

Short communication

PEG₁₀₀₀-DAIL / Toluene Temperature-dependent Biphasic System that Regulate Homogeneously Catalyzed Oxidation of Primary Alcohols to Carboxylic Acids

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Abstract

An efficient and convenient procedure for the hydrogen peroxide oxidation of primary alcohols to the carboxylic acids in aqueous media in regulated temperature-dependant; recyclable phase-separation catalytic system comprised of the PEG₁₀₀₀-based dicationic acidic ionic liquid and toluene under homogeneous conditions in good to excellent yield is reported.

Keywords: Primary alcohols, oxidation, carboxylic acids, PEG₁₀₀₀-DAIL, thermo-regulated ionic liquid biphasic system.

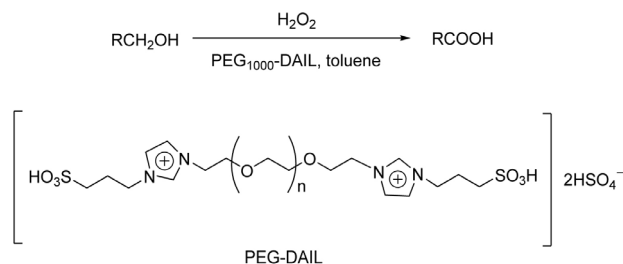
1. Introduction

Carboxylic acids are important classes of chemicals used extensively for the preparation of a variety of fine or special chemicals such as polymers, pharmaceuticals, solvents, and food additives,¹ and versatile methods for the preparation of these type of compounds have been reported. However, direct conversion of primary alcohols to the corresponding carboxylic acids is still a challenge especially in the presence of other functional groups. There are few reports for this oxidation of primary alcohols to the corresponding carboxylic acids including CrO₃/H₂SO₄,^{2,3} TEMPO/NaClO,^{4,5} RuCl₃/H₅IO₆,⁶ CrO₃/H₅IO₆,⁷ and Co(II)/H₂O₂.⁸ However, these procedures are invariably associated with one or more disadvantages such as long reaction time, high temperature, low yields, difficulties in work up, and unpleasant to the environment. Consequently, there is a great need to develop new and environmentally benign procedures that address these drawbacks in oxidation protocols.

Ionic liquids (ILs) have gained recognition as possible environmentally benign solvents because of their favorable properties such as negligible volatility and non-flammability under ambient conditions, large liquid ran-

ge, high thermal stability, wide electrochemical window, and strong ability to dissolve many chemicals.⁹ Therefore, ILs have found wide applications in chemical synthesis,^{10–12} biocatalytic transformations,¹³ electrochemistry,¹⁴ and analytical and separation science.¹⁵ In view of both the advantages and disadvantages of homogeneous and heterogeneous catalysts, and to improve catalyst recovery, multiphase systems, such as phase-transfer catalysis,^{16,17} thermo-regulated phase-transfer catalysis,¹⁸ and liquid-liquid biphasic catalysis,¹⁹ have been studied. Some novel temperature-dependent ionic liquid biphasic catalytic systems have been reported recently.^{20–22} Luo and co-workers reported very recently a new PEG₁₀₀₀-based dicationic ionic liquid exhibiting temperature-dependent phase behavior with toluene and had successfully applied it in one-pot synthesis of benzopyrans.²³ They found that the IL showed some advantages such as high conversions and selectivity, stability at high temperatures, and reusability, which provide a novel route for the separating and recycling of the catalysts. Based on the concept of thermo-regulated ionic liquid biphasic system (TRILC) and from Luo's good experiences in the application of the IL, we now report an efficient and convenient procedure for the oxidation of primary alcohols to the corresponding car-

boxylic acids with H_2O_2 , catalyzed by the PEG_{1000} -based dicationic acidic ionic liquid (PEG_{1000} -DAIL) in aqueous media (Scheme 1). We found that the PEG_{1000} -DAIL/toluene temperature-dependent biphasic system is active and an environmentally acceptable catalytic system for oxidation of alcohols.



Scheme 1

2. Results and Discussion

The initial study was carried out using 4-methylbenzyl alcohol as the substrate to optimize the reaction conditions, and the results are summarized in Table 1. At first, the oxidation was tested with H_2O_2 as the oxidant in the presence and absence of PEG_{1000} -DAIL catalytic system. In the absence of PEG_{1000} -DAIL, the reaction proceeded very slowly and the yield was only 26% after 24 hours (Table 1, entry 1). When the reaction was catalyzed with only 0.02 equivalents of PEG_{1000} -DAIL, the yield increased to 57% in 8 hours (Table 1, entry 2). The yield was improved with increasing the amount of PEG_{1000} -DAIL (Table 1, entries 2–5), and reached maximum with 0.1 equivalents of PEG_{1000} -DAIL (Table 1, entry 5). Further increasing of the equivalent of PEG_{1000} -DAIL, under the same conditions, did not significantly enhance the yield (Table 1, entry 6). These experiments revealed that 0.1 equivalents of the catalyst were necessary to complete the reaction in 4 hours.

The catalytic system could be recovered and reused for subsequent reactions with no appreciable decrease in yields and reaction rates (Figure 1). The recycling process involved the removal of the upper oil layer containing toluene and product by decantation, and concentration of the aqueous layer containing the catalytic system by removing the water through a water knockout drum. Fresh substrate and toluene were then recharged to the residual PEG_{1000} -DAIL and the mixture was heated to react once again. Only 6% loss of weight was observed after 8-times recycling.

Various benzylic and allylic alcohols can be successfully oxidized by this oxidation system to the corresponding carboxylic acids in good to high yields (Table 2, entries 1–10). However, aliphatic primary alcohol 2-phenylethanol was found inert in this oxidation reaction, and even under more drastic reaction conditions, no pro-

Table 1. Optimization of the reaction conditions for oxidation of 4-methylbenzyl alcohol to 4-methylbenzoic acid^a

Entry	Ionic liquid	Ionic liquid (equiv.)	Time (h)	Yield (%) ^b
1	PEG_{1000} -DAIL	–	24	26
2	PEG_{1000} -DAIL	0.02	8	57
3	PEG_{1000} -DAIL	0.07	6	84
4	PEG_{1000} -DAIL	0.09	4	91
5	PEG_{1000} -DAIL	0.10	4	96
6	PEG_{1000} -DAIL	0.11	4	96

^a Reaction conditions: 4-methylbenzyl alcohol (10 mmol), H_2O_2 (50%, 12 mL), toluene (12 mL), 85 °C. ^b Isolated yield.

duct was detected (Table 2, entry 12). The substituent's on the aromatic ring have influence on the oxidation rate, i.e., benzylic alcohols having electron-donating groups on the aromatic ring (Table 2, entries 2–6 and 8) are more reactive than those having electron-withdrawing groups (Table 2, entry 11).

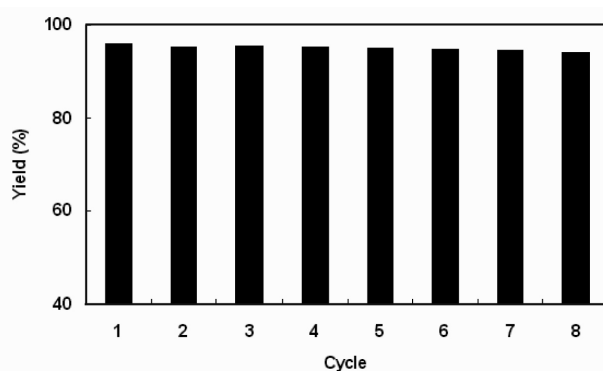


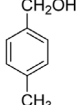
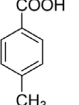
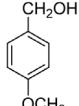
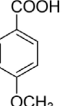
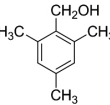
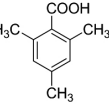
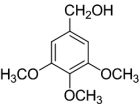
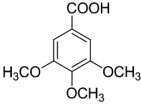
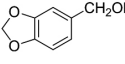
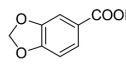
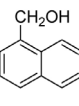
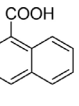
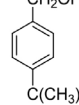
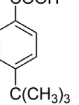
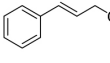
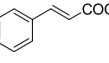
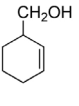
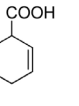
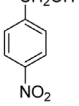
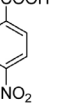
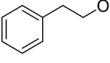


Fig. 1. Repeating reaction cycles using recovered PEG_{1000} -DAIL catalytic system.

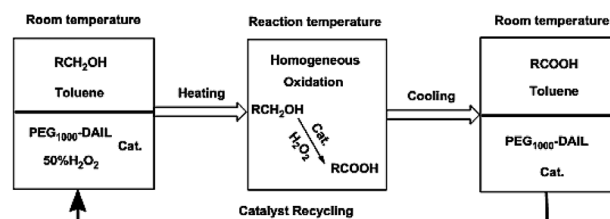
The proposed catalytic oxidation of alcohols with H_2O_2 in PEG_{1000} -DAIL / toluene system is schematically presented in Figure 2. Before the oxidation, there is an oil-water biphasic system, and the bottom layer (aqueous phase) consists of PEG_{1000} -DAIL and hydrogen peroxide. PEG_{1000} -DAIL catalytic system is completely dissolved in aqueous phase, and the upper layer (oil phase) consists of toluene and primary alcohol. During the oxidation, the oil-water layer disappears and a homogeneous reaction medium is formed. After the completion of the reaction, a complete phase-separation occurred again, after cooling to the room temperature. The next step involved the removal of the upper toluene layer, containing product, by decantation and concentration of the bottom layer with the catalytic system by removing the water through a water knockout drum. Fresh substrate and toluene were then recharged to the residual PEG_{1000} -DAIL and recycled. The PEG_{1000} -DAIL catalytic system has a crucial role in the oxidation process to locally concentrate the reacting spe-

Table 2. Oxidation of primary alcohols to carboxylic acids^a

Entry	Substrate	Product ^b	Time (h)	Yield (%) ^c
1			5	92
		1		
2			4	96
		2		
3			4	97
		3		
4			4	98
		4		
5			4	99
		5		
6			4	95
		6		
7			4	94
		7		
8			4	93
		8		
9			5	93
		9		
10			5	90
		10		
11			24	45d
		11		
12		— ^e	24	0

^a Reaction conditions: alcohol (10 mmol), H₂O₂ (50%, 12 mL), toluene (12 mL), PEG₁₀₀₀-DAIL (1 mmol), 85 °C. ^b All products are known compounds and were identified by comparing their HPLC spectra with those of commercially available materials. ^c Isolated yield. ^d 50% of starting material was recovered. ^e No product was detected.

cies by exhibiting a temperature-dependent phase behavior with toluene. Namely, the thermo-regulated biphasic behavior of mono-phase at high temperature and bi-phase at room temperature leads to a large increase in the effective reactant concentration and the excellent reaction yields. The yields of products obtained by this catalytic system could be remarkably improved by 10–20% in contrast to the synthetic methods reported previously.^{2–8}

**Figure 2.** Thermo-regulated ionic liquid biphasic catalytic oxidation process.

3. Conclusions

We have developed a simple and efficient procedure for the H₂O₂ oxidation of primary alcohols to carboxylic acids in the PEG₁₀₀₀-DAIL / toluene temperature-dependent biphasic system. Mild reaction conditions, easy work-up and isolation of products, high yields, stability, good thermo-regulated biphasic behavior of the ionic liquid, and excellent recyclability of the catalyst are the attractive features of this methodology. Further aspects of this catalytic system and the application to other organic systems are under investigation.

4. Experimental

All chemicals were from commercial sources and used without any pretreatment, and reagents were of analytical grade. The ionic liquids were synthesized according to the literature procedures.²³ High performance liquid chromatography (HPLC) analyses were performed on a Dionex Softron GmbH (America) system, consisting of a pump (P680), UV-vis detector system (170U), and Diacoverity C18 column (4.6 × 250 mm). NMR spectra were recorded on a Bruker 400-MHz spectrometer using CDCl₃ as the solvent with tetramethylsilane (TMS) as an internal standard. Elemental analyses were performed on a Vario EL III instrument (Elementar Analysensysteme GmbH, Germany).

General procedure for the oxidation of primary alcohols. To a stirred solution of alcohol (10 mmol) in ionic liquid PEG₁₀₀₀-DAIL (1 mmol) and toluene (12 mL) was added H₂O₂ (50%, 12 mL) at room temperature and stirring was continued at 85 °C for the appropriate time (see Table 2). The reaction progress was monitored by HPLC.

After completion of the reaction, the reaction mixture was cooled to the room temperature and the organic phase separated by decantation, and rinsed with water (3×10 mL). The organic phase was dried with sodium sulfate, filtered, and the solvent removed under reduced pressure. The residue was passed through silica gel pad to afford the pure product. All further runs were performed under identical reaction conditions. Spectroscopic data for selected products are as follows.

2,4,6-trimethylbenzoic acid (4). ^1H NMR (400MHz, CDCl_3): δ 2.24 (s, CH_3 , 3H), 2.49 (s, CH_3 , 6H), 7.28 (s, Ar-H, 2H), 11.5–12.9 (broad, COOH, 1H). ^{13}C NMR (400MHz, CDCl_3): δ 21.2, 22.5, 125.8, 129.4, 131.3, 140.9, 168.5. Anal. Calcd. for $\text{C}_{10}\text{H}_{12}\text{O}_2$: C, 73.15; H, 7.37; O, 19.49. Found: C, 73.11; H, 7.38; O, 19.50.

3,4,5-trimethoxybenzoic acid (5). ^1H NMR (400MHz, CDCl_3): δ 3.79 (s, CH_3O , 3H), 3.94 (s, CH_3O , 6H), 7.18 (s, Ar-H, 2H), 11.7–13.1 (broad, COOH, 1H). ^{13}C NMR (400MHz, CDCl_3): δ 52.6, 58.4, 104.5, 124.2, 141.7, 151.4, 169.1. Anal. Calcd. for $\text{C}_{10}\text{H}_{12}\text{O}_5$: C, 56.60; H, 5.70; O, 37.70. Found: C, 56.57; H, 5.70; O, 37.72.

3,4-(Methylenedioxy)-benzoic acid (6). ^1H NMR (400MHz, CDCl_3): δ 6.06 (s, CH_2 , 2H), 7.18–7.57 (m, Ar-H, 3H), 11.4–13.2 (broad, COOH, 1H). ^{13}C NMR (400MHz, CDCl_3): δ 97.8, 102.7, 109.5, 121.4, 122.8, 143.5, 150.4, 168.7. Anal. Calcd. for $\text{C}_8\text{H}_6\text{O}_4$: C, 57.84; H, 3.64; O, 38.52. Found: C, 57.79; H, 3.66; O, 38.53.

Cinnamic acid (9). ^1H NMR (400MHz, CDCl_3): δ 6.10 (d, CH, 1H), 7.14 (d, CH, 1H), 7.28–7.56 (m, Ar-H, 5H), 11.6–13.0 (broad, COOH, 1H). ^{13}C NMR (400MHz, CDCl_3): δ 112.8, 126.5, 127.4, 128.2, 131.7, 139.6, 169.8. Anal. Calcd. for $\text{C}_9\text{H}_8\text{O}_2$: C, 72.97; H, 5.43; O, 21.57. Found: C, 72.96; H, 5.44; O, 21.60.

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Povzetek

Avtorji v prispevku poročajo o učinkovitih in enostavnih oksidacijah primarnih alkoholov z vodikovim peroksidom do karboksilnih kislin v reguliranem sistemu s temperaturno odvisno fazno separacijo. Oksidacija poteka pod pogoji homogene katalize s PEG_{1000} -dikationsko kislino ionsko tekočino in toluenom v vodnem mediju z zelo dobrimi izkoristki.