



Self-associated, “Distillable” Ionic Media

Ulf P. Kreher *, Anthony E. Rosamilia, Colin L. Raston, Janet L. Scott and Christopher R. Strauss *

Centre for Green Chemistry, Monash University, PO Box 23, Victoria 3800, Australia. Fax: +61 3 8558 8001; Tel: +61 3 8558 8007.

* Authors to whom correspondence should be addressed; E-mail: UKreher@boronmolecular.com, Chris.Strauss@sci.monash.edu.au.

Received 18 February 2004 / Accepted: 22 February 2004 / Published: 31 May 2004

Abstract: Liquid or low melting association products of carbon dioxide and a secondary amine, both neutral molecules that may be gaseous, are recognised as “distillable” ionic media.

Keywords: DIMCARB, distillable, ionic liquid, ionic media, carbon dioxide, dimethylamine.

Introduction

Increased environmental awareness has led to demands and regulations for the control, at least, and preferably the avoidance of hazardous compounds. Spent volatile organic compounds (VOCs), particularly solvents, are major components of the Toxics Release Inventory [1]. Potential replacements for VOCs include ionic liquids, supercritical carbon dioxide, and water or solvent-free conditions [2].

Ionic liquids have attracted interest through their negligible vapour pressure, high solubility with many organic compounds, immiscibility with some organic solvents, and lack of flammability [3]. However, they tend to be expensive and are often available in only limited quantities. Also, toxicological data are limited for ionic liquids, their potential metabolites and their decomposition products. Furthermore, the isolation of non-volatile products from ionic liquids can present logistical problems through requirements for the application of bi- or multi-phase systems, an extraction step, or the use of pervaporation [4].

Products from the addition of carbon dioxide and a secondary amine, neutral molecules that both may be gaseous, herein are recognised as self-associated, “distillable” ionic media. This is significantly different from the recent report of a pre-existing ionic liquid (*N*-butyl, *N'*-(3-aminopropyl)-imidazolium tetrafluoroborate) the cation of which incorporated a primary amine that could react with carbon dioxide to form a carbamate [5]. In that case the ionic liquid was used as a carbon dioxide scavenger.

The present communication deals with a class of “distillable” ionic media, the *N,N*-dialkylammonium *N',N'*-dialkylcarbamates (herein referred to as dialcarbs) that although not new, have not been recognised or explored previously in this context.

Dialcarbs can be readily and inexpensively produced in bulk (litres can be prepared on the laboratory-scale within a few hours), merely by mixing the reactants in the appropriate ratio in the gas phase, with cooling [6].

Many dialcarbs melt below 100°C: *N,N*-dimethylammonium *N',N'*-dimethylcarbamate (DIMCARB) and *N,N*-diethylammonium *N',N'*-diethylcarbamate (DIETCARB) are liquids even at ambient temperature. By definition, ionic liquids have almost no vapour pressure [7]. This introduces a clear distinction between dialcarbs and conventional ionic liquids. At temperatures as low as 60°C, DIMCARB and DIETCARB undergo dissociation to the respective amine and carbon dioxide, which can then be re-associated by condensation [8]. Thus, through association-dissociation-reassociation, with cooling, heating and re-cooling respectively, the dialcarbs can be recovered by “distillation”. Although the process does not involve distillation of a single molecular entity, it affords a comparable result. Thus dialcarbs could be regarded as a separate category of solvents hierarchically located between VOCs and ionic liquids, based on their properties and behaviour.

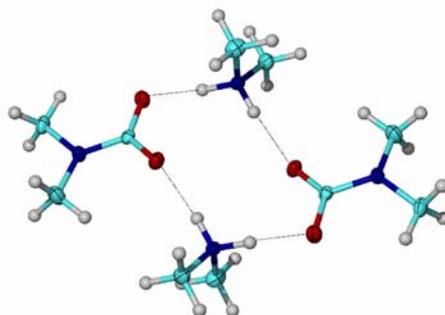
Although dialcarbs, and particularly DIMCARB, have been investigated by Schroth *et al* [6] and more recently by Hess and coworkers [9], their potential applicability appears to have been overlooked by others. The major focus of the aforementioned researchers [6,9] was on the utility of DIMCARB as a convenient and safe precursor of dimethylamine, carbon dioxide and dimethylcarbamate in synthetic chemistry.

DIMCARB is a clear colourless viscous liquid, existing as a stoichiometric salt (2:1 dimethylamine:carbon dioxide on a molar basis), with a melting point of 29°C and as a non-stoichiometric compound (1.6-1.9:1 dimethylamine:carbon dioxide on a molar basis). Both forms are stable at ambient pressure at temperatures up to 60°C.

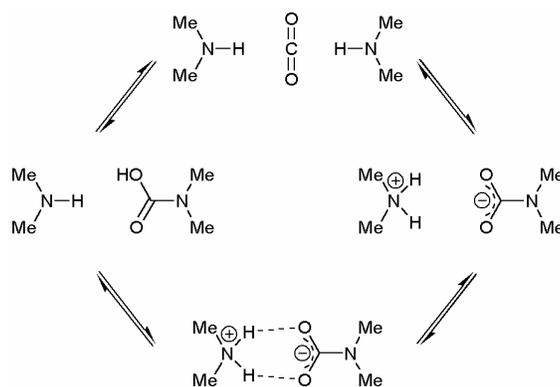
The single crystal X-ray structure [10] shows that the DIMCARB salt is stabilised by 4 hydrogen bonds forming a 12-membered ring between two *N,N*-dimethylcarbamate anions and two *N,N*-dimethylammonium cations (Figure 1).

Several inorganic salts are moderately soluble in DIMCARB, which in turn is highly soluble in water, where it suffers minimal depletion of carbon dioxide [11]. The solubility of some inorganic salts in DIMCARB [11] lies between that of water [12], and other organic solvents.

Except for hydrocarbons, organic solvents *e.g.* benzene, dichloromethane, diethyl ether and methanol, are highly miscible with DIMCARB, whose solvating power presumably results from its low molecular weight and large number of coordinating centres. As with conventional ionic liquids, these properties allow reactions to be carried out on a multigram scale in only a few mL of dialcarb.

Figure 1. The single crystal X-ray structure of DIMCARB

The viscosity [9] and the conductance [13] of DIMCARB depend strongly on the temperature. NMR investigations have indicated that this may result from rapid interchange between components in complex equilibria (Scheme 1) [14]. These properties make it an interesting medium for synthetic electrochemistry [13].

Scheme 1 Dynamic equilibrium of DIMCARB [14].**Table 1** Other known dialcarbs and their dissociation temperature [8].

R ¹	R ²	mp range (°C)	Dissociation temperature (°C)	bp amine (°C)
Me	Me	30-45	60-61	7.4
Me	Et	-	62	34-35
Et	Et	17-33	62-63	55
Me	n-Pr	-	70-71	62
-(CH ₂) ₄ -	-	55-80	105	87-88
-(CH ₂) ₅ -	-	48-63	-	106
Me	H	99-133	-	-6.5

The above properties of dialcarbs suggest that they could serve as a solvent in reactions, where an ionic liquid would be beneficial (e.g. in improving the chemoselectivity or yield of a reaction) and in particular, when products are formed that are either non-volatile or thermally labile. Thus, subsequent extraction of the products from the ionic liquid or the application of multiphase systems can be avoided.

Results and Discussion

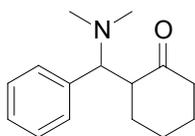
In this work, DIMCARB has been employed as a medium for aldol-condensation reactions (Scheme 2) [15], mainly between aryl aldehydes and symmetrical ketones i.e. cyclohexanone, acetone and cyclopentanone. When carried out in other media (except water), these reactions frequently produce bis arylidenecycloalkanones [16]. With DIMCARB, mono-arylidene cycloalkanones were formed preferentially when a 1:1 ratio of aldehyde : ketone was used and the yields were moderate to excellent.

Scheme 2 Aldol-condensation type reactions performed in DIMCARB.



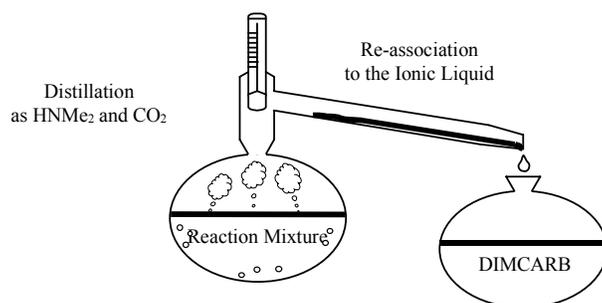
Bis-arylidene products were only minor. Reactions using cyclopentanone, resulted in greater selectivity toward the mono-arylidene alkanones and greater yields were obtained.

Figure 2. Mannich adduct seen in the reaction



We have also detected Mannich adducts among the products, suggesting that dimethylamine may play an important role. Apparently the Mannich adducts are formed *via* addition to transient iminium species. These then deaminate. It seems that, in the case of the aldol-condensation reactions, the DIMCARB is acting as both a dimethylamine donor and as a solvent/catalyst as previously observed [6,9].

An advantage of DIMCARB as the medium is the capacity for recovery by ‘distillation’ from the reaction mixture (see Figure 3). We have been able to recover up to 85 % DIMCARB by distillation.

Figure 3. Distillation of DIMCARB.

Conclusions

DIMCARB was found to be a useful medium for monoarylidene synthesis. High yields and selectivity were achieved. The methodology for mono-condensation products was simpler than for other literature methods (that require at least two steps). It involved the mixing of the aldehyde and ketone in the DIMCARB and heating up to 50 °C. Various workup methods were employed, including: distillation of the DIMCARB (both high vacuum and under a carbon dioxide atmosphere), addition of aqueous acid followed by extraction with typical water immiscible organic solvents, or quenching on silica gel followed by solvent elution. DIMCARB also has potential uses as an alternative to traditional ionic liquids that can be difficult to purify and recycle.

Experimental

General Method for Performing Aldol Condensations in DIMCARB

Benzaldehyde (1.0 g, 9.4 mmol) was added to DIMCARB (10 mL) at ambient temperature with stirring. Gas was evolved. The solution was heated to 52 °C and cyclopentanone (0.79 g, 9.4 mmol) was added in a single portion. Stirring at 52 °C was continued for 3 h, after which the colorless reaction mixture had become dark brown. DIMCARB (8.71 g, 83 %) was recovered from the reaction mixture by distillation at 60 °C under high vacuum.

The undistilled residue was acidified with 0.5 M H₂SO₄ (25 mL) and extracted with ethyl acetate (3 × 25 mL). The combined organic fraction was dried with anhydrous MgSO₄, filtered and the solvent removed *in vacuo* to afford a brown oil (1.21 g). Si gel chromatography with ethyl acetate elution yielded *E*-2-benzylidenecyclopentanone (1.06 g, 74 %) as a yellow solid m.p. 54–57 °C. ¹H-NMR (300 MHz, CDCl₃): δ 2.06 (app p, *J* = 7.6 Hz, 2H, -CH₂-), 2.44 (t, *J* = 8.0 Hz, 2H, -CH₂-C=O), 3.00 (td, *J* = 7.2, 2.7 Hz, 2H, C=CCH₂), 7.48 – 7.30 (m, 4H, 3 × ArCH, 1 × Ar-CH=C), 7.59 – 7.56 (m, 2H, ArCH). ¹³C-NMR (75 MHz, CDCl₃): δ 20.20 (-CH₂-); 29.36 (-CH₂-C=C); 37.79 (-CH₂-C=O); 128.73 (*o*-Ar); 128.36 (*p*-Ar); 130.55 (*m*-Ar); 132.42 (Ar-CH); 135.57 (Ar-CH=C); 136.12 (CH=C=O); 208.24 (C=O).

References and Notes

1. EPA Office of Compliance Sector Notebook Project 'Profile of the Organic Chemical Industry' **1995**, page 35 (to be found at www.epa.gov/oeca/sector).
2. For reviews on reactions in water see: (a) Li, C. -J., Aqueous Barbier-Grignard type reaction: scope, mechanism, and synthetic applications, *Tetrahedron*, **1996**, 52, 5643-68; (b) Lubineau, A.; Auge, J.; Y. Queneau, Water-promoted organic reactions. *Synthesis*, **1994**, 741-60; (c) Katritzky, A. R.; Nichols, D. A.; Siskin, M.; Murugan, R.; Balasubramanian, M., Reactions in high-temperature aqueous media. *Chem. Rev.*, **2001**, 101, 837-92; (d) Savage, P.E., Organic Chemical Reactions in Supercritical Water. *Chem. Rev.*, **1999**, 99, 603-21s. For examples from our lab see: (e) An, J.; Bagnell, L.; Cablewski, T.; Strauss, C. R.; Trainor, R. W., Applications of High-Temperature Aqueous Media for Synthetic Organic Reactions. *J. Org. Chem.*, **1997**, 62, 2505-11; For reviews on solvent-free reactions see: (f) Tanaka, K.; Toda, F., Solvent-Free Organic Synthesis. *Chem. Rev.*, **2000**, 100, 1025-74; (g) Loupy, A.; Petit, A.; Hamelin, J.; Texier-Boulet, F.; Jacquault, P.; Mathe, D., New solvent-free organic synthesis using focused microwaves. *Synthesis*, **1998**, 1213-34; For examples from our lab see: (h) Cave, G. W. V.; Raston, C. L.; Scott, J. L., Recent advances in solventless organic reactions: towards benign synthesis with remarkable versatility. *Chem. Commun.*, **2001**, 2159-69; (i) Kreher, U.; Strauss, C. R.; Walther, D., *5th International Electronic Conference on Synthetic Organic Chemistry (ECSOC-5)*, **2001**, <http://www.mdpi.net/ecsoc-5>. For reviews on applications of supercritical carbon dioxide as solvent in chemical synthesis see: (j) Oakes, R. S.; Clifford, A. A.; Rayner, C. M., The use of supercritical fluids in synthetic organic chemistry. *J. Chem. Soc., Perkin Trans. 1*, **2001**, 917-41; (k) Baiker, A.; Supercritical Fluids in Heterogeneous Catalysis. *Chem. Rev.*, **1999**, 99, 453-73.
3. For reviews on ionic liquids and their applications see: (a) Wasserscheid, P.; Keim, W., Ionic liquids - new "solutions" for transition metal catalysis. *Angew. Chem Int. Ed.*, **2000**, 39, 3772-89; (b) Welton, T., Room-Temperature Ionic Liquids. Solvents for Synthesis and Catalysis. *Chem. Rev.*, **1999**, 99, 2071-83;
4. Fadeev, A. G.; Meagher, M. M., Opportunities for ionic liquids in recovery of biofuels. *Chem. Commun.*, **2001**, 295-6.
5. Bates, E. D.; Mayton, R. D.; Ntai, I.; Davis, J. H., CO₂ Capture by a Task-Specific Ionic Liquid. *J. Am. Chem. Soc.*, **2002**, 124, 926-7.
6. Schroth, W.; Andersch, J.; Schändler, H.-D.; Spitzner, R., The dimethylamine-carbon dioxide complex DIMCARB and its preparative use. *Chemiker-Z.*, **1989**, 113, 261-71.
7. Wilkes, J. S., A short history of ionic liquids—from molten salts to neoteric solvents. *Green Chem.*, **2002**, 4, 73.
8. Schroth, W.; Schädler, H.-D.; Andersch, J., Structure and aggregation of dimethylammonium dimethylcarbamate (DIMCARB) and analogous dialkylammonium dialkylcarbamates *Z. Chem.*, **1989**, 29, 129-35.
9. Hess, U.; Dunkel, S.; Reck, G., Synthesis of cyano-substituted di- and tetrahydropyridines in DIMCARB (dimethylamine CO₂ adduct). *J. Prakt. Chem.*, **1997**, 339, 414-19.

10. Kreher, U.; Raston, C. L.; Strauss, C. R.; Nichols, P., *N,N*-Dimethylammonium *N',N'*-dimethylcarbamate. *Acta Cryst.* **2002**, *E58*, 948-9.
11. Schroth, W.; Schädler, H.-D.; Andersch, J., *Z. Chem.*, Dimethylammonium dimethylcarbamate (DIMCARB) as solvent and extractant. **1989**, *29*, 56-7.
12. *CRC Handbook of Chemistry and Physics*, Weast, R. C.; Astle, M. J., Eds.: CRC Press, Inc. Boca Raton, Florida, **1982**, *63rd ed.*, table B73-166.
13. Maschmeier, C.-P.; Krahnstöver, J.; Matschiner, H.; Hess, U., Electrochemical study of a dimethylamine-carbon dioxide addition compound - a new electrolyte. *Electrochimica Acta*, **1990**, *35*, 769-70.
14. Radeaglia R.; Andersch, J.; Schroth, W., The dynamic behavior of the dimethylamine-carbon dioxide complex (DIMCARB). *Z. Naturforsch.B: Chem. Sci.* **1989**, *44*, 181-6.
15. Results and Discussion are primarily taken from and can be viewed in this journal article: Kreher, U. P.; Rosamilia, A. E.; Raston, C. L.; Scott, J. L.; Strauss, C. R., Direct Preparation of Monoarylidene Derivatives of Aldehydes and Enolizable Ketones with DIMCARB. *Org. Lett.*, **2003**, *5*, 3107-10. Presented in preliminary form as an oral presentation, Rosamilia, A. E., A Distillable Ionic Liquid and its Application in Organic Synthesis, at the Royal Australian Chemical Institute's 27th Annual Synthesis Symposium, Melbourne, 6-12-2002.
16. Zheng, M.; Wang, L.; Shao, J.; Zhong, Q., A facile synthesis of α,α' -bis(substituted benzylidene)cycloalkanones catalysed by bis(*p*-ethoxyphenyl)telluroxide(BMPTO) under microwave irradiation. *Synth. Commun.* **1997**, *27*, 351.