REGIOSELECTIVE RING OPENING OF STYRENE OXIDE CATALYZED BY MoO$_2$(acac)$_2$

Hongwei Yang, Liming Xu, Cuicui Luo, Chunxu Lu, and Guangbin Cheng
School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, China

GRAPHICAL ABSTRACT

Abstract The ring-opening reaction of styrene oxide with various nitrogen, oxygen, and carbon nucleophiles catalyzed by MoO$_2$(acac)$_2$ was described. The corresponding ring-opening compounds with nearly 100% regioselectivities were obtained under mild conditions in moderate to good yields. MoO$_2$(acac)$_2$ is a highly efficient catalyst for the ring opening of styrene oxide. The reaction serves as a simple and efficient method for the synthesis of 1,2-bifunctional compounds.

Keywords MoO$_2$(acac)$_2$; ring opening; styrene oxide

INTRODUCTION

Epoxides are very important intermediates for organic synthesis because of their strong reactive potential with various reactants such as electrophiles, nucleophiles, acids, bases, and redox agents.[1] Among the various transformations of epoxides, regioselective ring opening of epoxides with various nucleophiles is an important reaction for synthetic organic and medicinal chemists because of the important role of the resulting 1,2-bifunctional compounds. For example, 1,2-amino alcohols are versatile synths with wide applications in biologically active natural and synthetic products, synthetic amino acids,[2] and chiral auxiliaries.[3] In addition,
2-substituted propanol, cyclohexanol, and cyclooctanol compounds were also evaluated for microfilaricidal and macrofilaricidal activity in vivo against *Acanthocheilonema viteae* and *Litomosoides carinii* in rodents.[3]

The classical route for the preparation of 1,2-bifunctional compounds is the direct aminolysis or alcoholysis of 1,2-epoxides.[4] These reactions are usually carried out in the presence of a large excess of amines and alcohols. The disadvantage of this classical approach is the requirement of elevated reaction temperatures and long reaction time. Various catalysts[5] such as transition metals, lanthanides, metal salts, and even some heterogeneous catalysts have been used under milder conditions to overcome these weaknesses.[5,6] Although some catalysts show improved selectivity for both aliphatic and aromatic amines, high temperatures and long reaction times were required, and more reactions failed to occur when deactivated anilines (especially those bearing electron-withdrawing components) were used.[7] Therefore, continuous efforts to explore efficient catalysts are needed for this industrially important reaction, the ring-opening reaction of epoxide.

cis-Dioxo complexes dominate the chemistry of molybdenum(VI), and their prevalence, ease of synthesis, and chemical attributes have led to their exploitation as oxidation catalysts, models of enzymes and surface oxides, sensors, and drug targets.[8] Although the research on the application of molybdenum dioxo-complexes in organic synthesis dates back to the 1970s, the exploration of nonoxidation reactions was very limited in comparison with oxygen atom transfer reactions.[9] Herein we report the ring-opening reaction of styrene oxide with various nucleophiles catalyzed by MoO₂(acac)₂ under mild conditions.

**RESULTS AND DISCUSSION**

To obtain optimized conditions, effects of reaction conditions such as the solvent, temperature, and catalyst loading on the yield of the ring-opening of epoxides were investigated. In initial experiments, the reactions of styrene oxide (1) and 2-nitrobenzenamine (2) using MoO₂(acac)₂ as catalyst were carried out with 5% catalyst loading at room temperature in different solvents. The results are summarized in Table 1. Although the reaction under solvent-free conditions can give 44% yield of product, the regioselectivity of the major isomer 3a is poor with only 79:21 (Table 1, entry 1). When tetrahydrofuran, acetonitrile, 1,2-dichloroethane, ethyl acetate, and toluene were used as solvents, the yield of isomer 3a was obtained in moderate yields in the range of 30–67% (Table 1, entries 3–7). However, MoO₂(acac)₂ showed high catalytic activity in dichloromethane and CCl₄ with 80% and 83% yield of the major isomer 3, respectively (Table 1, entries 2 and 8). Among various solvents tested, the CCl₄ was found to be the optimal solvent for further studies. As shown in Table 1, the ring opening of styrene oxide affords isomer 3a with a good yield of 90% in the CCl₄ solvent at 50 °C (Table 1, entry 9). However, the yield of 3a went down slightly when the reaction temperature changed from 50 °C to 70 °C (Table 1, entries 9 and 10), which could be attributed to side reactions accompanying the ring opening of styrene oxide at elevated temperature. On the basis of optimized reaction solvent and temperature, we investigated the effect of the catalyst loading on the reaction in the range of 0–10% with a span of 2.5%. Without the addition of any catalyst, the reaction proceeded sluggishly with only 18% yield of isomer 3a (Table 1,
entry 11). When increasing the catalyst loading to 5\%, the yield of 3a increased up to 90\%. However, the yield of 3a began to decrease when the molar ratio surpassed 5\%, and the yield of 3a keeps declining slightly to 73\% when the catalyst loading was 10\%. Meanwhile, the corresponding regioselectivity of isomer 3a decreased to 93:7 (Table 1, entry 14). A small amount of side product was isolated from reaction with 10\% catalyst loading. In the mass spectrum, the mass number of the side product 5 is 378 ([M – 1]− = 377), which shows that the decline of yield with the increased catalyst loading could be attributed to a side reaction of nucleophilic substitution reaction between isomers 4 and reagent 2a. Therefore, the reaction of styrene oxide with 2-nitrobenzenamine in the presence of MoO$_2$(acac)$_2$ proceeds smoothly under mild conditions with short reaction time (4 h) and high regioselectivity.

On the basis of the optimal conditions, we investigated the ring opening of styrene oxide with various nucleophiles including aromatic amines, substituted phenols, and anisoles to examine the scope of this reaction. The results are shown in Table 2. The ring opening takes place in a completely regioselective fashion, affording isomers 3 as the only product, and the corresponding isomer was not detected. As expected, 1,2-aminoalcohols are obtained in good yields in the ring opening of styrene oxide with aromatic amines that are different structurally and electronically (Table 2, entries 1–7). An electronic effect of substituent species on aromatic amines has almost no effect on the reaction activity. The anilines

---

**Table 1.** Treatment of styrene oxide (1) with 2-nitrobenzenamine (2a) catalyzed by MoO$_2$(acac)$_2$.

| Entry | Solvent     | Temp. (°C) | Time (h) | Catalyst (mol\%) | Yield$^b$ (%) |
|-------|-------------|------------|----------|------------------|---------------|
| 1     | None        | rt         | 24       | 5                | 44 (79:21)$^c$ |
| 2     | CH$_2$Cl$_2$| rt         | 16       | 5                | 80            |
| 3     | Toluene     | rt         | 24       | 5                | 67            |
| 4     | THF         | rt         | 24       | 5                | 47 (91:9)$^c$ |
| 5     | CH$_3$CN    | rt         | 24       | 5                | 30            |
| 6     | CICH$_2$CH$_2$Cl | rt     | 24       | 5                | 42            |
| 7     | EtOAc       | rt         | 24       | 5                | 58            |
| 8     | CCl$_4$     | rt         | 10       | 5                | 83            |
| 9     | CCl$_4$     | 50         | 4        | 5                | 90            |
| 10    | CCl$_4$     | 70         | 4        | 5                | 86            |
| 11    | CCl$_4$     | 50         | 24       | 0                | 18            |
| 12    | CCl$_4$     | 50         | 8        | 2.5              | 73            |
| 13    | CCl$_4$     | 50         | 4        | 7.5              | 81 (94:6)$^c$ |
| 14    | CCl$_4$     | 50         | 4        | 10               | 73 (93:7)$^c$ |

$^a$Reaction conditions: styrene oxide (1) (2.0 mmol), 2-nitrobenzenamine (2a) (2.0 mmol), solvent (5 mL).

$^b$Isolated yield of the major isomer 3a after chromatography on silica gel.

$^c$Isolated yield of products. In parentheses are ratios of the isomer 3a and 4 determined by GC.
Table 2. Ring-opening reaction of styrene oxide with different nucleophilic reagents catalyzed by MoO$_2$(acac)$_2$ in CCl$_4$.

| Entry | Nucleophilic reagent (2) | Product (3) | Time (h) | Yield$^b$ (%) |
|-------|--------------------------|-------------|----------|---------------|
| 1     | 2a                       | 3a          | 4        | 90            |
| 2     | 2b                       | 3b          | 4        | 91            |
| 3     | 2c                       | 3c          | 5        | 91            |
| 4     | 2d                       | 3d          | 3        | 91            |
| 5     | 2e                       | 3e          | 3        | 94            |
| 6     | 2f                       | 3f          | 3        | 90            |

(Continued)
substituted with electron-withdrawing group –NO₂ at the ortho, meta, para positions and -Cl at the meta position give similarly good yield of corresponding 1,2-aminoalcohols (about 91%, Table 2, entries 1–3 and 6). It was noteworthy that an aniline substituted with electron-donating group –C₉H₉ at the para position and aniline showed good reactivity with yields of up to 95% (Table 2, entries 5 and 7). Encouraged by these results, we studied the ring opening of styrene oxide with oxygen and carbon nucleophiles. The ring-opening reaction of styrene oxide proceeded smoothly with phenol and 4-phenylphenol as oxygen nucleophiles in moderate yields.

Table 2. continued

| Entry | Nucleophilic reagent (2) | Product (3) | Time (h) | Yieldb (%) |
|-------|-------------------------|-------------|----------|------------|
| 7     | 2g                      | 3g          | 2.5      | 95         |
| 8     | 2h                      | 3h          | 6        | 87         |
| 9     | 2i                      | 3i          | 8        | 77         |
| 10    | 2j                      | 3j          | 8        | 63         |
| 11    | 2k                      | 3k          | 12       | Trace      |

* Reaction condition: styrene oxide (1) (2.0 mmol), nucleophilic reagent (5) (2.0 mmol), MoO₂(acac)₂ (5 mol%), solvent (5 mL).

b Isolated yield of the major isomer 3 after chromatography on silica gel.
of 87% and 77%, respectively (Table 2, entries 8 and 9). In addition, although anisole as carbon nucleophile can give 2-(4-methoxyphenyl)-2-phenylethanol (3j) in a yield of 63%, an anisole bearing electron-donating groups of –NO₂ were not tolerated with this catalytic system, generating only a trace of product 3k (Table 2, entry 11).

**CONCLUSION**

We have developed the MoO₂(acac)₂-catalyzed ring opening of styrene oxide with different nucleophilic reagents in a wide range of nitrogen, oxygen, and carbon nucleophiles. The reaction proceeds smoothly with moderate to excellent yields. The ring opening of styrene oxide takes place in a completely or highly regioselective fashion. In conclusion, MoO₂(acac)₂ is a highly efficient catalyst for the opening of styrene oxide with different nucleophilic reagents under the mild conditions.

**EXPERIMENTAL**

Most of the chemical reagents were purchased from Aldrich and used without further purification. Solvents were purchased and dried by a standard method. Analytical gas chromatography was performed on an Agilent model GC-6820 instrument equipped with a capillary column of HP-5 (5% phenyl methyl-polysiloxane, 30 m × 0.32 mm × 0.25 μm) using nitrogen as carrier gas. ¹H NMR and ¹³C NMR spectra were recorded on Bruker Avance III 500-MHz instrument. Chemical shifts are in parts per million (ppm) from tetramethylsilane (TMS). Melting points were determined on an Electrothermal apparatus and uncorrected. All the major products were isolated by flash column chromatography on silica gel, with eluents of mixed solvents (ethyl acetate and petroleum ether). Thin-layer chromatography (TLC) was performed on Merck Kieselgel F₂₅₄, 0.2 mm thick.

**Reaction of Styrene Oxide (1) with Different Nucleophiles**

MoO₂(acac)₂ (32 mg, 0.1 mmol) was added to a magnetically stirred mixture of styrene oxide (1) (240 mg, 2.0 mmol) and the corresponding nucleophiles 2 (2.0 mmol) in CCl₄ (5 mL). Then the mixture was heated to a set temperature and refluxed for a certain time (Tables 1 and 2). After removal of solvent under vacuum, the crude residue obtained was separated by column chromatography on silica gel to afford the corresponding product.

**2-(2-Nitrophenylamino)-2-phenylethanol (3a)**

Red oil; yield: 464 mg, 90%. IR (KBr) ν_max( cm⁻¹): 3387 (ν O-H, N-H), 2877 (ν C-H, N-CH), 1417, 1348 (ν NO₂), 1506, 1569, 1620 (ν C=C aromatic ring); H NMR (500 MHz, CDCl₃) δ 7.48 (dt, J = 7.7, 3.9 Hz, 1H), 7.36 (dd, J = 8.2, 4.7 Hz, 5H), 7.34–7.27 (m, 1H), 7.20 (t, J = 8.1 Hz, 1H), 6.82 (dd, J = 8.2, 2.3 Hz, 1H), 5.30 (s, 1H), 4.55 (dd, J = 6.5, 4.0 Hz, 1H), 4.01 (dd, J = 11.2, 4.0 Hz, 1H), 3.83 (dd, J = 11.2, 6.5 Hz, 1H), 2.18 (s, 1H). ¹³C NMR (500 MHz, CDCl₃) δ 149.2, 148.3, 139.2, 129.8, 129.2, 128.1, 126.8, 119.6, 112.3, 107.9, 67.2, 59.9.
2-(3-Nitrophenylamino)-2-phenylethanol (3b)\[11\]
Red oil; yield: 470 mg, 91%. $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 8.77 (d, $J = 5.5$ Hz, 1H), 8.18 (d, $J = 8.5$ Hz, 1H), 7.38 (d, $J = 4.3$ Hz, 4H), 7.34–7.29 (m, 1H), 7.28 (t, $J = 3.7$ Hz, 1H), 6.68–6.58 (m, 2H), 4.74 (dd, $J = 10.6$, 6.0 Hz, 1H), 4.06–3.98 (m, 1H), 3.95–3.88 (m, 1H), 2.18 (s, 1H).

2-(4-Nitrophenylamino)-2-phenylethanol (3c)\[12\]
Red solid; yield: 470 mg, 91%; mp 88–90 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 8.74 (d, $J = 5.2$ Hz, 1H), 8.20–8.17 (m, 1H), 7.39–7.35 (m, 5H), 7.33–7.29 (m, 1H), 7.29–7.27 (m, 1H), 6.64 (dd, $J = 3.2$, 1.5 Hz, 1H), 4.73 (dt, $J = 10.6$, 5.3 Hz, 1H), 4.04 (dd, $J = 11.2$, 4.4 Hz, 1H), 3.94 (dd, $J = 11.2$, 6.2 Hz, 1H), 2.17 (s, 1H).

2-(p-Toluidino)-2-phenylethanol (3d)\[13\]
Yellow solid; yield: 413 mg, 91%; mp 59–61 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.41–7.31 (m, 4H), 7.27–7.25 (m, 1H), 7.00–6.84 (m, 2H), 6.53–6.48 (m, 2H), 4.52–4.47 (m, 1H), 3.94 (dd, $J = 11.0$, 4.1 Hz, 1H), 3.77–3.71 (m, 1H), 2.20 (d, $J = 2.9$ Hz, 3H).

2-(4-Methoxyphenylamino)-2-phenylethanol (3e)\[14\]
White solid; yield: 457 mg, 94%; mp 22–24 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.38–7.32 (m, 4H), 7.28–7.25 (m, 1H), 6.70 (t, $J = 6.1$ Hz, 2H), 6.55 (d, $J = 8.9$ Hz, 2H), 4.45 (dd, $J = 7.4$, 4.2 Hz, 1H), 3.93 (dd, $J = 11.1$, 4.2 Hz, 1H), 3.73 (dd, $J = 11.1$, 7.5 Hz, 1H), 3.70 (s, 3H).

2-(3-Chlorophenylamino)-2-phenylethanol (3f)\[15\]
White solid; yield: 446 mg, 90%; mp 52–53 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.37–7.34 (m, 3H), 7.33–7.28 (m, 1H), 7.27 (m, 1H), 7.00 (dd, $J = 10.4$, 5.7 Hz, 1H), 6.64 (dd, $J = 7.8$, 1.2 Hz, 1H), 6.55 (t, $J = 2.1$ Hz, 1H), 6.43 (dd, $J = 8.1$, 1.9 Hz, 1H), 4.48 (dd, $J = 6.6$, 4.2 Hz, 1H), 3.96 (dd, $J = 11.2$, 4.1 Hz, 1H), 3.78 (dd, $J = 11.1$, 6.6 Hz, 1H), 1.69 (s, 2H).

2-Phenyl-2-(phenylamino)ethanol (3g)\[16\]
Yellow solid; yield: 405 mg, 95%; mp 134–136 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.41–7.35 (m, 4H), 7.30–7.27 (m, 1H), 7.13 (t, 2H), 6.71 (t, 1H), 6.60 (d, 2H), 5.30 (s, 1H), 4.51 (m, 1H), 3.96–3.93 (dd, 1H), 3.78–3.74 (dd, 1H).

2-Phenoxy-2-phenylethanol (3h)\[17\]
Yellow solid; yield: 373 mg, 87%; mp 77–80 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.37 (dt, $J = 15.0$, 7.3 Hz, 4H), 7.33–7.29 (m, 1H), 7.21 (t, $J = 7.9$ Hz, 2H), 6.97–6.86 (m, 3H), 5.28 (dd, $J = 8.2$, 3.5 Hz, 1H), 3.98–3.90 (m, 1H), 3.87–3.80 (m, 1H), 2.34 (d, $J = 5.5$ Hz, 1H).
2-(4-Phenylphenol)-2-phenylethanol (3i)

White solid; yield: 344 mg, 77\%; mp 126–128 °C; $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.53–7.49 (m, 2H), 7.47–7.43 (m, 3H), 7.42 (dd, $J = 4.2$, 3.2 Hz, 3H), 7.40–7.37 (m, 2H), 7.35–7.28 (m, 2H), 7.01–6.91 (m, 2H), 5.34 (dd, $J = 8.3$, 3.5 Hz, 1H), 3.97 (dd, $J = 12.0$, 8.3 Hz, 1H), 3.90–3.80 (m, 1H), 2.29 (s, 1H). $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 156.34 (s), 139.65 (s), 136.74 (s), 133.42 (s), 127.86 (s), 127.72 (s), 127.28 (s), 127.15 (s), 125.74 (s), 125.32 (s), 115.17 (s), 80.28 (s), 76.31–75.80 (m), 66.64 (s). Anal. calcd. (\%) for C$_{20}$H$_{18}$O$_2$ (290.14): C, 82.72; H, 6.25; O, 11.03. Found: C, 83.03; H, 6.12; O, 11.95.

2-(4-Methoxyphenyl)-2-phenylethanol (3j)$^{[18]}$

Colorless oil; yield: 275 mg, 63\%. $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.34–7.31 (m, 3H), 7.27–7.23 (m, 2H), 7.20–7.18 (m, 2H), 6.88–6.86 (m, 2H), 4.16–4.13 (m, 2H), 3.79 (s, 3H). $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 156.4, 140.8, 133.2, 128.7, 128.0, 127.3, 125.9, 114.1, 66.7, 55.6, 53.2.

FUNDING

This work was supported by the Natural Science Foundation of Jiangsu Province (BK2011696) and the National Natural Science Foundation of China (No. 21376121).

SUPPLEMENTAL MATERIAL

Supplemental data for this article can be accessed on the publisher’s website.

REFERENCES

1. (a) Taylor, S. K. Tetrahedron 2000, 56, 1149; (b) Hu, X.; Gao, B.; Chu, Y.; Li, W.; Liu, X.; Lin, L.; Feng, X. Chem. Eur. J. 2012, 18, 3473; (c) Chen, X.; Wu, H.; Wang, S.; Huang, S. Synth. Commun. 2012, 42, 2440; (d) Dhakshinamoorthy, A.; Alvaro, M.; Concepcion, P.; Fornes, V.; Garcia, H. Chem. Commun. 2012, 48, 5443; (e) Erturk, E.; Tezeren, M. A.; Atalar, T.; Tilki, T. Tetrahedron 2012, 68, 6463; (f) Pineschi, M. Eur. J. Org. Chem. 2006, 4979; (g) Krake, S. H.; Bergmeier, S. C. Tetrahedron 2010, 66, 7337; (h) Murthy, S. N.; Madhav, B.; Reddy, V. P.; Rao, K. R.; Nageswar, Y. V. D. Tetrahedron Lett. 2009, 50, 5009; (i) Bonollo, S.; Lanari, D.; Vaccaro, L. Eur. J. Org. Chem. 2011, 2587; (j) Rai, V. K.; Sharma, R.; Kumar, A. Tetrahedron Lett. 2013, 54, 1071; (k) De, S. K.; Gibbs, R. A. Synth. Commun. 2005, 35, 2675; (l) Kamal, A.; Prasad, B. R.; Reddy, A. M.; Khan, M. N. Catal. Commun. 2007, 8, 1876.

2. (a) Chng, B. L.; Ganesan, A. B. Bioorg. Med. Chem. Lett. 1997, 7, 1511; (b) Ruediger, E.; Martel, A.; Meanwell, N.; Solomon, C. Tetrahedron Lett. 2004, 45, 739; (c) Corey, E. J.; Zhang, F. Angew. Chem. Int. Ed. Engl. 1999, 38, 1931; (d) Johannes, C. W.; Visser, M. S.; Weatherhead, G. S.; Hoveyda, A. H. J. Am. Chem. Soc. 1998, 120, 8340.

3. (a) Alka, A.; Satish, K. A.; Murthy, P. K. Med. Chem. Res. 2011, 20, 430; (b) Li, G. G.; Chang, H. T.; Sharpless, K. B. Angew. Chem. Int. Ed. Engl. 1996, 35, 451; (c) O’Brien, P. Angew. Chem. Int. Ed. Engl. 1999, 38, 326; (d) Ager, D. J.; Prakash, I.; Schaad, D. R. Chem. Rev. 1996, 96, 835.
4. (a) Boa, A. N.; Clark, S.; Hirst, P. H. *Tetrahedron Lett.* 2003, 44, 9299; (b) Hanson, R. M. *Chem. Rev.* 1991, 91, 437; (c) Mitsunobu, O.; Trost, B. M.; Fleming, I. *Comprehensive Organic Synthesis*; Pergamon: Oxford, 1991; pp. 6, 88 (d) Deyrup, J. A.; Moyer, C. L. *J. Org. Chem.* 1969, 34, 175; (e) Freifelder, M.; Stone, G. R. *J. Org. Chem.* 1961, 26, 1477.
5. Chakraborti, A. K.; Kondaskar, A. *Tetrahedron Lett.* 2003, 44, 8315.
6. Harrak, Y.; Pujol, M. D. *Tetrahedron Lett.* 2002, 43, 819.
7. (a) Iqbal, J.; Pandey, A. *Tetrahedron Lett.* 1990, 31, 575; (b) Carree, F.; Gil, R.; Collin, J. *Tetrahedron Lett.* 2004, 45, 7749; (c) Robinson, M. W. C.; Timms, D. A.; Williams, S. M.; Graham, A. E. *Tetrahedron Lett.* 2007, 48, 6249.
8. (a) Stiefel, E. I. In *Comprehensive Coordination Chemistry*; Wilkinson, G., Gillard, R. D., Mccleverty, J. A., Eds.; Pergamon: Oxford, UK, 1987; Chapter 36.5, pp. 1375–1420; (b) Kühn, F. E.; Zhao, J.; Herrmann, W. A. *Tetrahedron: Asymmetry* 2005, 16, 3469; (c) Kühn, F. E.; Santos, A. M.; Abrantes, M. *Chem. Rev.* 2006, 106, 2455.
9. (a) Kühn, F. E.; Santos, A. M.; Herrmann, W. A. *Dalton Trans.* 2005, 2483; (b) Sensato, F. R.; Custodio, R.; Longo, E.; Safont, V. S.; Andres, J. *J. Org. Chem.* 2003, 68, 5870; (c) Rudolph, J.; Reddy, K. L.; Chiang, J. P.; Sharpless, K. B. *J. Am. Chem. Soc.* 1997, 119, 6189; (d) Velusamy, S.; Ahamed, M.; Punniyamurthy, T. *Org. Lett.* 2004, 6, 4821; (e) Maiti, S. K.; Abdul Malik, K. M.; Bhattacharyya, R. *Inorg. Chem. Commun.* 2004, 7, 823.
10. Mancilla, G.; Femenia-Rios, M.; Macias-Sanchez, A. J.; Collado, I. G. *Tetrahedron* 2008, 64, 11732.
11. Krishnan, G. R. *Polymer* 2008, 24, 5233.
12. Mancilla, G.; Femenia-Rios, M.; Macias-Sanchez, A. J.; Collado, I. G. *Tetrahedron* 2008, 61, 11732.
13. Chakraborti, A. K.; Kondaskar, A.; Rudrawar, S. *Tetrahedron* 2004, 61, 9085.
14. Balasubramaniam, S.; Kommidi, H.; Aidhen, I. S. *Tetrahedron Lett.* 2011, 21, 2683.
15. Zhang, C.-F.; Chen, J.-X.; Yu, X.-C.; Chen, X.; Wu, H.-Y.; Yu, J.-P. *Synth. Commun.* 2008, 12, 1875.
16. Shivarkar, A. B.; Gupte, S. P.; Chaudhari, R. V. *Synlett* 2006, 9, 1374.
17. Zvagulis, A.; Bonollo, S.; Lanari, D. *Adv. Synth. Catal.* 2010, 14, 2489.
18. Chen, Y. L.; Hoppe, D. *J. Org. Chem.* 2009, 74, 4188.