



The syntheses of carbamates from reactions of primary and secondary aliphatic amines with dimethyl carbonate in ionic liquids

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Abstract—At 170°C and using ionic liquids as solvent and catalyst, primary and secondary aliphatic amines could react with dimethyl carbonate to give alkyl carbamates with good yield. Due to its insolubility, the desired carbamate solid could be recovered by simple filtration from the two-layer mixture of dimethyl carbonate and ionic liquid after reaction and the formation of *N*-methylated and deammoniated products were restrained. © 2002 Published by Elsevier Science Ltd.

Carbamates are important intermediates in the synthesis of pharmaceuticals, pesticides, herbicides and other fine and commodity chemicals.^{1,2} Furthermore, the development of an environmentally friendly process for synthesis of isocyanates, which are usually obtained by phosgenation of amines, through thermal decomposition of carbamates has also attracted extensive attention.^{3–6}

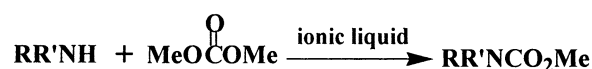
Now, many alternative routes, such as catalytic reductive carbonylation of nitro compounds, oxidative carbonylation of amines, reaction of amines with carbon dioxide and alkyl halides, etc., with low environmental impact have been studied.^{7–10} A phosgene and halogen free process through reaction of amines and dimethyl carbonate was put forward in the last few years. No high selectivity could be achieved if no solvents and catalysts were added even if this reaction could easily occur. As reported previously, Pb and alumina based catalysts were effective for this reaction.^{11,12} More recently, Selva et al. reported that good results could be obtained in the presence of *sc*CO₂, but its pressure was relatively high.¹³

Room temperature ionic liquids, a new kind of green solvent and catalyst with unique chemical and physical properties, have attracted growing interest, and many catalytic reactions proceeded in ionic liquids were

reported with excellent performance.^{14–17} Based on the extensive studies on ionic liquids in our laboratory,^{18–20} they were firstly used in the carbonylation of aliphatic amines with dimethyl carbonate. High yield was achieved and the formation of deammoniated, *N*-methylated byproducts was restrained (Scheme 1).

The following ionic liquids were used in the reactions: BMImCl (BMIm = 1-butyl-3-methyl); BMImBF₄; BMImPF₆; BMImHSO₄; BuPyBF₄ (BuPy = 1-butyl pyridine); EMImBF₄ (EMIm = 1-ethyl-3-methyl imidazole); HMImBF₄ (HMIm = 1-cetyl-3-methyl imidazole); and BeMImBF₄ (BeMIm = 1-benzyl-3-methyl imidazole). All ionic liquids were synthesized according to the previous paper with slight modifications.²¹ The purity of prepared ionic liquids was characterized with FTIR (IFS 120HR, Bruker), and satisfactory results were obtained.

In order to avoid the reaction between amines and carbon dioxide in air, all reactions were conducted in a 90 ml autoclave with a glass tube inside equipped with magnetic stirring. In each reaction, 2 ml of ionic liquid, 2 ml of amines and 5 ml of dimethyl carbonate were introduced in turn without any additional organic sol-



T=170°C, t=1 hour

Scheme 1.

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vent and catalyst. The reaction was proceeded at 170°C for 1 h. If the conversion and selectivity were high enough, large amounts of solid product would be formed in dimethyl carbonate layer (a two-layer mixture of dimethyl carbonate and ionic liquid formed after reaction), and the carbamate products could be more efficiently recovered by simple filtration after removal of residual dimethyl carbonate and methanol with distillation and then addition of water to 'precipitate' the products due to their almost complete insolubility in water. However, in order to achieve accurate data of the reaction, a moderate amount of acetone was added into the resulted two-layer mixture to obtain a homogeneous solution after the reaction. Qualitative and quantitative analyses were conducted with a HP 6890/5973 GC MS and all results were given by the chemstation directly.

In the reusability experiment of the ionic liquids, the used ionic liquid was reused after it was easily separated from the resulted water containing percolate by vacuum purification at 100°C and ca. 5 mmHg.

Firstly, cyclohexyl amine as substrate was selected to test the catalytic activities of different kinds of ionic liquids because it is relatively difficult to react with dimethyl carbonate and the diversity of its products. As is shown in Table 1, cyclohexyl amine could easily react with dimethyl carbonate but poor selectivity (33.4%) could be obtained in the absence of ionic liquids (entry 1). The main byproducts were cyclohexene (16.8%), *N,N*-dimethyl cyclohexyl amine (39.6%) and *N*-cyclohexyl-*N*-methyl carbamate (10.2%). The formation of cyclohexene and *N,N*-dimethyl cyclohexyl amine could be, however, evidently restrained when BMImCl was

employed as solvent and catalyst, and selectivity of 82.7% to *N*-cyclohexyl carbamate was obtained. Only 0.46% of cyclohexene, and 2.9% of *N,N*-dimethyl cyclohexyl amine were found while the amount of *N*-cyclohexyl-*N*-methyl carbamate was 14.2%. Several other ionic liquids with different anions were used to investigate the effect of anions on the reactions (entries 2–5). Similar results were obtained in comparison with BMImCl results, and the selectivities to *N*-cyclohexyl carbamate were 78.5 and 80.6% when BMImBF₄ and BMImPF₆ were employed. Unexpectedly, only 46.9% of *N*-cyclohexyl carbamate was given, even no cyclohexene could be detected, and 38.5% of selectivity to *N*-cyclohexyl-*N*-methyl carbamate was produced if BMImHSO₄ was tested. This result indicates that the HSO₄⁻ containing BMImHSO₄ might have some detrimental effect on the reaction between amine and dimethyl carbonate.

Ionic liquids with different cations were also employed in the reactions and exhibited quite different results (entries 6–10). The experimental results suggested that the chain length of substituted group of imidazole had a very strong impact on the catalytic activity of ionic liquids, and 84.7% of selectivity to *N*-cyclohexyl carbamate was achieved in EMImBF₄, which was higher than that using BMImBF₄ as solvent and catalyst. With increasing carbon number of the substituents, more *N*-methylated product was produced and its selectivity reached 60.8% in HMImBF₄ while only 23.3% of selectivity to desired product. This implies that ionic liquids could be suitable reaction media and catalysts for the formation of dimethylated compounds from the reactions between amines and dimethyl carbonate under proper reaction conditions. With BeMImBF₄ ionic liq-

Table 1. Results of carbonylation of amines with dimethyl carbonate

| Entry | Substrate | RTIL | Con. (%) | | | | Products (%) | | | | |
|-----------------|-----------|----------------------|----------|------|------|--|--------------|--|------|------|------|
| 1 | | ---- | 96 | | 16.8 | | 39.6 | | 33.4 | | 10.2 |
| 2 | | BMImCl | >99 | | 0.46 | | 2.9 | | 82.7 | | 14.2 |
| 3 | | BMImPF ₆ | >99 | | 0.30 | | 4.4 | | 78.5 | | 16.8 |
| 4 | | BMImBF ₄ | >99 | | 0.41 | | 3.9 | | 80.6 | | 14.1 |
| 5 | | BMImHSO ₄ | >99 | | ---- | | 38.5 | | 46.9 | | 13.9 |
| 6 | | EMImBF ₄ | >99 | | 0.6 | | ---- | | 84.7 | | 14.7 |
| 7 ^a | | EMImBF ₄ | >99 | | 0.4 | | 0.3 | | 85.3 | | 13.8 |
| 8 | | HMImBF ₄ | >99 | | 4.1 | | 60.8 | | 23.3 | | 11.8 |
| 9 | | BeMImBF ₄ | >99 | | 0.4 | | ---- | | 82.7 | | 16.8 |
| 10 | | BuPyBF ₄ | >99 | | 3.9 | | 56.8 | | 34.9 | | 4.5 |
| 11 | | BMImCl | >99 | ---- | ---- | | ---- | | >99 | | ---- |
| 12 | | BMImCl | >99 | ---- | ---- | | ---- | | >99 | | ---- |
| 13 | | BMImCl | >99 | ---- | ---- | | ---- | | >99 | ---- | ---- |
| 14 | | BMImCl | >99 | ---- | ---- | | ---- | | >99 | ---- | ---- |
| 15 ^b | | BMImCl | 23.7 | | 0.1 | | 4 | | 95 | | 1 |
| 16 ^b | | BMImCl | 87.4 | ---- | ---- | | ---- | | >99 | | ---- |

a: EMImBF₄ was used for the fifth times; b: reacted at 120°C.

uid, high selectivity to *N*-cyclohexyl carbamate was given, and no *N*-methylated product could be observed. In addition, EMImBF₄ was also selected to investigate the reusability of ionic liquid as solvent and catalyst, 85.3% of selectivity was maintained after it was reused the fifth time. This result showed that the reusability of the ionic liquid as solvent and catalyst for the reactions of aliphatic amines with dimethyl carbonate was possible.

It is worth noting that no mono-*N*-methylated product was found in the above reaction processes. The reason might be attributed to easy transformation of mono-*N*-methylated product to dimethylated or carbonylated products.

The ionic liquid as solvent and catalyst also showed high activity for the reactions of unbranched alkyl substituted and alkyl disubstituted amines with dimethyl carbonate. Much better results were achieved if *n*-butyl amine, *n*-hexyl amine, dibutyl amine and *N*-benzyl-*N*-methyl amine were used as substrates in the presence of BMImCl ionic liquid (entries 11–14), and the selectivities to corresponding carbamates were higher than 99%.

As indicated above, if the conversion and selectivity were high enough, large amounts of solid product would be formed due to lower solubility of carbamates in dimethyl carbonate and ionic liquids. For entry 6, ca. 80% of isolated yield (desired carbamate+*N*-cyclohexyl-*N*-methyl carbamate) could be achieved by direct filtration after reaction. However, the carbamate products could be more efficiently recovered by simple filtration after removal of residual dimethyl carbonate and methanol with distillation and then addition of water to 'precipitate' the products due to their almost complete insolubility in water, and 94.7 and 97.3% of isolated yields were obtained for entries 6 and 11, respectively.

Finally, the effect of reaction temperatures was also examined using BMImCl as solvent and catalyst (entries 15–16). At 120°C, only 23.7% of conversion was obtained when cyclohexyl amine was used as substrate, although its selectivity was further increased to 95%. On the contrary, high conversion and selectivity (87.4% and >99%) was still maintained for *n*-butyl amine as substrate. These results suggested that unbranched alkyl substituted amines could react with dimethyl carbonate for desired products at lower temperature (120°C) with good yield, while a higher temperature was necessary for cyclohexyl amine.

In summary, ionic liquids were effective solvent and catalyst to mediate the clean carbonylation reactions of primary and secondary aliphatic amines with dimethyl

carbonate to yield the desired carbamate products without any additional solvents and catalysts. The *N*-methylated products could be produced if appropriate ionic liquids and reaction conditions were chosen, which was unexpectedly found in this work for the first time. Due to its lower solubility in dimethyl carbonate and the ionic liquid saturated with dimethyl carbonate and almost complete insolubility in water, the desired carbamate solid could be efficiently recovered through simple treatment with distillation, water addition and filtration after reaction, and the ionic liquid could be reused without losing activity. Further investigation about the reaction mechanism and optimization of the ionic liquid as reaction medium with catalytic function is now underway.

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