

Solvent-free preparation of ionic liquids using a household microwave oven*

Rajender S. Varma[†] and Vasudevan V. Namboodiri

Clean Processes Branch, National Risk Management Research Laboratory,
U.S. Environmental Protection Agency, MS 443, 26 W. Martin Luther King Drive,
Cincinnati, OH 45268, USA

Abstract: An efficient solventless protocol for the preparation of a wide variety of ionic liquids is described, which requires a simple exposure of admixed 1-methylimidazole and alkyl halides to microwave irradiation in open glass containers. The details of this clean process using a common household microwave oven, which exploits the newer inverter technology system for better power attenuation, are described. The characterization and thermal stability data on selected ionic liquids and their potential applications are summarized.

INTRODUCTION

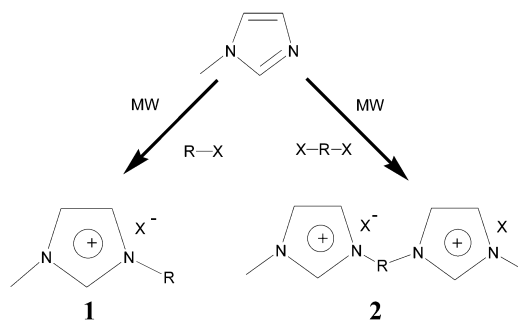
The development of cleaner technologies is a major emphasis in green chemistry. Among the several aspects of green chemistry, the reduction/replacement of volatile organic solvents from the reaction medium is of utmost importance. The use of a large excess of conventional volatile solvents required to conduct a chemical reaction creates ecological and economic concerns. The search for a nonvolatile and recyclable alternative is thus holding a key role in this field of research. The use of fused organic salts, consisting of ions, is now emerging as a possible alternative. A proper choice of cations and anions is required to achieve ionic salts that are liquids at room temperature and are appropriately termed room-temperature ionic liquids (RTILs). Common RTILs consist of *N,N'*-dialkylimidazolium, alkylammonium, alkylphosphonium or *N*-alkylimidazolium as cations [1]. Most of these ionic salts are good solvents for a wide range of organic and inorganic materials and are stable enough to air, moisture, and heat. Ionic liquids are polar (but consist of poorly coordinating ions), are immiscible with a number of organic solvents, and provide polar alternatives for biphasic systems. The usefulness of RTIL in electrochemistry [2], heavy metal ion extraction [3], phase-transfer catalysis, and polymerization [4] has now been extended as a replacement of conventional volatile organic solvents [5]. Other salient features of these ionic liquids are negligible vapor pressure, ease of handling, accelerated reaction rates, potential for recycling, and compatibility with various organic compounds and organometallic catalysts [6]. Also, the products from reactions conducted in ionic liquids can be easily extracted using various organic solvents.

The ionic liquids based on 1,3-dialkylimidazolium are becoming more important for several synthetic applications. The preparation of the 1,3-dialkylimidazolium halides via conventional heating method in refluxing solvents requires several hours to afford reasonable yields and also uses a large excess of alkyl halides/organic solvents as the reaction medium [7]. In view of the emerging importance of the ionic liquids as reaction media [8] and our general interest in microwave-assisted chemical processes [9], we decided to explore the synthesis of ionic liquids using microwave (MW) irradiation under solvent-free conditions. Herein, we report an efficient method for the preparation of ionic liquids

*Lecture presented at the IUPAC CHEMRAWN XIV Conference on Green Chemistry: Toward Environmentally Benign Processes and Products, Boulder, Colorado, USA, 9–13 June 2001. Other presentations are published in this issue, pp. 1229–1330.

[†]Corresponding author: Tel: (513)-487-2701; Fax: (513)-569-7677; E-mail: Varma.Rajender@epa.gov

that simply involves exposing neat reactants in open glass containers to microwaves using an unmodified household MW oven. This solvent-free approach requires only a few minutes of reaction time in contrast to several hours needed under conventional heating condition, which uses an excess of reactants. A general schematic representation for the preparation of mono (**1**) and dicationic (**2**) 1,3-dialkylimidazolium halides is depicted below (Scheme 1).



Scheme 1

EXPERIMENTAL PROCEDURES

The 1-methyl imidazole (MIM) and alkyl halides, obtained from Aldrich Chemical Co., are used as such. The NMR spectra of the samples are recorded on a Bruker 250 MHz spectrometer using D_2O as solvent and $CD_3OD/CDCl_3$ as the standards. The new compounds are characterized by elemental analyses, 1H and ^{13}C NMR. The thermogravimetric analyses (TGA) of the samples are performed by heating from 25 to 500 °C at a rate of 10 °C/min, and differential scanning calorimetry (DSC) is conducted from 25 to 450 °C at a heating rate of 10 °C/min.

Preparation of ionic liquids using microwaves

In a typical reaction, 1-bromobutane (2.2 mmol) and MIM (2 mmol) are placed in a test tube, mixed thoroughly on a vortex mixer (Fisher, Model 231), and the mixture is heated intermittently in an unmodified household MW oven (Panasonic NN-S740WA-1200W) at 240 W (30 s irradiation with 10 s mixing) until a clear single phase is obtained. The bulk temperature recorded is in the range 70 to 100 °C. The resulting ionic liquid is then cooled, washed with ether (3 X 2 mL) to remove unreacted starting materials, and the product is dried under vacuum at 80 °C to afford 1-butyl-3-methylimidazolium bromide (86%), 1H NMR (250 MHz; D_2O), δ_H : 0.72 (t, CH_3), 1.15 (m, CH_2), 1.81 (m, CH_2), 3.71 (s, N- CH_3), 4.09 (m, N- CH_2), 7.38 (s, NCH), 7.43 (s, NCH), 8.7 (s, N(H)CN); ^{13}C NMR δ_C 12.89 (t, CH_2), 19.02 (m, CH_3), 31.51 (m, CH_2), 35.86 (N- CH_2), 49.51 (N- CH_3), 122.40 (NCH), 123.73 (NCH), 136.21 (N(H)CN). A relatively large-scale preparation (22 mmol of 1-bromobutane and 20 mmol of MIM) afforded 87 % yield.

The data for a representative dicationic compound, entry 11, δ_H (250 MHz; D_2O) 1.29 (m, CH_2), 1.82 (m, CH_2), 3.71 (s, N- CH_3), 4.14 (m, N- CH_2), 7.38 (s, NCH), 7.43 (s, NCH), 8.7 (s, NC (H)N); δ_C : 24.99 (t, CH_2), 29.17 (m, CH_3), 36.18 (N- CH_2), 49.57 (N- CH_3), 122.35 (NCH), 123.64 (NCH), 135.97 (NC (H)N), (Calc. for $C_{14}H_{24}N_4I_2$: C, 33.49; H, 4.82; N, 11.16; Found. C, 33.69; H, 4.93; N, 11.68%).

Suzuki cross-coupling reaction in ionic liquid

The synthesis of 4-methylbiphenyl is representative: ionic liquid, butylimidazolium chloride (1 g), palladium chloride (0.050 g, 0.282 mmol), base KF (0.390 g), water (1.0 mL), 4-methylphenylboronic acid (0.150 g, 1.0 mmol) and bromobenzene (0.156 g, 1 mmol) are placed in a 25-ml round-bottomed flask

and mixed well. The flask is then heated in a MW oven at 240 W for (30 + 10 + 10 + 10) seconds. The product was extracted with ether and was purified by flash chromatography to yield 4-methyl biphenyl (80%); mp 44.0–45.0 °C; ¹H NMR (CDCl₃; δ) 7.40 (m, 9H), 2.37 (s, 3H). The ionic liquid containing palladium catalyst and base are then recycled.

Table 1 Preparation of alkyl imidazolium halides using a household microwave oven.

Entry	Alkyl halide (RX)	RX mmol	MIM mmol	MW-(240 W) (time: s)	Yield %	Yield ^a % (time: h)
1	1-bromobutane	2.2	2	(30 + 15 + 15 + 15)	86	76 (5)
2	1-chlorohexane	2.2	2	(30 + 15 + 15 + 15 + 15)	81	53 (5)
3	1-bromohexane	2.2	2	(30 + 15 + 15 + 15)	89	78 (5)
4	1-iodohexane	2.2	2	(30 + 10 + 10 + 10)	93	89 (3)
5	1-iodoheptane	2.2	2	(30 + 10 + 10 + 10)	94	95 (3)
6	1-bromooctane	2.2	2	(30 + 15 + 15 + 15)	91	73 (5)
7	1,4-dibromobutane	1	2.2	(30 + 15 + 15 + 15)	81	76 (5)
8	1,4-diiodobutane	1	2.2	(15 + 15 + 10 + 10)	91	89 (3)
9	1,6-dichlorohexane	1	2.2	(30 + 15 + 15 + 15 + 15)	82	56 (5)
10	1,6-dibromohexane	1	2.2	(30 + 15 + 10 + 10)	92	72 (5)
11	1,6-diiodohexane	1	2.2	(15 + 15 + 10 + 10)	85	97 (3)
12	1,8-dichlorooctane	1	2.2	(30 + 15 + 15 + 15 + 15)	78	72 (5)
13	1,8-dibromooctane	1	2.2	(30 + 15 + 15 + 15)	92	76 (5)
14	1,8-diiodooctane	1	2.2	(15 + 15 + 10 + 10)	94	93 (3)

^aAlternative heating method (oil bath at 80 °C).

RESULTS AND DISCUSSIONS

In an unmodified household MW oven it is not possible to effectively adjust the MW power. The reduction in power level simply entails that it operates at its full power but for a reduced period of time. A recently introduced household MW oven (Panasonic) equipped with inverter technology provides a realistic control of the microwave power to a desirable level. We examined the effect of microwave power on a set of reactions using alkyl halides and MIM as reactants and found that operating the MW oven at reduced power level of 240 W afforded the highest yields. Upon microwave irradiation, the ionic liquid starts forming, which increases the polarity of the reaction medium thereby increasing the rate of microwave absorption. It is observed that at elevated power levels evaporation of alkyl halide and partial decomposition/charring of the ionic liquid occurs possibly owing to the localized overheating of ionic liquid, which eventually results in lower yields. To circumvent this problem, the reactions are conducted with intermittent heating and mixing at a moderate power level to obtain better yields and cleaner ionic liquid formation. After the first irradiation for 30 s at 240 W (~bulk temperature 70–100 °C) the homogeneity of the reaction mixture changes due to formation of a small amount of ionic liquid. The reaction mixture is then taken out, mixed again for 10 s, and then heated at same power level for additional 15 s. This process is repeated until the formation of a clear single phase is obtained. Thus, the formation of ionic liquid could be monitored visibly in the reaction as it turns from clear solution to opaque and finally clear. Any unreacted starting materials are removed by washing with ether, and the product is dried under vacuum at 80 °C.

This method is ideally suited for the preparation of ionic liquids with longer alkyl chains or with higher boiling points. Comparison of a series of ionic liquids prepared by MW heating and similar preparation using conventional heating (oil bath at 80 °C) is summarized in Table 1. Most of the halides used in this study have higher boiling points and are converted efficiently to ionic liquids under MW irradiation. The relatively less reactive and low boiling reactants such as 1-bromobutane incurred loss due to evaporation and require excess quantity for best results. The reactivity trend of halides is found

to be in the order $I^- > Br^- > Cl^-$. Highly reactive iodides afforded excellent yield of ionic liquids in all cases with minimum exposure time. In contrast, the conventional methods reported in the literature generally use a large excess of alkyl halide or tetrahydrofuran as solvents.

In view of the emerging interest in ionic liquids bearing polycations, we have prepared novel dicationic compounds (**2**) utilizing alkyl dihalides. The butyl and hexyl dicationic salts (entries 7–11, Table 1) are solids at room temperature. The corresponding octyl analogs with bromide/chloride as the anions are viscous liquids (entries 12 and 13, Table 1), whereas the iodo compound (entry 14, Table 1) is a solid. The NMR data shows that the dicationic salts generated from chloro and bromoalkanes (entries 7, 9, 10, 12, and 13, Table 1) are slightly contaminated with the corresponding monocationic intermediate (<5%). However, the diiodoalkanes, being reactive, expeditiously affords pure products. The purity of ionic salts prepared via MW heating are found to be superior to those prepared via conventional heating methods, presumably due to inefficient mixing in the latter, once the solid product (**2**) begins to form.

The TGA and DSC data show that all ionic liquids (Table 1) are pure and are free of any starting materials. These studies also establish that the compounds are thermally stable up to 280 °C and then start decomposing with complete decomposition occurring above 300 °C.

The use of 1,3-dialkylimidazolium cation bearing different anions as catalyst or supports for a variety of metal-catalyzed reactions has been explored. A combination of palladium chloride (0.5 mmol) and butylimidazolium tetrafluoroborate (0.25 g) is found to be effective for the solventless oxidation of styrene (100 mmol) with oxygen or hydrogen peroxide. The oxidation in presence of oxygen (10.3 bar) and carbon dioxide (10.3 bar) at 60 °C affords 77% conversion of styrene to acetophenone (43%) and benzaldehyde (Wacker reaction). The oxidation with hydrogen peroxide (30 mL), however, at 65 °C for 5 h under carbon dioxide pressure (20.8 bar) completely consumes styrene to afford enhanced selectivity for acetophenone (68%). The conditions for these reactions are being optimized at the present time.

We have also evaluated ionic liquids as a medium for the Suzuki coupling reaction, an important carbon–carbon bond formation reaction and recyclability of expensive palladium catalysts. High viscosity of the ionic liquid and more solubility of aryl boronic acids in ionic liquids compared to aryl halides results in the formation of self-coupled biphenyls as contaminants. The use of water as a co-solvent reduces the viscosity of the medium, improves the effective mixing of the reactants, thus affording higher yields of the products. However, we find the use of polyethylene glycol, an inexpensive and relatively nontoxic medium, to be much better than ionic liquids for Suzuki cross-coupling reaction [10].

Briefly, a solvent-free MW-assisted protocol is developed for the synthesis of mono and dicationic 1,3-dialkylimidazolium halides using an unmodified household MW oven, a method that precludes the usage of volatile organic solvents and is relatively much faster, efficient, and eco-friendly.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Ballard Mullins for the TGA and DSC analyses. V.V.N. is a postgraduate research participant at the National Risk Management Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Environmental Protection Agency.

REFERENCES

1. T. Welton. *Chem. Rev.* **99**, 2701 (1999).
2. J. S. Wilkes, J. A. Levinsky, R. A. Wilson, C. L. Hussey. *Inorg. Chem.* **21**, 1263 (1982).
3. A. E. Visser, R. P. Swatloski, R. D. Rogers. *Green Chemistry*, **2**, 1 (2000); A. E. Visser, R. P. Swatloski, W. M. Reichert, R. D. Rogers, R. Mayton, S. Sheff, A. Wierzbicki. J. H. Davis, Jr. *Chem. Commun.* 135 (2001).

4. A. J. Carmichael, D. M. Haddleton, S. A. F. Bon, K. R. Seddon. *Chem. Commun.* 1237 (2000).
5. J. S. Wilkes, M. J. Zaworotko. *J. Chem. Soc. Chem. Commun.* 965 (1992).
6. J. D. Holbrey and K. R. Seddon. *Clean Products Processes* **1**, 223 (1999); J. G. Huddleston, H. D. Willauer, R. P. Swatloski, A. E. Visser, R. D. Rogers. *Chem. Commun.* 1765 (1998).
7. P. Volker, W. Bohm, W. A. Herrmann. *Chem. Eur. J.* **6**, 1017 (2000).
8. For the recent commentary on the general utility of ionic liquids see: M. Freemantle. *Chem. Eng. News*, 1 January, p. 21 (2001); M. Freemantle. *Chem. Eng. News*, 15 May, p. 37 (2000).
9. R. S. Varma. In *Green Chemistry: Challenging Perspectives*, P. Tundo, P. T. Anastas (Eds.), pp. 221, Oxford University Press, Oxford (2000); R. S. Varma. *J. Heterocyclic Chem.* **35**, 1565 (1999); R. S. Varma. *Green Chemistry* **1**, 43 (1999); R. S. Varma. *Clean Products Processes* **1**, 132 (1999); R. S. Varma. *Pure Appl. Chem.* **73**, 193 (2001).
10. V. V. Namboodiri and R. S. Varma. *Green Chemistry* **3**, 146 (2001).