

Catalytic asymmetric dihydroxylation of olefins using polysulfone-based novel microencapsulated osmium tetroxide

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Abstract—A polysulfone based novel polymer-supported osmium catalyst has been developed. The catalyst was prepared from commercially available polysulfone, based on a microencapsulation technique and was employed in the asymmetric dihydroxylation of various olefins using (DHQD)₂PHAL as the chiral ligand and NMO as the co-oxidant in H₂O–acetone–CH₃CN (1:1:1). The catalyst was recovered by simple filtration and was reused to obtain excellent yields with good enantioselectivity up to five times.
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1. Introduction

Osmium catalyzed dihydroxylation of olefins is one of the most efficient methods for the preparation of vicinal diols.¹ In particular, the asymmetric dihydroxylation of olefins using catalytic amounts of osmium tetroxide in the presence of chiral ligands allows access to a wide variety of enantiomerically pure vicinal diols.² In 1992, Sharpless et al. reported a catalytic system based on bis-cinchona alkaloids such as 1,4-bis-(9-*O*-dihydroquinidinyl)phthalazine ((DHQD)₂PHAL), which has received a great deal of interest due to the broad scope of substances available and the high enantioselectivities attained.³ Although a number of processes have utilized this asymmetric dihydroxylation for the synthesis of pharmaceuticals, fine chemicals, etc.,⁴ few useful industrial applications have been accomplished, probably because osmium tetroxide itself is highly toxic, expensive, volatile, and can be difficult to recover.

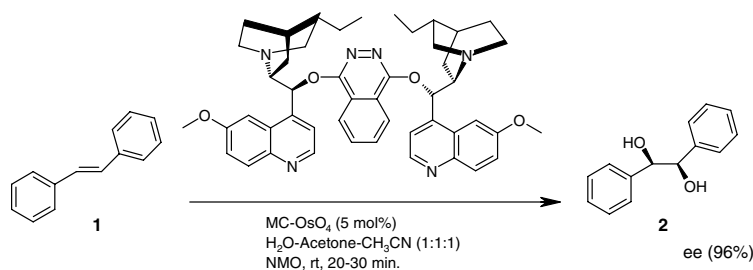
To address this issue, several groups have investigated immobilization of chiral ligands onto soluble and insoluble polymers.⁵ In 1998, Kobayashi et al. reported microencapsulated osmium tetroxide on polystyrene (PS–MC–OsO₄), with complete recovery and reuse of

the osmium component in achiral oxidations.⁶ Later they modified the polymer support and achieved asymmetric dihydroxylation with acrylonitrile–butadiene–polystyrene (ABS) polymer⁷ and phenoxyethoxy-methyl–polystyrene (PEM) based polymer supported osmium tetroxide reagents.⁸ A few other groups have also recovered and reused osmium tetroxide by utilizing different polymer supports,⁹ macroporous resins,¹⁰ ionic liquids,¹¹ PEG (400),¹² Tentagel supports,¹³ phase selective soluble dendrimers,¹⁴ and ion-exchangers.¹⁵ The above methods possess several merits which include recovery and reusability of the catalyst, reactions in water as a solvent without using organic co-solvents, use of different ligands, different co-oxidants, and phase selective soluble reagents. However, there are certain drawbacks associated in a few cases, which include slow addition of the alkene with associated problems such as a tedious procedure, difficulties when using insoluble substances, long reaction times, low yields, and low ee. Hence, there is a scope for the preparation of a versatile reagent which can overcome these difficulties.

Herein, we report (Scheme 1) a new recoverable and reusable microencapsulated osmium tetroxide catalyst (polysulfone–MC–OsO₄) derived from a polymer. This catalyst performs asymmetric dihydroxylation of olefins, without the need for slow addition of the olefin, with high yields and excellent enantio- and diastereoselectivity (Scheme 1, Table 1). After completion of the reaction, the catalyst can be recovered by simple filtration.

Keywords: Microencapsulation; Asymmetric dihydroxylation; Chiral ligand; Enantioselectivity.

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Scheme 1.

Table 1. Asymmetric dihydroxylation of olefins using polysulfone-MC-OsO₄

Entry	Olefin	Time (min)	Yield ^a (%)	ee ^b (%)
1		30	94	96
2		25	92	99
3		25	90	99
4		25	86	92
5		25	89	90
6		30	92	89

^a Isolated yields after column chromatography.^b Enantiomeric excess was determined by chiral HPLC.

The versatility of the catalyst, polysulfone-MC-OsO₄, was first tested in the achiral dihydroxylation of olefins. Initially, styrene was subjected to dihydroxylation using polysulfone-MC-OsO₄ and *N*-methyl morpholine-*N*-oxide (NMO) as the co-oxidant in H₂O-acetone-CH₃CN (1:1:1) to yield the corresponding diol in excellent yield. This result encouraged us to extend the reagent for the dihydroxylation of several other olefins to give the corresponding diols in good yields (Table 2).

The catalyst was also used for the asymmetric dihydroxylation reaction of *trans*-stilbene using (DHQD)₂PHAL for chiral induction, and NMO as the co-oxidant in H₂O-acetone-CH₃CN (1:1:1) (Scheme 1, Table 1, entry 1) to afford the corresponding cis diol in 94% yield with 96% ee. This result encouraged us to extend the generality of the resin for the asymmetric dihydroxylation of various olefins to give the corre-

sponding cis diols in good yields and with high enantioselectivities (Table 1). Further, we established the recyclability of the catalyst in asymmetric dihydroxylation reactions of *trans*-stilbene, using (DHQD)₂PHAL and NMO in H₂O-acetone-CH₃CN (1:1:1), and found that the asymmetric dihydroxylation proceeded with high yields and with high enantiomeric excess (ee 96–97%) even with recycled resin (Table 3). The catalyst was recovered by simple filtration, washed several times with acetonitrile, dried, and reused. Even after five cycles, the activity of the catalyst was unchanged with respect to the yield or ee (Table 3).

2. Preparation of the catalyst (MC-OsO₄)

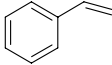
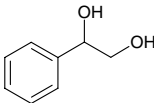
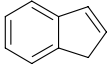
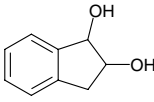

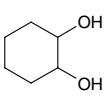

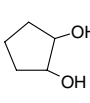

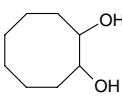
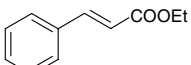
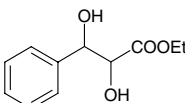
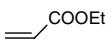
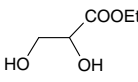
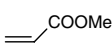
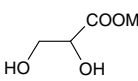
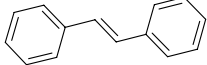
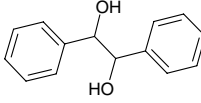

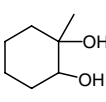
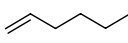
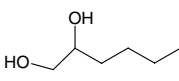
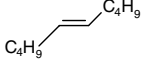
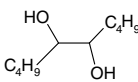
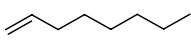
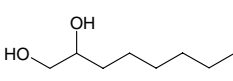
To a solution of polysulfone¹⁶ (4 g) in dichloromethane (25 mL) was added a solution of OsO₄ (0.8 g) in dichloromethane (5 mL) with stirring for 3 h. This mixture was slowly added to 1.5% polyvinyl pyrrolidone dissolved in water (300 mL) and the reaction was further stirred for 8 h at constant RPM (750) to give solid beads. The solid beads of microencapsulated osmium tetroxide were filtered, washed several times with excess water to remove un-encapsulated osmium tetroxide and dried. The catalyst can be stored for several days at room temperature without loss of activity.

In summary, we have prepared a novel polysulfone based microencapsulated osmium tetroxide catalyst, which was found to be very effective in the asymmetric dihydroxylation reactions of olefins. Polysulfone-MC-OsO₄ can easily be prepared, and can be recovered from the reaction mixture by simple filtration. The reagent is air stable, nonvolatile, and easy to handle. Significantly, the catalyst can be recycled and re-used several times without significant loss of activity.

3. Typical experimental procedure

To a mixture of *trans*-stilbene (**1**) (1 mmol), (DHQD)₂PHAL (5 mol %), and NMO (2 mol %) in H₂O-acetone-CH₃CN (1:1:1) (20 mL) was added polysulfone-MC-OsO₄ (5 mol %), and the reaction was stirred for the appropriate time (Scheme 1, Table 1). After completion of the reaction as monitored by TLC, the catalyst was filtered from the reaction mixture and the solvent was concentrated under reduced pressure to give predominantly an aqueous solution. The product was

Table 2. Achiral dihydroxylation of olefins using polysulfone based MC-OsO₄^a

Entry	Olefin	Product ^b	Time (min)	Yield ^c (%)
a			20	98
b			20	96
c			20	96
d			20	98
e			25	96
f			25	95
g			25	96
h			25	96
i			20	94
j			30	88
k			25	96
l			25	92
m			20	98

^a Dihydroxylation was carried out using 5 mol % of catalyst and NMO in MeCN–H₂O–acetone (1:1:1).^b All the products gave satisfactory analytical data.^c Isolated and un-optimized yields.

extracted into ethyl acetate and the organic layer was concentrated to give a crude product, which was purified on silica gel to afford the corresponding diol in good yield. The catalyst was reused after several washings with acetonitrile. The same experimental procedure was followed for other substrates without the addition of the chiral ligand (DHQD)₂PHAL (Table 2). Spectroscopic data for selected compounds: (a) Spectral data

for the product in entry 1, (Table 1): IR (neat) ν_{\max} : 3404 cm⁻¹; ¹H NMR (CDCl₃, 200 MHz): δ 7.19–7.21 (6H, m), 7.00–7.10 (4H, m), 4.66 (2H, s), 2.86 (1H, br s), 1.52 (1H, br s). EIMS (*m/z*): 190 (M⁺), 179, 167, 141, 107, and 79. (b) Spectral data for the product in entry 5 (Table 1): viscous liquid, IR (neat) ν_{\max} : 3324 cm⁻¹; ¹H NMR (CDCl₃, 200 MHz): δ 7.26–7.28 (5H, m), 4.71–4.75 (1H, dd, *J* = 8.31, 3.02 Hz),

Table 3. Asymmetric dihydroxylation of *trans*-stilbene with recycled polysulfone–MC–OsO₄^a

Run	Time (min)	Yield ^b (%)	ee ^c (%)
1	25	94	96
2	30	94	97
3	30	92	96
4	30	90	97
5	30	86	97

^a Asymmetric dihydroxylation of *trans*-stilbene was carried out with (DHQD)₂PHAL, and H₂O–acetone–CH₃CN (1:1:1) as solvent in the presence of NMO.

^b Isolated yields after column chromatography.

^c Enantiomeric excess was determined by chiral HPLC.

3.52–3.67 (2H, m). EIMS (*m/z*): 138 (M⁺), 107, 106, 79, 57, and 42.

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