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N,N'-Dialkylimidazolium Dimethyl Phosphates – Promising Media and Catalysts at the Same Time for Condensation Reactions

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Authors' contributions

This work was carried out in collaboration between all authors. Author SB performed all analyses – spectroscopic, thermogravimetric and titrimetric analyses and determined the moisture content in ionic liquids. Authors LF and LK synthesized N,N'-dialkylimidazolium dimethyl phosphates and chlorides, as well as measured rates of condensation reactions. Author AZ designed the study, managed the literature searches and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

The objective of the current work is the elaboration of an alternative method for synthesis of *N,N'*-dialkylimidazolium dimethyl phosphates – ionic liquids useful both as media and catalysts for condensation reactions in organic synthesis. The proposed method consists of alkylation of 1-substituted imidazoles with 1-alkyl chlorides in a closed steel cylinder followed by treating of obtained imidazolium chlorides with trimethyl phosphate. Data of qualitative analyses made by ^{1}H NMR, quantitative analysis made by potentiometric titration, and thermal stability measured by thermogravimetry of these elaborated advanced materials are presented. Two successful examples of their use in the Knoevenagel condensation reactions are demonstrated.

Keywords: Ionic liquids; dimethyl phosphate anion; synthesis; condensation reaction.

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1. INTRODUCTION

The Knoevenagel condensation reaction is widely used in organic synthesis for the formation of C=C bond. The reaction is usually carried out in the medium of an organic solvent in the presence of a catalyst – a base or an acid [1,2]. Nowadays ionic liquids (ILs) increasingly replace organic solvents in the Knoevenagel reaction. They serve for the medium of the reaction in most cases due to well-known advantages compared to molecular liquids (organic solvents) – they are not volatile, they allow carrying out the condensation in a broad temperature interval, they can be used repeatedly without any purification, etc. [3-5]. Sometimes ILs may also serve as catalysts at the same time for condensation reactions [6]. ILs with acetate anion are used most frequently for condensation reactions [7,8], the ILs with other carboxylate anions or inorganic ions being very much less used [9–13].

Thermal and chemical stability, as well as the price are important characterizing parameters of ILs when they are used as reaction media or catalysts. Imidazolium ions are considered as the most stable among cations of ILs, and ILs with choline cation are regarded as the most advantageous economically. Acetate anion is the most frequently used among anions of ILs because of its excellent catalytic properties [8]. Unfortunately, ILs with acetate or other carboxylate anion are thermally less stable than other salts – they decompose at temperature above 120ºC [3-5]. ILs with dimethyl phosphate (DMP) anion are much more stable, they withstand heating to 290ºC if they have imidazolium cations [3,14]. Such ILs provide an opportunity to run organic synthesis at temperature interval from room temperature to at least 250℃.

Sometimes difficulties arise in preparing imidazolium dimethyl phosphates with long-chain substituents at N_1-atom by alkylation of 1-substituted imidazole with trialkyl phosphates, mainly due to problems concerning syntheses of pure corresponding *N*-alkyl imidazoles. An alternative method would allow avoiding the problem, and it is discussed in the present communication.

2. MATERIALS AND METHODS

2.1 Materials and Apparatus

2.1.1 ^{1}H NMR spectroscopy

Spectra of ILs and condensation products were registered in deuterated solvents on spectrometer *Bruker Fourier 300* and using the solvent as the internal standard.

2.1.2 Thermal stability

Thermogravimetric analysis (TGA) was made with the equipment *SII Extar6000 TG/DTA6300* starting from 30ºC and raising temperature 10ºC/min, the final temperature being 330ºC.

2.1.3 Moisture

Water content in ILs was analyzed with Karl Fisher automatized titrator 836 *Titrant Metrohm*. One-component titrant (reagent) *Hydranal-Composite 5 (Riede de Haën®)* was used, the highest possible systematic error of the analysis being ± 0.2%.

2.1.4 Potentiometric titration

Solvotrode (*Metrohm AG 9101 Herisau*) was used for non-aqueous titration.

2.1.5 Melting points

They were registered with the instrument *Stuart SMP3* (accuracy ± 0.1ºC).

2.2 Syntheses of Ionic Liquids

2.2.1 1,2,3-Trimethylimidazolium dimethyl phosphate (2a)

Trimethyl phosphate (8.41 g; 0.06 mol) was added drop by drop to the 1,2-dimethylimidazole (**1a**; 4.81 g; 0.05 mol) with vigorous stirring in a round-bottom flask. The mixture was stirred for 1 h at room temperature, then temperature was raised to 80℃. 10 mL of acetonitrile was added after 30 minutes, and the content of the flask was stirred at 80℃ for 48 hours. The hot solution was poured into a conical flask and left at room temperature for 24 hours. The precipitate formed was filtered, washed with ethyl acetate on the filter and dried in vacuum (0.5 mbar) during 6 hours after that. The IL (**2a**; 12.66 g; 91%) was obtained as white crystalline substance with m.p. 124-126℃.

^{1}H NMR spectrum: (300 MHz, DMSO-d_6, δ): 7.59 (2H, s, NCH=CHN); 3.75 (6H, s, CH_3N-$C(CH_3)$=NCH_3); 3.23 (6H, d, $P(OCH_3)_2$); 2.55 (3H, s, $NC(CH_3)N$) ppm.

2.2.2 1,3-Dimethylimidazolium dimethyl phosphate (2b)

2b (9.78 g; 88%) was obtained from 1-methylimidazole (**1b**; 4.10 g; 0.05 mol) in a similar way in form of a thick oil. ^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 9.36 (1H, s, CH_3N-CH=NCH_3); 7.73 (2H, d, NCH=CHN); 3.85 (6H, s, CH_3N-$C(CH_3)$=NCH_3); 3.26 (6H, d, $P(OCH_3)_2$) ppm.

2.2.3 1-Butyl-2,3-dimethylimidazolium chloride (3a)

1,2-Dimethylimidazole (**1a**; 9.61 g; 0.10 mol), 1-chlorobutane (12.03 g; 0.13 mol), magnetic stirrer, and ethyl acetate (6 mL) were placed in a sealed screw-top home-made steel pressure tube. The airproof tube was placed in a glycerol bath and stirred at 80℃ for 72 hours. Reaction mixture was poured in a round-bottom flask after cooling to room temperature and placed in the freezer for 24 hours. The obtained crystalline mass was filtered, washed with ethyl acetate (4 x 25 mL) on the filter, then dried under vacuum of rotary evaporator at 40ºC and after that under high vacuum (0.5 mbar) at 60ºC for 6 hours. The IL (**3a**; 23.34 g; 89%) was obtained as white crystalline substance with m.p. 93-94℃. ^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 7.63 (2H, s, NC<u>H</u>=C<u>H</u>N); 4.11 (2H, t, NC<u>H</u>$_2$-CH_2- CH_2- CH_3); 3.74 (3H, s, C<u>H</u>$_3$NCCH_3); 2.58 (3H, s, CH_3NCC<u>H</u>$_3$); 1.68 (2H, m, NCH_2-C<u>H</u>$_2$-CH_2-CH_3); 1.29 (2H, m, NCH_2-CH_2-C<u>H</u>$_2$-CH_3); 0.92 (3H, t, NCH_2-CH_2-CH_2-C<u>H</u>$_3$) ppm.

Other ILs with chloride anion (**3**) were obtained in a similar way; results of their syntheses and analyses are shown below and presented in Table 1.

2.2.4 1,2-Dimethyl-3-octylimidazolium chloride (3b)

Yield 92%.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 7.65 (2H, s, NC<u>H</u>=C<u>H</u>N); 4.10 (2H, t, NC<u>H</u>$_2$-CH_2-$(CH_2)_5$-CH_3); 3.75 (3H, s, C<u>H</u>$_3$NCCH_3); 2.58 (3H, s, CH_3NCC<u>H</u>$_3$); 1.69 (2H, m, NCH_2-C<u>H</u>$_2$-$(CH_2)_5$-CH_3); 1.25 (10 H, m, NCH_2-CH_2-$(CH_2)_5$-CH_3); 0.85 (3H, t, NCH_2-CH_2-$(CH_2)_5$-C<u>H</u>$_3$) ppm.

2.2.5 1-Dodecyl-2,3-dimethylimidazolium chloride (3c)

Yield 93%.^{1}H NMR spectrum (300 MHz, $CDCl_3$, δ): 7.76 (1H, d, NC<u>H</u>=CHN); 7.33 (1H, d, NCH=C<u>H</u>N); 4.15 (2H, t, NC<u>H</u>$_2$-CH_2-$(CH_2)_9$-CH_3); 4.02 (3H, s, C<u>H</u>$_3$NCCH_3); 2.76 (3H, s, CH_3NCC<u>H</u>$_3$); 1.81 (2H, m, NCH_2-C<u>H</u>$_2$-$(CH_2)_9$-CH_3); 1.27 (18 H, m, NCH_2-CH_2-$(CH_2)_9$-CH_3); 0.89 (3H, t, NCH_2-CH_2-$(CH_2)_9$-C<u>H</u>$_3$) ppm.

2.2.6 1-Butyl-3-methylimidazolium chloride (3d)

Yield 83%.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 9.19 (1H, s, N-CH=N); 7.72 (2H, s, NC<u>H</u>=C<u>H</u>N); 4.16 (2H, t, NC<u>H</u>$_2$-CH_2-CH_2-CH_3); 3.85 (3H, s, C<u>H</u>$_3$NC); 1.76 (2H, m, NCH_2-C<u>H</u>$_2$-CH_2-CH_3); 1.27 (2H, m, NCH_2-CH_2-C<u>H</u>$_2$-CH_3); 0.90 (3H, t, NCH_2-CH_2-CH_2-C<u>H</u>$_3$) ppm.

2.2.7 1-Methyl-3-octylimidazolium chloride (3e)

Yield 92%.^{1}H NMR spectrum (300 MHz, $CDCl_3$, δ):10.55 (1H, N-CH=N); 7.65-7.42 (2H, d, NC<u>H</u>=C<u>H</u>N); 4.23 (2H, t, NC<u>H</u>$_2$-CH_2-$(CH_2)_5$-CH_3); 4.04 (3H, s, C<u>H</u>$_3$NCCH_3); 1.82 (2H, m, NCH_2-C<u>H</u>$_2$-$(CH_2)_5$-CH_3); 1.15 (10 H, m, NCH_2-CH_2-$(CH_2)_5$-CH_3); 0.77 (3H, t, NCH_2-CH_2-$(CH_2)_5$-C<u>H</u>$_3$) ppm.

2.2.8 1-Dodecyl-3-methylimidazolium chloride (3f)

Yield 93%.^{1}H NMR spectrum (300 MHz, $CDCl_3$, δ): 10.56 (1H, s, N-CH=N); 7.65 (1H, d, NC<u>H</u>=CHN); 7.42 (1H, d, NCH=C<u>H</u>N); 4.23 (2H, t, NC<u>H</u>$_2$-CH_2-$(CH_2)_9$-CH_3); 2.09 (3H, s, C<u>H</u>$_3$NCCH_3); 1.82 (2H, m, NCH_2-C<u>H</u>$_2$-$(CH_2)_9$-CH_3); 1.16 (18 H, m, NCH_2-CH_2-$(CH_2)_9$-CH_3); 0.79 (3H, t, NCH_2-CH_2-$(CH_2)_9$-C<u>H</u>$_3$) ppm.

2.2.9 1-(2-Hydroxyethyl)-3-methylimidazolium chloride (3g)

Yield 87%.^{1}H-NMR spectrum (300 MHz, $CDCl_3$, δ): 9.52 (1H, s, N-CH=N), 7.53 (1H, d, CH_{arom}), 7.36 (1H, d, CH_{arom}), 4.34 – 4.29 (2H, m, CH_2O), 3.83 – 3.79 (m, 2H, CH_2N), 3.54 – 3.49 (m, 3H) ppm. ^{13}C-NMR spectrum (100 MHz, $CDCl_3$, δ): 137.29 (CH), 128.06 (CH), 122.77 (CH), 61.69 (CH_2), 46.03 (CH_2), 35.85 (CH_3) ppm.

2.2.10 1-Butyl-2,3-dimethylimidazolium dimethyl phosphate (4a)

1-Butyl-2,3-dimethylimidazolium chloride (18.67 g; 10.0 mmol) and trimethyl phosphate (35.02 g;

25.0 mmol) were placed in a 50 mL round-bottomed flask equipped with a reflux condenser and $CaCl_2$ drying tube. The obtained mixture was stirred at the 110ºC for 24 h. Toluene (5 x 10 mL) was added to the crude product and the mixture was vigorously stirred and heated to reflux for 10 minutes. The toluene layer was then decanted while hot. The procedure was repeated a further four times. Any remaining solvent was removed by rotary evaporation (10 mbar, 70ºC, 4 h). The pure product was dried under high vacuum (0.5 mbar, 70ºC, 8 h) and was subjected to $AgNO_3$ analysis to confirm the absence of a starting material. The dimethyl phosphate (**4a**; 24.13 g; 92%) was obtained as an oil that solidifies into a white crystalline substance with m.p. 92-93ºC during 24 h in a refrigerator.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 7.64 (2H, d, NC<u>H</u>=C<u>H</u>N); 4.13 (2H, t, NC<u>H</u>$_2$-CH$_2$-CH$_2$-CH$_3$); 3.74 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.23 (6H, d, P(OCH$_3$)$_2$); 2.58 (3H, s, CH$_3$NCC<u>H</u>$_3$); 1.67 (2H, m, NCH$_2$-C<u>H</u>$_2$-CH$_2$-CH$_3$); 1.29 (2H, m, NCH$_2$-CH$_2$-C<u>H</u>$_2$-CH$_3$); 0.92 (3H, t, NCH$_2$-CH$_2$-CH$_2$-C<u>H</u>$_3$) ppm.

Other ILs with dimethyl phosphate anion (**4**) were obtained in a similar way; results of their syntheses and analyses are shown below and presented in Table 1.

2.2.11 1,2-Dimethyl-3-octylimidazolium dimethyl phosphate (4b)

Yield 87%.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 7.65 (2H, s, NC<u>H</u>=C<u>H</u>N); 4.10 (2H, t, NC<u>H</u>$_2$-CH$_2$-CH$_2$-CH$_3$); 3.75 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.32 (6H, d, P(OCH$_3$)$_2$); 2.58 (3H, s, CH$_3$NCC<u>H</u>$_3$); 1.67 (2H, m, NCH$_2$-C<u>H</u>$_2$-(CH$_2$)$_5$- CH$_3$); 1.25 (10 H, m, NCH$_2$-CH$_2$-(C<u>H</u>$_2$)$_5$-CH$_3$); 0.86 (3H, t, NCH$_2$-CH$_2$-(CH$_2$)$_5$-C<u>H</u>$_3$) ppm.

2.2.12 1-Dodecyl-2,3-dimethylimidazolium dimethyl phosphate (4c)

Yield 92%.^{1}H NMR spectrum (300 MHz, $CDCl_3$, δ): 7.76 (1H, d, NC<u>H</u>=CHN); 7.33 (1H, d, NCH=C<u>H</u>N); 4.15 (2H, t, NC<u>H</u>$_2$-CH$_2$-(CH$_2$)$_9$-CH$_3$); 4.02 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.54 (6H, d, P(OCH$_3$)$_2$); 2.76 (3H, s, CH$_3$NCC<u>H</u>$_3$); 1.81 (2H, m, NCH$_2$-C<u>H</u>$_2$-(CH$_2$)$_9$- CH$_3$); 1.27 (18 H, m, NCH$_2$-CH$_2$-(C<u>H</u>$_2$)$_9$-CH$_3$); 0.89 (3H, t, NCH$_2$-CH$_2$-(CH$_2$)$_9$-C<u>H</u>$_3$) ppm.

2.2.13 1-Butyl-3-methylimidazolium dimethyl phosphate (4d)

Yield 98%.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 9.40 (1H, s, N-CH=N); 7.74 (2H, d, NC<u>H</u>=C<u>H</u>N); 4.17 (2H, t, NC<u>H</u>$_2$-CH$_2$-CH$_2$-CH$_3$); 3.86 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.26 (6H, d, P(OCH$_3$)$_2$); 1.75 (2H, m, NCH$_2$-C<u>H</u>$_2$-CH$_2$-CH$_3$); 1.27 (2H, m, NCH$_2$-CH$_2$-C<u>H</u>$_2$-CH$_3$); 0.89 (3H, t, NCH$_2$-CH$_2$-CH$_2$-C<u>H</u>$_3$) ppm.

2.2.14 1-Methyl-3-octylimidazolium dimethyl phosphate (4e)

Yield 93%.^{1}H NMR spectrum (300 MHz, $CDCl_3$, δ): 10.38 (1H, s, N-CH=N); 7.30 (2H, s, NC<u>H</u>=C<u>H</u>N); 4.16 (2H, t, NC<u>H</u>$_2$-CH$_2$-CH$_2$-CH$_3$); 3.96 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.49 (6H, d, P(OCH$_3$)$_2$); 1.78 (2H, m, NCH$_2$-C<u>H</u>$_2$-(CH$_2$)$_5$-CH$_3$); 1.25 (10 H, m, NCH$_2$-CH$_2$-(C<u>H</u>$_2$)$_5$-CH$_3$); 0.84 (3H, t, NCH$_2$-CH$_2$-(CH$_2$)$_5$-C<u>H</u>$_3$) ppm.

2.2.15 1-Dodecyl-3-methylimidazolium dimethyl phosphate (4f)

Yield 96%.^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 9.46 (1H, N-CH=N); 7.82 (1H, d, NC<u>H</u>=CHN); 7.75 (1H, d, NCH=C<u>H</u>N); 4.16 (2H, t, NC<u>H</u>$_2$-CH$_2$-(CH$_2$)$_9$-CH$_3$); 3.86 (3H, s, C<u>H</u>$_3$NCCH$_3$); 3.28 (6H, d, P(OCH$_3$)$_2$); 1.77 (2H, m, NCH$_2$-C<u>H</u>$_2$-(CH$_2$)$_9$- CH$_3$); 1.25 (18H, m, NCH$_2$-CH$_2$-(C<u>H</u>$_2$)$_9$-CH$_3$); 0.84 (3H, t, NCH$_2$-CH$_2$-(CH$_2$)$_9$-C<u>H</u>$_3$) ppm.

2.2.16 1-(2-Hydroxyethyl)-3-methylimidazolium dimethyl phosphate (4g)

Yield 97%.^{1}H-NMR spectrum (300 MHz, $CDCl_3$, δ): 9.41 (1H, s, N-CH=N), 7.57 (1H, s, CH_{arom}), 7.39 (1H, s, CH_{arom}), 6.67 (s, 1H, OH), 4.31 (2H, t, CH_2O), 3.78 (3H, s, CH_3N), 3.76 (2H, t, CH_2N), 3.50 (6H, d, OCH_3) ppm.

2.3 Quantitative Analyses of Ionic Liquids with Dimethyl Phosphate Anion

A sample of an ionic liquid (**2** or **4**) (~ 100 mg) was dissolved in glacial acetic acid (50 mL) and titrated with the solution of perchloric acid in glacial acetic acid (0.05 mol/L) in the equipment of potentiometric titration. The purity (content of the main substance, %) of the sample was calculated from obtained titration curves (Table 1).

2.4 Utilization of Ionic Liquids with Dimethyl Phosphate Anion in Condensation Reactions

2.4.1 Ethyl 2-cyano-3-(4-methoxyphenyl) propenoate (7a)

4-Methoxybenzaldehyde (**5a**; 0.68 g; 5 mmol), ethyl cyanoacetate (0.57 g; 5 mmol), 1-butyl-3-methylimidazolium dimethyl phosphate (**4d**; 1.32

g; 5 mmol) and magnetic stirrer were placed in a round-bottomed flask. The obtained mixture was stirred at 80℃ for 15 minutes, then cooled to room temperature and extracted with ethyl acetate (5 x 10 mL). The joint extract was dried with $MgSO_4$ for 16 h, filtered, organic layer evaporated to dryness in a rotary vacuum evaporator. Slightly yellow crystalline substance – technical product (**7a**, 1.09 g; 94%) was obtained. Pure product – ethyl 2-cyano-3-(4-methoxyphenyl)-propenoate (**7a**; 1.03 g; 89%) was obtained after crystallization from ethanol as a slightly yellow crystalline substance with m.p. 83-84 ℃. ^{1}H NMR spectrum (300 MHz, DMSO-d_6, δ): 8.19 (s,1H, HC=); 8.03 (d, 2H); 7.02 (d, 2H); 4.37(m, 2H); 3.91 (s, 3H); 1.41 (t, 3H) ppm.

2.4.2 Ethyl 2-cyano-3-(2,4-dimethoxyphenyl) propenoate (7b)

(**7b**; 1.18 g; 95%) was obtained in a similar way from 2,4-dimethoxybenzaldehyde (**5b**; 0.83 g; 5 mmol), ethyl cyanoacetate (0.57 g; 5 mmol) and 1-butyl-3-methylimidazolium dimethyl phosphate (**4d**; 1.32 g; 5 mmol) as a yellow crystalline substance with m.p. 141-142 ℃. ^{1}H NMR spectrum: (300 mHz, $CDCl_3$, δ): 8.71 (1H, s, =C-H), 8.41 (1H, d, C_{arom}-H); 6.62 (1H, d, C_{arom}-H); 6.46 (1H, d, C_{arom}-H); 4.35 (2H, m, OCH_2CH_3), 3.90 (6H, s, $CH_3OCCH{=}COCH_3$), 1.40 (3H, t, OCH_2CH_3) ppm.

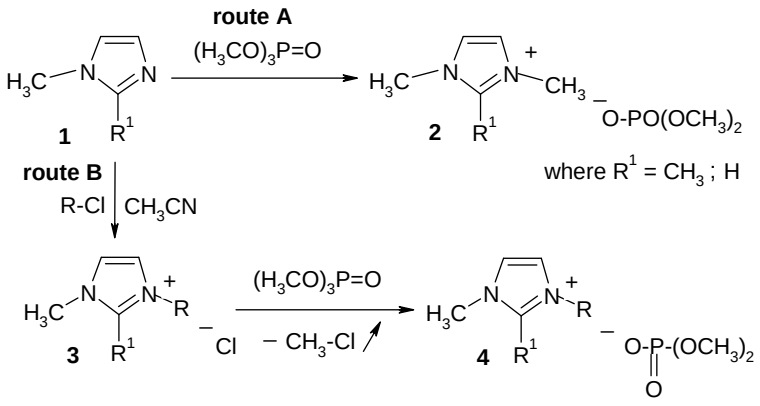
3. RESULTS AND DISCUSSION

ILs with dimethyl phosphate anion use to synthesize by alkylating tertiary amines with trialkyl phosphates, most often with trimethyl phosphate [14]. 1,2,3-Trimethyl- (**2a**) and 1,3-dimethyl imidazolium dimethyl phosphate (**2b**) were prepared in such a way also in our laboratory (route A, Scheme 1), just for comparison with the proposed in this communication synthesis. Yields of ILs **2** obtained by the well-elaborated known method were high (Table 1), the only limitation of the method being the availability of the necessary 1-substituted imidazole. The latter becomes problematic when imidazoles are needed with chains at nitrogen atom in the imidazole ring containing more than four carbon atoms or/and other functional groups, such as OH, OAlk, CN a.o.

Therefore, another method is discussed and proposed in this communication in order to supplement the existing method and to provide an opportunity for easy syntheses of different imidazolium salts (and ILs in general). The second method has appeared recently [15], and it is highly advantageous in cases when 1-substituted imidazoles are hard to get. This method foresees the preparation of ILs with a chloride anion with further alkylation of the chloride anion in the obtained salts with trimethyl phosphate (route B, Scheme 1). The advantage of such an approach is the possibility to use a well-known protocol for the synthesis of the necessary starting materials – corresponding 1-alkylimidazoles. We have only modified the old method a little by carrying out the alkylation reaction of 1-methyl imidazoles with 1-chloroalkanes in a tightly closed screw-top steel pressure tube. No inert gas is needed in this case for maintaining the quality of the product, and 1-chloroalkanes with low boiling temperatures can also be used.

1-Methyl- and 1,2-dimethylimidazoles (**1**) were alkylated by 1-chloroalkanes in the mentioned steel pressure tube in our laboratory at 80ºC during 72 h; the twofold molar excess of the alkylating reagent was applied. Expected imidazolium chlorides (**3**) have formed in high yields, and the excess of the reagent was removed by extracting the reaction mixture by ethyl acetate at the end. The obtained ILs with the chloride anion (**3**) (Table 1) were ready for use or for further transformations after careful drying in high vacuum (0.5 mbar, 60ºC, 6 h) and analysis (Scheme 1).

The second stage of the process (in the route B) – the exchange of the chloride ion for dimethyl phosphate anion (alkylation of chloride ion with trimethyl phosphate) was accomplished at 110ºC, the gas (CH_3-Cl) release accompanying it and providing the shift of the reaction equilibrium to the right. The negative $AgNO_3$ test together with the end of the evolution of gas allow fixing the end of the reaction. Complete conversion of the chloride ion can be ensured by using twofold molar excess of the alkylating reagent – trimethyl phosphate. There is no problem to get rid of the unreacted trimethyl phosphate – simple extraction of the reaction mixture by ethyl acetate followed by drying of the obtained product in high vacuum (0.5 mbar, 70ºC, 8 h) is sufficient. Obtained imidazolium dimethyl phosphates (**4**) were colorless or slightly yellow oils. ILs with methyl group in their cations at C_2-atom have crystallized after being kept in the fridge for several days while non-substituted at C_2-atom substances remained as thick oils. Yields of the chloride ion alkylation were high in all experiments (≥ 87%) (Table 1).



Scheme 1. Two different routes to obtain imidazolium dimethyl phosphates (2, 4)

Table 1. Investigated ionic liquids with dimethyl phosphate anions and their precursors

Ionic liquid			Anion	Yield,	m.p.,	Purity,	Water,	$T_{5\%dec}$,
No	**R**	**R^1**		**%**	**°C**	**%****	**%*****	**°C******
2a)	R = CH_3	CH_3	DMP*	93	124-126	99.6	0.33	290
2b)	R = CH_3	H	DMP	93	liquid	99.5	0.44	302
3a)	R = C_4H_9	CH_3	Cl	89	93-94			
3b)	R = C_8H_{17}	CH_3	Cl	92	liquid			
3c)	R = $C_{12}H_{25}$	CH_3	Cl	93	81-82			
3d)	R = C_4H_9	H	Cl	83	66-69			224
3e)	R = C_8H_{17}	H	Cl	92	liquid			
3f)	R = $C_{12}H_{25}$	H	Cl	93	126-127			
3g)	R = CH_2CH_2OH	H	Cl	87	85-86			
4a)	R = C_4H_9	CH_3	DMP	92	92-93	99.4	0.55	297
4b)	R = C_8H_{17}	CH_3	DMP	87	liquid	99.3	0.62	231
4c)	R = $C_{12}H_{25}$	CH_3	DMP	92	113-114	99.2	0.71	218
4d)	R = C_4H_9	H	DMP	98	liquid	99.5	0.43	315
4e)	R = C_8H_{17}	H	DMP	93	liquid	99.4	0.45	286
4f)	R = $C_{12}H_{25}$	H	DMP	96	liquid	99.2	0.60	261
4g)	R = CH_2CH_2OH	H	DMP	97	liquid	99.4	0.46	284

*Where: *DMP means dimethyl phosphate; **purity determined by potentiometric titration with perchloric acid in glacial acetic acid; ***water content (moisture) determined by Karl Fisher titration; **** decomposition temperatures ($T_{5\%dec}$) were determined by TGA from onset to 5 wt% mass loss, heating at 10°C min^{-1} under air*

Spectroscopic, titrimetric [16,17], and thermogravimetric methods were used for characterization of all obtained ILs. ^{1}H NMR spectroscopy was useful for the qualitative analysis (confirmation of structures) of ILs. ^{1}H NMR spectra contained all characteristic for imidazolium salts resonance signals (see Experimental), and the NMR data were consistent with literature data. The complete exchange of chloride ions was confirmed not only by above-mentioned negative $AgNO_3$ test but also by NMR data. For example, integral intensities of the resonance signals of protons of both O-CH_3 groups (6H) with δ 3.23-3.26 ppm were fully corresponding to those of protons C_4-H and C_5-H (2H) in the imidazolium cation ring with δ 7.73-7.81 ppm in the spectrum of 1-butyl-3-methylimidazolium dimethyl phosphate (**4d**) (Fig. 1).

Titration of ILs containing DMP anion with perchloric acid in glacial acetic acid according to our recently published method [17] was used for the quantitative analysis of ILs. The method presents excellent titration curves, and all obtained and carefully dried ILs have shown high purity (the content of the main substance in the product) – above 99% (Table 1).

ILs containing DMP anion (**2** and **4**) are highly hygroscopic substances, and they should be stored in tightly closed containers. The Karl Fisher titration method was used for the control of moisture content in obtained ILs. The water content has not exceed 1.0% in all analyzed samples (Table 1), but it is recommended to check the moisture content in ILs before their use, particularly in samples kept for longer time.

Thermogravimetric analysis (TGA) of ILs (**2, 4**) has also allowed appreciating the moisture content of ILs, albeit the analysis was mainly used as an indicator of the thermal stability of ILs. Our results have shown that investigated ILs have lost the attached moisture at temperatures ~ 105ºC, and their decomposition of 5% was observed only at temperatures ≥ 218ºC. Accordingly, ILs with DMP anion are considerably more stable substances than similar ILs with acetate anion even in cases when their cation contains long alkyl groups (C_8, C_{12}) at nitrogen atom. This property noticeably expands temperature interval for organic syntheses made in these ILs, including condensation reactions of both aldehydes and ketones with activated methylene compounds.

Just for demonstration of the usefulness of obtained ILs containing dimethyl phosphate anion, two Knoevenagel condensation reactions were tested – reactions of 4-methoxy-(**5a**) and 2,4-dimethoxybenzaldehyde (**5b**) with ethyl cyanoacetate (**6**) without any other catalyst. The selected aromatic aldehyde contained one or two methoxy groups and therefore had lower reactivity of C=O group by comparison with benzaldehyde, the last being usually tested as a substrate in similar condensations. IL with DMP anion (**4d**) itself has served both as the reaction medium and as the catalyst in these experiments.

Both condensation reactions have been fast reaching the conversion around 96% during first 15 minutes (Fig. 2). The aldehyde with two methoxy groups (**5b**) reacted somehow slower than another substrate (**5a**) with one methoxy group, as it was expected. The difference can well be observed by the comparison of both kinetic curves (Fig. 2).

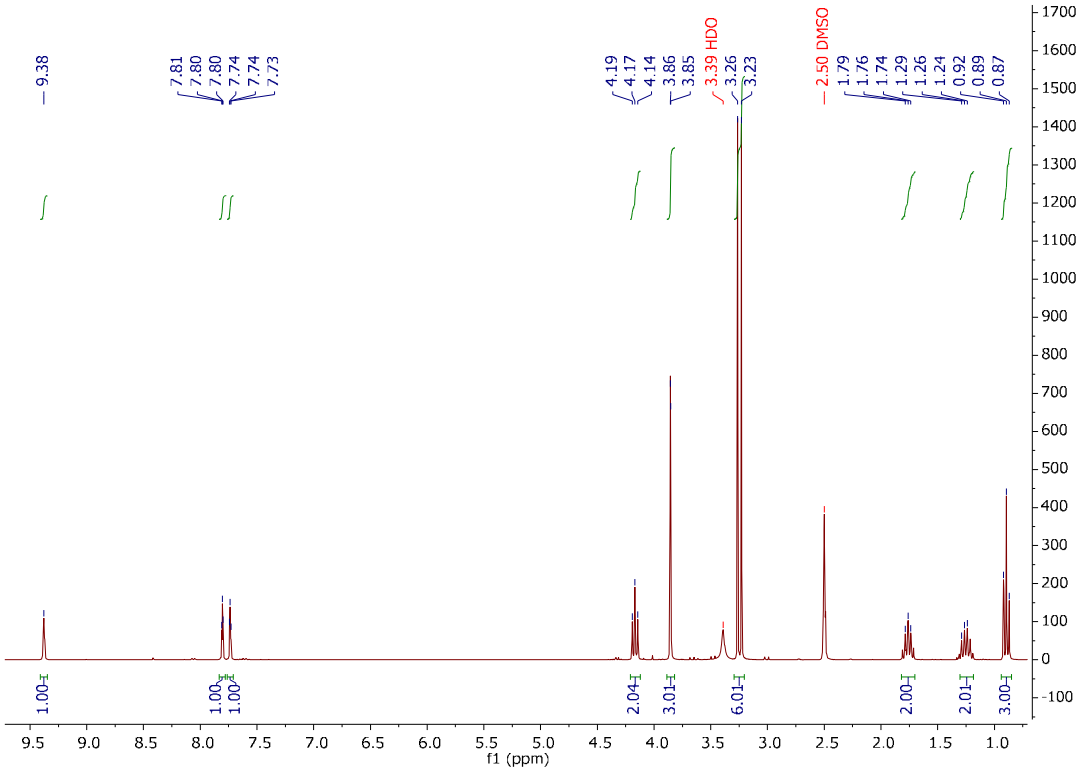
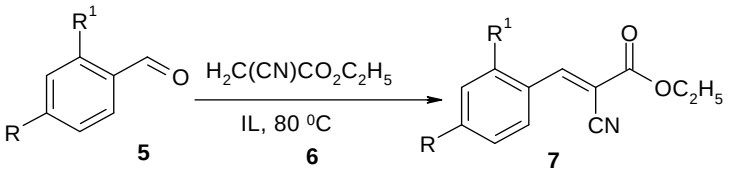


Fig. 1. ^{1}H NMR spectrum of 1-butyl-3-methylimidazolium dimethyl phosphate (4d)



where **5a**, 7**a** R = OCH_3, R^1 = H
5b, **7b** R = R^1 = OCH_3

Scheme 2. Condensation reactions of aromatic aldehydes containing electron donating groups (5) with ethyl cyanoacetate (6) in ionic liquid media

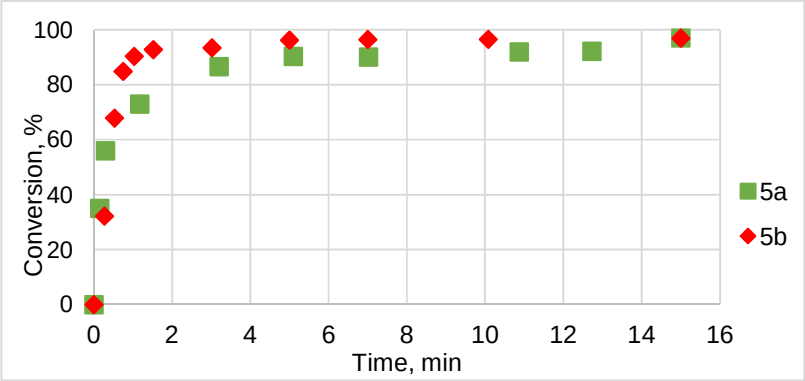


Fig. 2. Rates of condensation reactions of 4-methoxy- (5a) and 2,4-dimethoxybenzaldehyde (5b) with ethyl cyanoacetate in IL (4d) at 80℃

Thereby an attempt is made in this communication to expand synthetic possibilities of ILs with DMP anion – to use alkylation of chloride ion in imidazolium chlorides as an alternative route to the existing synthetic method of such ILs. Both methods together ensure the preparation of practically all ILs with DMP anions which are highly useful as media and catalysts at the same time for condensation reactions.

4. CONCLUSION

Alkylation of 1-substituted imidazoles with 1-chloroalkanes followed by another alkylation of the chloride ion of obtained imidazolium chlorides by trimethyl phosphate form a powerful alternative method for the preparation of ionic liquids with dimethyl phosphate anion to the well-known alkylation of 1-substituted imidazoles with trimethyl phosphate. The alternative method is particularly useful when some difficulties arise with the preparation of 1-alkyl imidazoles. Both methods together allow the preparation of every imaginable imidazolium dimethyl phosphate.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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