



# Dimeric chiral Mn(III) Schiff base complex-catalysed enantioselective epoxidation of non-functionalised alkenes

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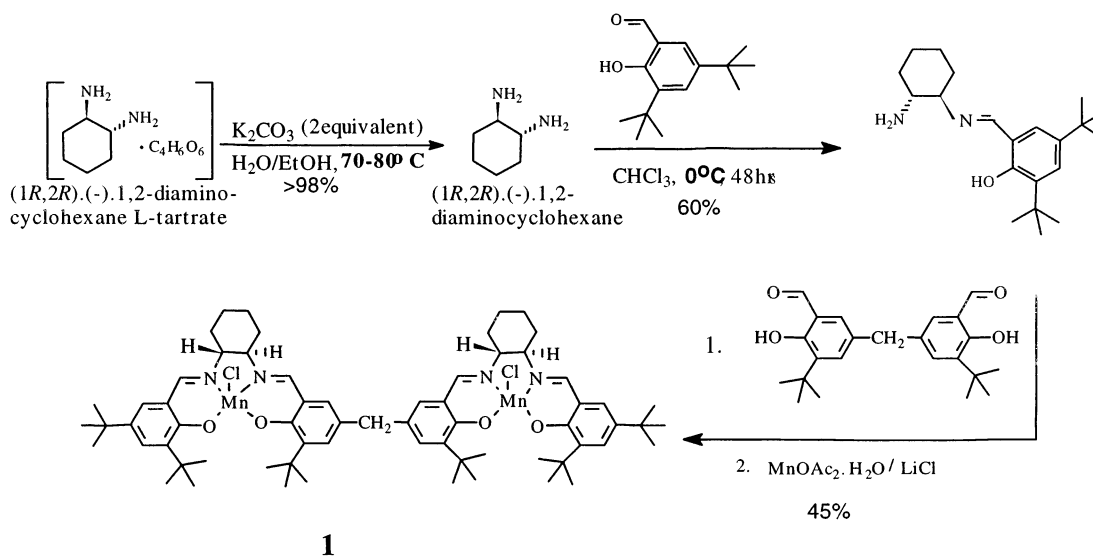
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**Abstract**—Dimeric chiral Mn(III) Schiff base complex **1** has been investigated as a catalyst for enantioselective epoxidation of chromenes, indene and styrene with an objective to explore its efficiency and recycling capability. Excellent conversions were obtained with all alkenes. More than 99% chiral induction, as determined by  $^1\text{H}$  NMR using the chiral shift reagent  $\text{Eu}(\text{hfc})_3$ , was obtained in the case of electron deficient chromenes, viz. nitro and cyano chromene. © 2001 Elsevier Science Ltd. All rights reserved.

Simple synthesis, ease of handling, high activity and selectivity are some of the advantages associated with Jacobsen's Mn SALEN complexes reported<sup>1</sup> for the epoxidation of a wide range of non-functionalised *cis* olefins. While adequate enantioselective epoxidation is achieved with these catalysts under homogeneous biphasic conditions, separation and recycling of the catalyst is still a problem as it limits its application for a batch process. Therefore, various approaches, viz. anchoring the catalyst on a solid support, or a

polymer chain,<sup>3–5</sup> encapsulation in a zeolite,<sup>6</sup> 'van der Waals wrapping' in the elastomer network of a polydimethylsiloxane membrane,<sup>7–9</sup> use of a two-phase system,<sup>2b</sup> and using ionic liquids<sup>10</sup> have all been reported to overcome this problem. All of these approaches are interesting but demand additional modifications to the structure of the catalyst or require the reaction to be carried out in the presence of some reagent which often results in loss of activity and selectivity.



Scheme 1.

**Keywords:** dimeric; chiral; non-functionalized alkenes; manganese.

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An interesting dimeric form of Jacobsen's catalyst was recently reported<sup>11</sup> for its improved retention in a polydimethylsiloxane membrane. In the present report, a similar dimeric dissymmetric Mn(III) complex **1** was synthesized (Scheme 1) by modifying a reported procedure.<sup>11</sup> *1R,2R* (-) Diamino cyclohexane, obtained from its mono tartrate salt, was condensed with 3,5-di-*tert*-butylsalicylaldehyde in a 2:1 molar ratio in CHCl<sub>3</sub> at 0°C to give a 1:1 condensed product which was reacted with 5,5'-methylene-di-3-*tert*-butylsalicylaldehyde to obtain a dimeric ligand. This dimeric ligand was complexed with manganese(II) acetate which after work-up gave the desired complex 5,5'-methylene di-[(*R,R*)-{*N*-(3-*tert*-butylsalicylidine)-*N'*-(3',5'-di-*tert*-butylsalicylidine)}-1,2-cyclohexanediaminato (2-) manganese(III) chloride]<sup>12</sup> **1** in quantitative yield. The complex **1** was used as a catalyst in the enantioselective epoxidation of chromenes, indene and styrene using pyridine *N*-oxide as a proximal ligand and sodium hypochlorite as an oxidant. The complex **1** has a tendency to precipitate from hexane and thus could be easily separated from the products and reused up to five times.

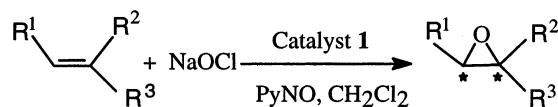
Asymmetric epoxidation reactions were performed following an established procedure.<sup>1</sup> Typically, the reaction was conducted at 0°C using 2 mol% of complex **1** and 1.29 mmol of substrate in 1 ml of dichloromethane in the presence of 0.13 mmol of pyridine *N*-oxide and

2.75 mmol of NaOCl as the oxidant. Various substrates were studied and include: 2,2-dimethylchromene (entry 1), 6-cyano-2,2-dimethylchromene (entry 2), 6-nitro-2,2-dimethylchromene (entry 3), 6-methoxy-2,2-dimethylchromene (entry 4), spiro[cyclohexane-1,2'-[2*H*][1]-chromene (entry 5), styrene (entry 6) and indene (entry 7). Reaction conversions and enantiomeric excess values are given in Table 1.

Excellent conversions were obtained with all the alkenes but the highest chiral induction (>99%) (as determined by <sup>1</sup>H NMR using the chiral shift reagent (+)Eu(hfc)<sub>3</sub>) was observed for nitro and cyano chromene (entry 2 and 3). However, the ee's were not encouraging in the case of styrene (entry 6).

The monomeric Jacobsen complex<sup>1</sup> with 2 mol% catalyst loading (with 4-phenyl pyridine *N*-oxide) gave 96% conversion with 97% ee's for cyano chromene in 9 h. However, the dimeric complex **1** takes only 2.5 h with 100% conversion and >99% ee's under similar reaction conditions even with simple pyridine *N*-oxide. Moreover, a catalyst loading of 0.6 mol% is sufficient to achieve similar conversion and selectivity within 6 h. Further reduction in catalyst loading (0.2 mol%) caused a reduction in reaction rate with marginal decrease in ee's value in 24 h. Below 0.2 mol% of catalyst loading, the reaction rate and selectivity deteriorate rapidly. The

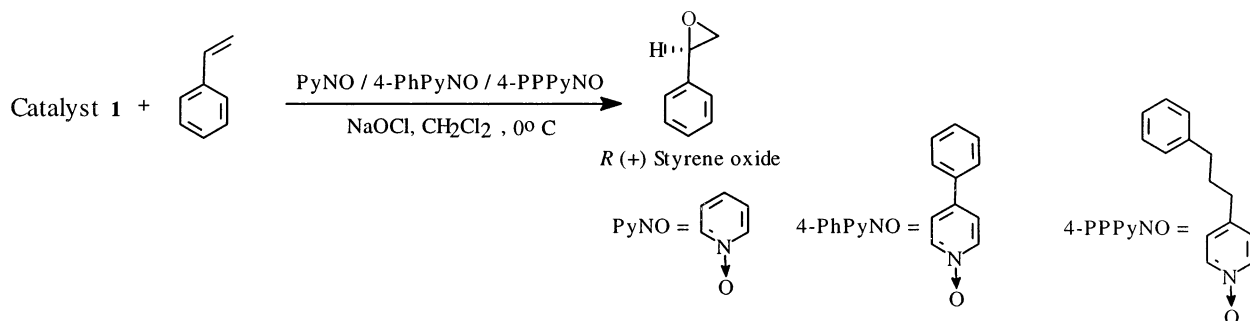
**Table 1.** Data for enantioselective epoxidation of non-functionalised alkenes catalysed by dimeric Mn(III) chiral Schiff base complex **1** in presence of pyridine *N*-oxide



entry	Substrate	Product	Conversion <sup>a</sup> (%)	Time (hr)	Ee <sup>b</sup> (%)	Absolute Configuration <sup>d</sup>
1			97	11	83	3 <i>R</i> , 4 <i>R</i>
2			100	2.5	>99	3 <i>R</i> , 4 <i>R</i> <sup>d</sup>
3			100	11	>99	3 <i>R</i> , 4 <i>R</i>
4			100	4	69	3 <i>R</i> , 4 <i>R</i>
5			100	20	78	3 <i>R</i> , 4 <i>R</i>
6			100	3	35 <sup>c</sup>	<i>R</i> <sup>c</sup>
7			100	5.5	60	1 <i>R</i> , 2 <i>S</i>

Reactions were carried out in CH<sub>2</sub>Cl<sub>2</sub> (1 ml) with catalyst (2mol %), Substrate (1.29 mmol), Pyridine *N*-oxide (0.13 mmol), NaOCl (2.75 mmol). <sup>a</sup> Determined by GC. <sup>b</sup> By <sup>1</sup>H NMR using chiral shift reagent (+)Eu(hfc)<sub>3</sub>. <sup>c</sup> By chiral capillary column GTA type. <sup>d</sup>

The configuration of the major enantiomer was determined by comparing the chemical shifts with that of an authentic sample of (3*S*,4*S*)-CN-chromene oxide in <sup>1</sup>H NMR using (+)Eu(hfc)<sub>3</sub> as chiral shift reagent. For other oxides absolute configuration was assigned by analogy to (3*R*, 4*R*)-CN-chromene oxide.

**Table 2.** Data for the enantioselective epoxidation of styrene with catalyst **1** using pyridine *N*-oxide and substituted pyridine *N*-oxides as an axial base

Axial base	Conversion (%)	Time (h)	ee's (%)
PyNO	100	3	35
4-PhPyNO	100	1.5	35
4-PPPyNO	100	0.5	35

enhanced activity of dimeric catalyst **1** indicates that the two units are not working in isolation but have a cooperative interaction. It is reported<sup>13</sup> that the monomeric catalyst with appropriate *N*-oxide derivatives as additive serves to activate and stabilize the catalyst system. Analogously, for dimeric catalyst **1** the epoxidation of styrene was observed to be faster in the presence of the 4-phenyl pyridine *N*-oxide (4-PhPyNO) and 4-(3-phenyl propyl) pyridine *N*-oxide (4-PPPyNO) as compared to pyridine *N*-oxide. However, no improvement in chiral induction was observed (Table 2).

Furthermore, after one epoxidation cycle the catalyst was separated from the reaction mixture by precipitation using hexane. The recovered catalyst was reused for catalytic reactions without further purification. The results with recycled catalyst are shown in Table 3.

The activity of the recycled catalyst gradually decreased upon successive use, indicating some degradation of the catalyst **1** under the epoxidation conditions. However, no loss was observed in the product ee's.

In conclusion, the dimeric dissymmetric chiral Mn(III) Schiff base complex worked very well with all non-functionalised alkenes and the best chiral induction was obtained with nitro and cyano chromene. Higher rates of reaction were observed in the presence of substituted pyridine *N*-oxides. However, the activity of the recycled catalyst gradually decreased upon successive use, showing the degradation of the catalyst **1** under epoxidation conditions. As the catalyst loading could be reduced to more than half without adversely effecting activity and selectivity, the two units in the dimer seem to be working with cooperativity. Further, the symmetry of individual SALEN units is affected due to the absence of a tertiary butyl group at the point of connectivity. However, in spite of this, the catalyst still works well.

**Table 3.** Data for enantioselective epoxidation of styrene with recycled catalyst in presence of pyridine *N*-oxide

Run	1	2	3	4	5
Conversion (%)	100	90	80	60	55
ee's (%)	35	35	35	35	35
Time (h)	3	3	5	6	9

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12. Spectroscopic data for the complex **1**. IR (KBr): 3431 (br), 2947 (s), 2866 (s), 1612 (s), 1538 (s), 1475 (sh), 1435 (s), 1388 (m), 1342 (s), 1309 (s), 1285 (sh), 1238 (sh), 1201 (m), 1170 (m), 1100 (w), 1030 (m), 940 (w), 833 (m), 780 (w), 731 (w), 690 (w), 568 (s), 475 (w). UV-vis: (CH<sub>2</sub>Cl<sub>2</sub>)  $\lambda_{\text{max}}$  ( $\epsilon$ ) 250 (50000), 266 (49960), 345 (47540), 420 (41460), 451 (41040), 510 (36060)
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