donors; Chloramine-T

1. Introduction

The aziridination of alkenes is a potentially important reaction since aziridines are of value as precursors to pharmaceuticals and agrochemicals. Evans et al. [1,2] showed that copper(II) compounds in solution could catalyse the aziridination of alkenes using [*N*-(*p*-tolylsulfonyl)imino]phenyliodinane (PhI=NTs) as nitrene donor. In the presence of chiral bis(oxazolines) enantioselective aziridination could be achieved. Subsequently, we have shown [3,4] that copper-exchanged zeolite Y (CuHY) modified with a bis(oxazoline) can act as an asymmetric heterogeneous catalyst for this reaction, using this nitrene donor. Recently, Taylor and co-workers [5,6] and Ando et al. [7] have reported that chloramine-T is also an effective nitrene source. In addition, Vyas et al. [8] have reported similar reactions using bromamine-T with a manganese catalyst. Bromamine-T has recently been used as a nitrene donor by Antunes et al. [9] for the homogeneously catalysed aziridination of alkenes with Pd^{2+}, and by Dauban and Dodd [10] to form bicyclic aziridines. In the previous study by Taylor, PhI=NTs and

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chloramine-T were compared for the sulfimidation of sulfides using copper(I) triflate as a homogeneous catalyst, and both nitrene sources gave comparable yields. In this note, we compare chloramine-T and bromamine-T with PhI=NTs as nitrene donors for the aziridination of styrene with the CuHY catalyst, to determine if the less expensive nitrene donor could be used with the heterogeneous catalyst. In addition, we examine the effect on the reaction of toluene sulfonamide, a degradation product of the nitrene donor.

2. Experimental

PhI=NTs was prepared according to the method of Yamada et al. [11]. Chloramine-T ($TsNClNa{\cdot}xH_2O$) and copper(II) triflate were obtained from Aldrich. Bromamine-T and dibromamine-T were synthesised by the method of Chandra and Bedekar [12]. The CuHY catalyst was prepared and the aziridination reactions were carried out as described previously [4]. For a typical reaction, the copper catalyst ($Cu(OTf)_2$, 0.045 g or CuHY, 0.3 g; both containing an equivalent amount of copper, 3600 ppm in the reaction mixture) was pre-stirred in acetonitrile (2.5 cm^3) for 15 min. For reactions involving the chiral bis(oxazoline), the ligand was added (0.07 mmol) at this stage. The nitrene donor and styrene (0.101 g) were then added so that the nitrene donor:styrene molar ratio was 1.5:1. Following the reaction, the mixture was filtered through celite and the aziridine product recovered by flash column chromatography. Copper leaching into solution from CuHY was determined by atomic absorption spectroscopy. For enantioselective reactions, the ee was determined by chiral HPLC using a 25 cm chiral cel OJ column with a hexane–isopropanol (95:5) eluent system.

3. Results and discussion

The aziridination of styrene was carried out using chloramine-T and PhI=NTs as nitrene donors and the results are summarised in Table 1. Chloramine-T is found to give very low yields of the aziridine even after the extensive reaction time of 72 h (Table 1, experiments 5–8). The homogeneous catalyst, $Cu(OTf)_2$, and the heterogeneous catalyst, CuHY, gave similar results which were not significantly affected by the addition of the chiral bis(oxazoline), **1** (2,2-bis[(4*R*)-4-phenyl-1,3-oxazoline-2-yl]propane):

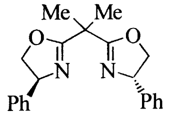

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Table 1
Aziridination of styrene using PhI=NTs and chloramine-T as nitrene donors[a]

Experimental number	Catalyst	Nitrene donor	Time (h)	Aziridine yield (%)	ee
1	$Cu(OTf)_2$	PhI=NTs	1	85.0	–
2	$Cu(OTf)_2$ + ***1***[c]	PhI=NTs	1	91.0	73
3	CuHY	PhI=NTs	5	81.0	–
4	CuHY + ***1***[c]	PhI=NTs	3	78.0	76
5	$Cu(OTf)_2$	Chloramine-T	72	8.1	–
6	$Cu(OTf)_2$ + ***1***[c]	Chloramine-T	72	3.4	nd[b]
7	CuHY	Chloramine-T	72	2.3	–
8	CuHY + ***1***[c]	Chloramine-T	72	5.7	nd
9	$Cu(OTf)_2$	PhI=NTs	17	95.0	–
10	$Cu(OTf)_2$ + Cu[d]	PhI=NTs	17	94.3	–
11	CuHY	PhI=NTs	17	93.1	–
12	CuHY + Cu[d]	PhI=NTs	17	70.0	–
13	Cu[d]	PhI=NTs	17	70.2	–

[a] Reaction conditions: 25 °C, CH_3CN, nitrene donor:styrene = 1.5:1.

[b] Insufficient yield to enable ee to be determined.

[c] Chiral bis(oxazoline) **1** added.

[d] Cu powder added (5×10^{-3} mol, Aldrich).

Indeed, the yields were too low to permit the product to be analysed by chiral HPLC. In contrast, the reaction with PhI=NTs for both $Cu(OTf)_2$ and CuHY was rapid and gave very high yields of the aziridine, ca. 80% (Table 1, experiments 1–4).

With chloramine-T, previous work [6] has shown that improved product yields are obtained when copper powder is added to the reaction mixture. In a further set of experiments, we investigated the effect of the addition of copper powder to the reaction mixture of both $Cu(OTf)_2$ and CuHY (Table 1, experiments 9–12) for a reaction time of 17 h using PhI=NTs as the nitrene donor. Addition of copper powder did not affect the yield of the aziridine, in contrast to when chloramine-T is used as nitrene donor [6]. Use of copper powder as a catalyst, in the absence of $Cu(OTf)_2$ and CuHY, was found to be as effective as $Cu(OTf)_2$ (Table 1, experiment 13). However, over the course of the 17 h experiment; the copper dissolved in the reaction mixture. This dissolution was similarly observed when chloramine-T was used in place of PhI=NTs. In a separate experiment (Fig. 1), toluene sulfonamide (equivalent to 10% decomposition of the nitrene donor) was added to a homogeneously catalysed reaction with PhI=NTs as nitrene donor. The addition of only a relatively low level of the sulfonamide at the start of the reaction led to an almost total loss of catalyst activity for the homogeneous catalyst, presumably due to the high affinity of the sulfonamide for Cu^{2+} in solution. In view of this, we consider that the enhancement in yields observed with chloramine-T, for homogeneously catalysed reactions when copper powder is added, is due to the relatively slow dissolution of the copper powder providing fresh copper cations in solution to compensate for the poisoning effect of the sulfonamide by-product.

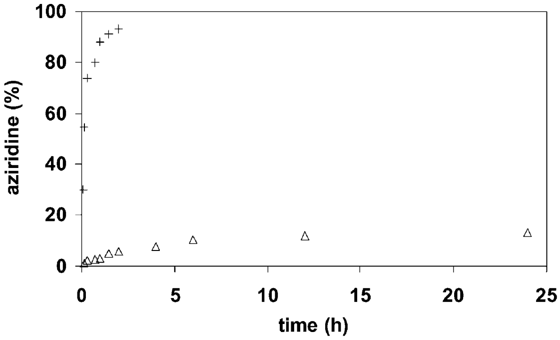

Fig. 1. Effect of addition of toluene sulfonamide on the aziridination of styrene using $Cu(OTf)_2$ as catalyst. Reaction conditions: 25 °C, CH_3CN, PhI=NTs:styrene = 1.5:1. (+) Standard reactions; (△) with the addition of 10% toluene sulfonamide at the start of the reaction.

The experiments with copper powder demonstrate that the heterogeneous forms of copper can be readily solubilised under the reaction conditions used in these studies. However, it should be stressed that these conditions are similar to those used in previous studies [1–6]. In view of this, the leaching of Cu into solution for CuHY was studied for both PhI=NTs and chloramine-T as nitrene donors. The results, shown in Table 2, confirm that PhI=NTs is the preferred

Table 2
Cu-leaching from CuHY[a]

Catalyst	Nitrene donor	Reaction time (h)	Cu leached (wt.%)	
			10 °C	25 °C
CuHY	PhI=NTs	3	–	0
CuHY + ***1***[b]	PhI=NTs	3	–	0.9
CuHY	Chloramine-T	72	55	71
CuHY + ***1***[b]	Chloramine-T	72	49	91
CuHY/NaCl[c]	Chloramine-T	72	55	77
CuHY/NaCl + ***1***[b,c]	Chloramine-T	72	66	74
CuHY/NaCl[c]	None	72	–	2.4
CuHY/NaCl + ***1***[b,c]	None	72	–	24
CuHY	None	72	–	0

[a] Reaction conditions: CH_3CN, nitrene donor:styrene = 1.5:1.

[b] Chiral bis(oxazoline) **1** added.

[c] NaCl added (NaCl:Cu = 2:1 mole ratio).

nitrene donor for the heterogeneous catalyst system. With PhI=NTs, negligible leaching of copper into solution is observed. In a separate investigation [13], we have carried out a detailed study of Cu-leaching for CuHY and it is concluded that the small amount of copper leached from CuHY during the reaction with PhI=NTs does not contribute significantly to the yield of aziridine. Indeed, our previous studies [3,4] have confirmed that the solution phase of the reaction mixture has no reactivity for the formation of aziridine. In contrast, chloramine-T effectively causes leaching of the majority of the copper from CuHY. Addition of NaCl, in the absence of the bis(oxazoline) **1**, but with chloramine-T, enhances the copper leaching, indicating that the Na^+ component of chloramine-T can contribute to this leaching problem. In addition, increasing the reaction temperature always increases Cu-leaching with chloramine-T as nitrogen donor. In the absence of chloramine-T, the addition of NaCl has a negligible effect on Cu-leaching in the absence of the bis(oxazoline) (Table 2). However, addition of the bis(oxazoline) does significantly enhance Cu-leaching in the absence of chloramine-T when NaCl is added.

To investigate whether improved aziridination could be achieved using bromamine-T ($TsNBrNa{\cdot}xH_2O$) or dibromamine-T ($TsNBr_2$), the reactions were carried out with these nitrene donors and the results are given in Table 3. It is apparent that significantly higher yields of the aziridine are formed with both these nitrene donors when compared to chloramine-T (see experiments 7 and 8 in Table 1). Unfortunately, the yields were still too low to permit accurate determination of the ee. However, both nitrene donors still resulted in most of the Cu^{2+} being leached from the CuHY catalyst, although the extent of Cu-leaching was found to be slightly lower than that observed for chloramine-T under the same conditions. Interestingly, the comparable Cu-leaching levels are observed for both bromamine-T and dibromamine-T indicating that in this case, the presence of Na^+ is not significant in this respect.

Table 3
Aziridination of styrene using bromamine-T and dibromamine-T as nitrene donors[a]

Catalyst	Nitrene donor	Aziridine yield (%)	Cu leached (wt.%)
CuHY	Bromamine-T	8.7	49.8
CuHY + ***1***	Bromamine-T	12.1	57.3
CuHY	Dibromamine-T	10.1	58.8
CuHY + ***1***	Dibromamine-T	15.8	64.2

[a] Reaction conditions: 25 °C, CH_3CN, nitrene donor:styrene = 1.5:1, 72 h.

From the results presented in this note, we conclude that chloramine-T and bromamine-T cannot be used as effective nitrene donors with the heterogeneous CuHY catalyst for the aziridination of alkenes. In contrast to PhI=NTs, it is observed that chloramine-T and bromamine-T solubilise the Cu^{2+} present within CuHY and thereby destroys the integrity of the heterogeneous catalyst. The solubilisation of Cu^{2+} occurs by a mechanism of ion exchange. When the copper nitrene intermediate is formed, sodium chloride is formed in situ. Solvation of this by acetonitrile can lead to Cu^{2+} being exchanged by Na^+ cations. Indeed, if a saturated solution of sodium chloride in acetonitrile is stirred with the CuHY catalyst, Cu^{2+} leaching, comparable with that in the chloramine-T experiments, is observed. The results further suggest that related reagents, which contain exchangeable cations, e.g. aqueous sodium hypochlorite, will also be unsuitable for use with these immobilised systems, since aqueous reagents will also be expected to solubilise the Cu^{2+} from the CuHY.

Acknowledgements

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