Available online at www.sciencedirect.com

ScienceDirect

Tetrahedron Letters 48 (2007) 4845–4848

Tetrahedron
Letters

Pd(Phen)Cl_2 stabilized by ionic liquid: an efficient and reusable catalyst for biphasic oxidative cyclocarbonylation of β-aminoalcohols and 2-aminophenol

Fuwei Li* and Chungu Xia*

State Key Laboratory for Oxo Synthesis and Selective Oxidation, Lanzhou Institute of Chemical Physics,
Chinese Academy of Sciences, Lanzhou 73000, China

Received 23 April 2007; revised 8 May 2007; accepted 10 May 2007

Abstract—Biphasic oxidative cyclocarbonylation of β-aminoalcohols and 2-aminophenol to synthesize corresponding 2-oxazolidinones were investigated in the presence of ionic liquid stabilized Pd(phen)Cl_2 complex. Catalytic comparison results showed that, 1-butyl-3-methyl-imidazolium iodide salts (BMImI) can serve simultaneously as a specific stabilizer to protect the transition metal complex against deactivation, a promoter to increase the catalytic performance and a reaction medium to recycle the catalyst with unprecedented TOF value.

2-Oxazolidinones are very important intermediates in the manufacture of pharmaceuticals, cosmetics, pesticides and other fine chemicals.[1,2] They are mainly produced by phosgenation of the corresponding 1,2-aminoalcohols or 2-aminophenols,[3] which has resulted in serious social and environmental problems. With the increasing environmental concerns, it is worthy to develop efficient and environmentally benign non-phosgene methodologies for the production of 2-oxazolidinones. As one of the approaches adopted recently, oxidative cyclocarbonylation of 1,2-aminoalcohols or 2-aminophenols using carbon monoxide as the carbonyl source catalyzed by transition metal catalysts represents a valid one-step alternative for the synthesis of 2-oxazolidinones. In 2000, Gabriele and his co-workers reported a homogeneous palladium catalytic system for the synthesis of 2-oxazolidinones using oxidative carbonylation process,[4] and we developed a first heterogeneous catalyst with good catalytic efficiency.[5a] Although the recycle of expensive transition metal catalyst was achieved, its catalytic performance was still not so efficient. Consequently, it is necessary to investigate another efficient, stable and reusable catalyst for the production of 2-oxazolidinones.

The three important factors with respect to transition metal catalyzed reactions are the stabilization of catalysts, finding effective promoter cooperating with the expensive metal catalyst to enhance its catalytic efficiency and the reuse of catalysts. Therefore, how to design and search for an additive that may serve simultaneously in the reaction as a stabilizer to protect the noble metal catalyst against deactivation, a promoter to increase activity of the main metal catalyst and a reaction medium to recycle catalyst deserve to be pursued in order to search for an efficient catalytic system.

Recently, the combination of task specific ionic liquids (TSILs) as versatile and novel reaction media with transition metal complex has resulted in many diverse and flexible ‘platforms’ to establish a highly effective and easily separable catalytic system. More latest reported studies and our previous investigation have shown that the stabilization of metal complexes may be achieved by the use of imidazolium ILs that may provide electronic and/or steric protections.[6,7] With our continuous research in oxidative cyclocarbonylation,[5] in this work, we reported here an effective and reusable process for the preparation of 2-oxazolidinones by oxidative cyclocarbonylation of β-aminoalcohols and 2-aminophenol

---

Keywords: Biphasic oxidative cyclocarbonylation; Reuse of catalyst; Ionic liquid; 2-Oxazolidinone.

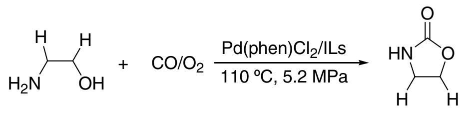
* Corresponding authors. Tel.: +86 931 4968089; fax: +86 931 8277088; e-mail addresses: chmlifw@nus.edu.sg; cgxia@lzb.ac.cn

0040-4039/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2007.05.048

catalyzed by specific ILs (BMImI) promoted Pd(Phen)Cl_2 system under biphasic conditions, in which the stabilization and recycle of noble metal catalyst were accomplished, simultaneously.

Initially, ethanolamine (**1a**) was selected as a probe substrate to investigate the possibility of a certain ILs acting simultaneously as a stabilizer, promoter and reaction medium in the reaction, the results are listed in Table 1[8]. As shown, with $BMIm^+$ as cation, the effect of different types of anions on the reaction was studied first under the same reaction conditions. Only about 15% of conversions were achieved, respectively, using $BMImBF_4$, $BMImPF_6$, BMImCl or BMImBr as an additive for the palladium complex catalyst while high selectivity was obtained (Table 1, entries 1–4). Subsequently, the comparison experiment was carried out using Pd(phen)Cl_2 as a catalyst in the absence of ionic liquid, only 6% conversion of **1a** and 90% selectivity of 2-oxazolidinone (**2a**) were observed (Table 1, entry 5); furthermore, the deactivation of palladium catalyst was founded in the reaction while this phenomenon was not observed in the presence of ILs. All the above mentioned results show that BF_4^-, PF_6^-, Br^-, Cl^- involved $BMIm^+$ type ILs can stabilize and protect the palladium catalyst particle free from deactivation, and then improve the activity and selectivity of the imidazolium ILs-promoted palladium complex system to a certain content in comparison with that of Pd(phen)Cl_2 alone. However, their abilities in promoting catalytic performances were quite unsatisfactory. When BMImI was introduced into the catalytic system as a promoter or stabilizer instead of other anion type ILs, interestingly, the catalytic activity was greatly improved and 94% conversion of **1a** with high selectivity was obtained at mild reaction conditions, the corresponding TOF exceeded 3200 h^{-1}, which is 3.0 times higher than our previous reported record of 1000 h^{-1} (Table 1, entry 6). This experiment as result showed that the anions of the ILs had a strong impact on the catalytic activity and BMImI was maybe the best co-catalyst for Pd(phen)Cl_2 complex in the oxidative cyclocarbonylation of ethanolamine. In order to gain insight of the BMImI-promoted Pd(phen)Cl_2 system, other two comparison experiments were carried out to investigate the difference between BMIm and other conventional iodide salts, in which inorganic iodide salt KI and organic tetraethylammonium iodide salt $[Et]_4I$ utilized as additives, respectively, instead of BMImI, the catalyst black precipitate was observed after the completion of catalytic reaction, only 35% conversion of **1a** obtained (Table 1, entries 7 and 8). The results of these three comparison experiments suggested that imidazolium cation involved IL, BMImI showed more efficient ability in increasing catalytic activity than that of other conventional inorganic or organic ammonium iodide salts. It is probably because that some special interaction between the imidazolium-based iodide IL and palladium complex happened and therefore BMImI can act not only as a promoter to enhance the catalytic performance but also as a novel stabilizer to protect the palladium complex against deactivation.[6a]

Table 1. Oxidative cyclocarbonylation of ethanolamine (**1a**) catalyzed by imidazolium ILs-promoted palladium complex system[a]



Entry	Ionic liquid	Conv. (%)	Select. (%)	TOF (h^{-1})[b]
1	$BMImBF_4$	15	95	508
2	$BMImPF_6$	13	90	417
3	BMImCl	16	95	540
4	BMImBr	13	95	440
5[c]	—	6	90	190
6	BMImI	94	98	3288
7[d]	KI	36	97	1246
8[e]	$[Et]_4I$	35	95	1187
9[f]	BMImI	85	96	2913

[a] Reaction conditions: the mol ratio of substrate/Pd catalyst = 3570, BMImI 1 ml; temperature 110 °C, $P_{CO/O_2} = 5.0/0.2$, time 1 h.

[b] Moles of 2-oxazolidinones produced per mole of catalyst per hour.

[c] Deactivation of palladium catalyst was observed.

[d] KI 10 mg and 20 equiv of Pd complex, were used.

[e] $[Et]_4I$ 14.5 mg and 20 equiv of Pd complex, were used.

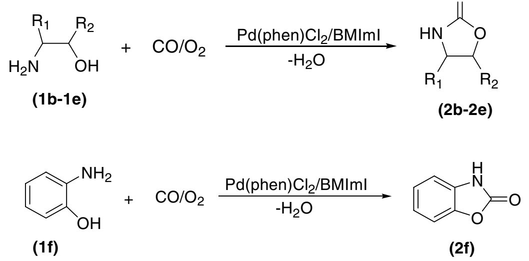
[f] The catalyst system used for the third time.

In order to investigate the capability of ILs as a reaction medium under a two-phase condition, the recycling of the Pd(phen)Cl_2/BMImI catalyst system was also examined. Since BMImI is insoluble with DME, after reaction, the resulting product and unreacted substrate dissolved in the DME phase while the Pd(phen)Cl_2 was immobilized in the ILs phase;[11] therefore, the reaction mixture containing 2-oxazolidinones can be separated from the system by simple decantation and the IL phase including the palladium complex catalyst can be reused after evaporation to remove the water liberated in the reaction. When catalyst was used three times in the oxidative cyclocarbonylation of 1,2-aminoalcohol under the same conditions shown in this typical reaction, a minor loss in activity and 2913 h^{-1} of TOF were obtained (Table 1, entry 9). This result indicated, in addition to high activity and selectivity, that the Pd(phen)Cl_2/BMImI showed good stability in recycle process.

The highly efficient BMImI/Pd(phen)Cl_2 catalytic system was also found to be applicable to a variety of β-aminoalcohols (**1b–e**) under the optimal reaction conditions. The results are listed in Table 2. As shown, Pd(phen)Cl_2/BMImI catalytic system exhibited excellent catalytic activity to almost all the employed β-aminoalcohols under the same reaction conditions, providing the corresponding 2-oxazolidinones with high turnover frequency and selectivity. Furthermore, the high efficiency of fulfilling the reaction under considerably mild oxidizing conditions has also permitted the application of this methodology to 2-aminophenol (**1f**), and 89% of conversion and 2955 h^{-1} of TOF were obtained. These above mentioned results suggested that Pd(phen)Cl_2/BMImI was a robust and efficient catalytic system for the oxidative cyclocarbonylation of β-aminoalcohols and 2-aminophenol.

As to the reaction mechanism of this process, it is not well understood at this stage. Since a poor result was ob-

Table 2. Oxidative cyclocarbonylation of β-aminoalcohols (**1b**–**e**) and 2-aminophenol (**1f**) to synthesize corresponding 2-oxazolidinones



Sub.	R_1	R_2	Conv. (%)	Select. (%)	TOF (h^{-1})
1b	H	CH_3	94	97	3250
1c	CH_3	H	93	97	3220
1d	CH_3CH_2	H	96	99	3390
1e[b]	$(CH_3)_2CH$	H	92	95	3120
1f[c]	2-Aminophenol		90	94	3020

[a] Reaction conditions: the mol ration of substrate/Pd catalyst = 3570, BMImI 1 ml; temperature 110 °C, $P_{CO/O_2} = 5.0/0.2$, time 1 h.

[b] L enantiomer.

[c] 10 ml DME was used.

tained with Pd(phen)Cl_2 complex alone as the catalyst, and the addition of conventional inorganic or organic ammonium iodide salts still could not enhance the catalytic performance markedly, an excellent selectivity of 2-oxazolidinone and TOF was obtained over BMImI stabilized Pd(phen)Cl_2 complex system. Based on the latest published results by Dupont and Migowski,[6a] it can be conjectured that the highly synergistic stabilization effect between Pd(phen)Cl_2 and the task specific ILs leads to the outstanding stability and activity of our IL-stabilized palladium complex catalyst system.

In conclusion, we have developed a Pd(phen)Cl_2/BMImI catalytic system that gave good catalytic activity in oxidative cyclocarbonylation reaction under considerably mild conditions (a temperature of 110 °C and a total pressure of 2.1 MPa), 1-butyl-3-methyl-imidazolium iodide salts showed better ability in the stabilization of transition metal active sites and promotion of catalytic performance than other anion type of imidazolium ionic liquids and conventional iodide salts; furthermore, the catalyst could be recycled with minor loss in activity and selectivity. All these results demonstrate that the combination of a suitable ionic liquid as stabilizer, promoter and reaction medium with a metal complex is a pathway towards highly effective and stable heterogeneous catalysts for the oxidative cyclocarbonylation.

Acknowledgements

This research was financially supported by the National Science Foundation of China (20533080) and the National Science Fund for Distinguished Young Scholars (20625308).

References and notes

1. (a) Ager, D. J.; Prakash, I.; Schaad, D. R. *Chem. Rev.* **1996**, *96*, 835; (b) Köll, P.; Lützen, A. *Tetrahedron: Asymmetry* **1996**, *7*, 637; (c) Lützen, A.; Köll, P. *Tetrahedron: Asymmetry* **1997**, *8*, 29; (d) Lützen, A.; Köll, P. *Tetrahedron: Asymmetry* **1997**, *8*, 1193; (e) Fonquerna, S.; Moyano, A.; Pericàs, M. A.; Riera, A. *Tetrahedron: Asymmetry* **1997**, *8*, 1685; (f) Bravo, P.; Fustero, S.; Guidetti, M.; Volonterio, A.; Zanda, M. *J. Org. Chem.* **1999**, *64*, 8731; (g) *Catalytic Asymmetric Synthesis*; Ojima, I., Ed.; Wiley: New York, 2000.
2. (a) Seneci, P.; Caspani, M.; Ripamonti, F.; Ciabatti, R. *J. Chem. Soc., Perkin Trans. 1* **1994**, 2345; (b) Grega, K. C.; Barbachyn, M. R.; Brickner, S. J.; Mizsak, S. A. *J. Org. Chem.* **1995**, *60*, 5255; (c) Brikner, S. J.; Hutchinson, D. K.; Barbachyn, M. R.; Manninen, R. R.; Ulanowicz, D. A.; Garmon, S. A.; Grega, K. C.; Hendges, S. K.; Toops, D. S.; Ford, C. W.; Zurenko, G. E. *J. Med. Chem.* **1996**, *39*, 673; (d) Lohray, B.; Baskaran, S.; Rao, B. S.; Reddy, B. Y.; Rao, I. N. *Tetrahedron Lett.* **1999**, *40*, 4855; (e) Bager, D. J.; Prakas, I. H.; Schaad, D. R. *Aldrichim. Acta* **1997**, *30*, 3; (f) Bach, J.; Bull, S. D.; Davies, S. G.; Nicholson, R. L.; Sanganee, H. J.; Smith, A. D. *Tetrahedron Lett.* **1999**, *40*, 6677.
3. Puschin, N. A.; Mitic, R. V. *Justus Leibigs Ann. Chem.* **1937**, *532*, 300.
4. (a) Gabriele, B.; Salerno, G.; Brindisi, D.; Costa, M.; Chiusoli, G. P. *Org. Lett.* **2000**, *2*, 625; (b) Gabriele, B.; Mancuso, R.; Salerno, G.; Costa, M. *J. Org. Chem.* **2003**, *6*, 601; (c) Gabriele, B.; Mancuso, R.; Salerno, G.; Costa, M. *Chem. Commun.* **2003**, 486.
5. (a) Li, F. W.; Xia, C. G. *J. Catal.* **2004**, *227*, 542; (b) Li, F. W.; Peng, X. G.; Xia, C. G.; Hu, B. *Chin. J. Chem.* **2005**, *23*, 643; (c) Peng, X. G.; Li, F. W.; Xia, C. G. *Synlett* **2006**, 1161; (d) Liu, J. M.; Peng, X. G.; Liu, J. H.; Zheng, S. Z.; Sun, W.; Xia, C. G. *Tetrahedron Lett.* **2007**, *48*, 929.
6. (a) Migowski, P.; Dupont, J. *Chem. Eur. J.* **2007**, *13*, 32–39; (b) Ott, L. S.; Cline, M. L.; Deetlefs, M.; Seddon, K. R.; Finke, R. G. *J. Am. Chem. Soc.* **2005**, *127*, 5758; (c) Dupont, J.; Spencer, J. *Angew. Chem., Int. Ed.* **2004**, *43*, 5296; (d) Dupont, J.; Fonseca, G. S.; Umpierre, A. P.; Fichtner, P. F. P.; Teixeira, S. R. *J. Am. Chem. Soc.* **2002**, *124*, 4228.
7. Li, F. W.; Xiao, L. F.; Xia, C. G.; Hu, B. *Tetrahedron Lett.* **2004**, *45*, 8307.
8. The ionic liquid, BMImI (BMIm = 1-butyl-3-methyl-imidazolium), $BMImBF_4$, $BMImPF_6$, BMImCl, BMImBr and Pd(phen)Cl_2 complexes were, respectively, synthesized according to the reported literatures.[9,10] Oxidative cyclocarbonylation reactions were performed in a 100-mL stainless-steel reactor which was equipped with a magnetic stirrer and an automatic temperature control system. For each typical reaction, known quantities of β-aminoalcohols (**1a**–**e**) or 2-aminophenol (**1f**) (10 mmol), Pd complex catalyst (1 mg), IL (1 ml) and 6 ml DME were successively charged into the reactor, the reactor was flushed three times with CO, and then was pressurized with CO and O_2 to a total pressure of 5.2 MPa (CO 5.0 MPa and O_2 0.2 MPa). This condition corresponded to about 96% of CO in the CO–O_2 mixture and is already beyond the explosive limit for CO–O_2 mixture.[4c] Then the reaction proceeded at 120 °C for 1 h. After the reaction, the DME phase containing 2-oxazolidinones can be easily separated from the reaction mixture by simple decantation and the ILs phase including the palladium complex catalyst can be reused after evaporation with a vacuum pump to remove water liberated in the reaction. Qualitative analyses were conducted with a HP 6890/5973 GC–MS with chemstation ?tul?> containing a NIST Mass Spectral Database

and quantitative analyses were carried out over a HP 6892 GC equipped with a FID detector.

9. Bontempi, A.; Alessio, E.; Chanos, G.; Mestroni, G. *J. Mol. Catal.* **1987**, *42*, 67.
10. Bonĥote, P.; Dias, A. P.; Papageorgiou, N.; Kalyanasundaram, K.; Grätzel, M. *Inorg. Chem.* **1996**, *35*, 1168.
11. Shi, F.; Deng, Y. Q. *J. Catal.* **2003**, *219*, 372.