

새로운 이온용액의 제조 및 브롬화반응 응용

Hua Li*, Juan Liu, Jiang Zhu, and Hongkai Wang

School of Chemical and Energy Engineering, Zhengzhou University, Zhengzhou 450001, China

(접수 2011. 3. 5; 수정 2011. 4. 11; 게재확정 2011. 6. 5)

Preparation of Novel Ionic Liquids and Their Applications in Brominating Reaction

Hua Li*, Juan Liu, Jiang Zhu, and Hongkai Wang

School of Chemical and Energy Engineering, Zhengzhou University, Zhengzhou 450001, China. *E-mail: Lihua@zzu.edu.cn

(Received March 5, 2011; Revised April 11, 2011; Accepted June 5, 2011)

요약. 새로운 산성 이온용액인 1-(ω -sulfonicacid)propyl-3-methylimidazolium bromide ([HSO₃pmim]Br)과 1-(ω -sulfonicacid)-butyl-3-methylimidazolium bromide([HSO₃bmim]Br)을 제조하였다. 이 화합물들을 브롬화 시약 및 용매로 사용하여 100 °C, 2시간 반응시켰으며, 간단히 상분리에 의해 1,7-dibromoheptane을 95% 수율로 합성하였다. 이 산성 이온용액을 5회 재사용하였으나 수율 감소가 관찰되지 않았다.

주제어: 이온용액, 1,7-dibromoheptane; 브롬화 시약, 촉매

ABSTRACT. Novel acidic ionic liquids, 1-(ω -sulfonicacid)propyl-3-methylimidazolium bromide ([HSO₃pmim]Br) and 1-(ω -sulfonicacid)butyl-3-methylimidazolium bromide ([HSO₃bmim]Br), were prepared and used as brominating agents, catalysts and solvents in the synthesis of 1,7-dibromoheptane, respectively. 1,7-dibromoheptane with a yield of 95% was obtained at 100 °C for 2 h by simple phase separation. The acidic ionic liquid [HSO₃pmim]Br was recycled for 5 times and the yield of 1,7-dibromoheptane did not decrease remarkably, which indicates that catalysts still maintain good selectivity and activity after recycling. The structure of the acidic ionic liquid [HSO₃pmim]Br was characterized with IR, and it was found that [HSO₃pmim]Br had stronger acidity than other ionic liquid.

Keywords: Ionic liquid (IL), 1,7-dibromoheptane, Brominating agent, Catalyst

INTRODUCTION

1,7-Dibromoheptane, an important pharmaceutical intermediate, is widely applied in the fields of pharmacy, bionic chemistry, petroleum, food and cosmetics, being commonly used in drugs, chiral macrocyclic ligands, long-chain fatty alcohol, and the synthesis of cationic surfactants. In the traditional synthesis methods, PBr₃ or HBr or NaBr or *n*-bromosuccinimide (NBS) or dimethylbromosulfonium bromide (DMBS) is usually selected as the brominating agent.¹⁻³ However, there are many disadvantages in the above methods, such as pollution to environment, difficulty in product separation and corrosion to equipment. At present some new methods for synthesizing halogenated hydrocarbons have been reported,⁴⁻⁷ in which ionic liquids are chosen as halogenated agents and solvents, with organic or inorganic acids as catalysts. These methods can avoid toxicity and corrosion of traditional halogenated agents, but the resulting environmental pollution

still exists, because strong acids are still used as catalysts. To solve the above problems, in this paper, a novel ionic liquid, 1-(ω -sulfonicacid) alkyl-3-methylimidazolium bromide [HSO₃Rmim]Br, is designed and prepared. As we know, ionic liquids usually have many particular properties, such as nonvolatility and nonflammability, and some may have acidity or even superacidity, which allow them to be good solvents and catalysts. In this brominating reaction for preparation of 1,7-dibromoheptane, [HSO₃Rmim]Br has superacidity and is used simultaneously as brominating agent, catalyst and solvent. The reaction is considered as a green process with mild effects, in which a high product yield is reached, and the ionic liquid is easy to be recycled.

EXPERIMENTAL

Reagents and Instruments

Reagents, 1,7-Heptanediol, 1,7-dibromoheptane, *N*-

methylimidazolium, 1,3-propane sultone, 1,4-butane sultone, were all of AR grade and were obtained from ALDRICH Company with purities of 0.995 in mass fractions. CTAB, PBr_3 and HBr were obtained from Tianjin Chemical Reagent Co., Ltd., Nafion-CTAB/MCM-41 was prepared by us in the laboratory. Deionized water was used.

The GC spectrum of 1,7-dibromoheptane was tested by GC9800 gas chromatograph (Shanghai Gas Chromatograph Co., Ltd); IR spectrum was tested by Shimadzu IR2408; The ^1H NMR was tested by Bruker DPX-400 NMR Spectrometer.

Preparation of $[\text{HSO}_3\text{pmim}]\text{Br}$

The synthesis process of $[\text{HSO}_3\text{pmim}]\text{Br}$ can be seen in Fig. 1. Firstly, 1-(ω -sulfonates) propyl-3-methylimidazolium (2) was synthesized according to the procedures previously published.⁸ Secondly, the resulting white compound (2) was dissolved in deionized water, after which, equimolar hydrobromic acid was added in incremental drops at room temperature, and then the temperature was increased to 70°C and the reaction was performed at 70°C for 3 h. After this reaction, the mixture was extracted by dichloromethane 3 times, and the extracts were consolidated and carefully evaporated to remove dichloromethane with a vacuum evaporator. The final solution was dried in a vacuum at 60°C for 12 h and then $[\text{HSO}_3\text{pmim}]\text{Br}$ (3) was obtained. Ionic liquid $[\text{HSO}_3\text{bmim}]\text{Br}$ was prepared in the same way.

Preparation of 1,7-dibromoheptane

The synthesis of 1,7-dibromoheptane is shown in Fig. 2. 1,7-Heptanediol and $[\text{HSO}_3\text{pmim}]\text{Br}$, with a mole ratio of 1:2.5~3, were mixed and added into a 3-neck round bottom flask, and the reaction was run under the protection of N_2 at 100°C for 1~2 hours. After the reaction was com-

pleted, the solution became two phase, the organic phase and the aqueous phase could be separated by simple phase separation, and the aqueous phase which contains 1-(ω -sulfonates)propyl-3-methylimidazolium (2) and unreacted $[\text{HSO}_3\text{pmim}]\text{Br}$ was treated to recycle $[\text{HSO}_3\text{pmim}]\text{Br}$. In fact, to increase yield of product, the solution was washed by deionized water as soon as the system was cooled to room temperature, then the solution was extracted by cyclohexane to obtain the organic phase. Cyclohexane was evaporated from the organic phase and recycled, and the product 1,7-dibromoheptane was obtained. The purity of 1,7-dibromoheptane analyzed by gas chromatography is greater than 98% and the yield is 95%.

Regeneration and recycling of $[\text{HSO}_3\text{pmim}]\text{Br}$

Seen from Fig. 2, it can be found that $[\text{HSO}_3\text{pmim}]\text{Br}$ has been consumed and transformed to 1-(ω -sulfonates) propyl-3-methylimidazolium (2); (2) and unreacted $[\text{HSO}_3\text{-pmim}]\text{Br}$ are in the aqueous phase. To regenerate $[\text{HSO}_3\text{pmim}]\text{Br}$, a certain amount of hydrobromic acid is added to the aqueous phase to make sulfonate (2) transform to $[\text{HSO}_3\text{pmim}]\text{Br}$. And then the following post-treatment are the same as the procedures 1.2 and the process of regeneration and recycling is shown in Fig. 3.

The characterization of $[\text{HSO}_3\text{pmim}]\text{Br}$

The IR spectra of $[\text{HSO}_3\text{pmim}]\text{Br}$ is shown in Fig. 4. As seen in Fig. 4, waves 1195 and 1044 cm^{-1} are the characteristic absorption peaks of $-\text{SO}_3^-$, and waves 3435 cm^{-1} is the characteristic absorption peak of $-\text{OH}$. Then the characteristic absorption peaks of C-H bonds in imidazole ring are at waves 3154 and 3110 cm^{-1} . C=C and C=N bonds have the characteristic absorption peaks at waves 1638 and 1575 cm^{-1} respectively.

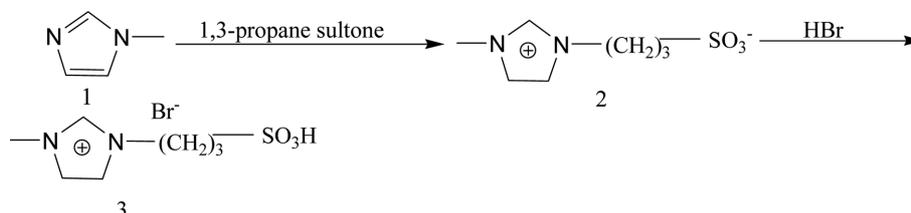


Fig. 1. Synthesis of $[\text{HSO}_3\text{pmim}]\text{Br}$.

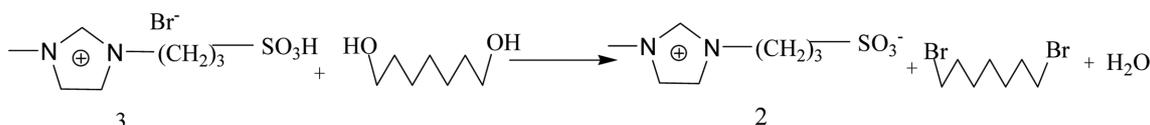


Fig. 2. Synthesis of 1, 7-dibromoheptane with $[\text{HSO}_3\text{pmim}]\text{Br}$.

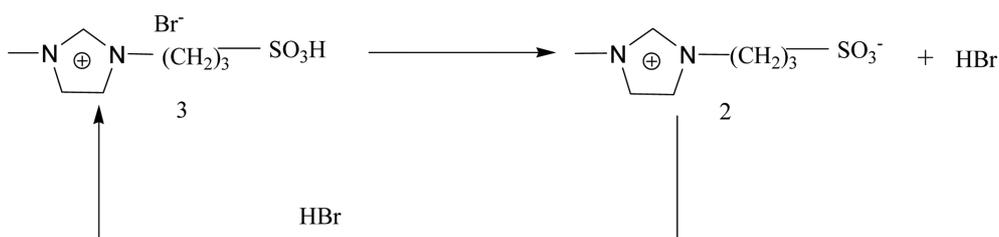


Fig. 3. Regeneration and recycling of [HSO₃pmim]Br.

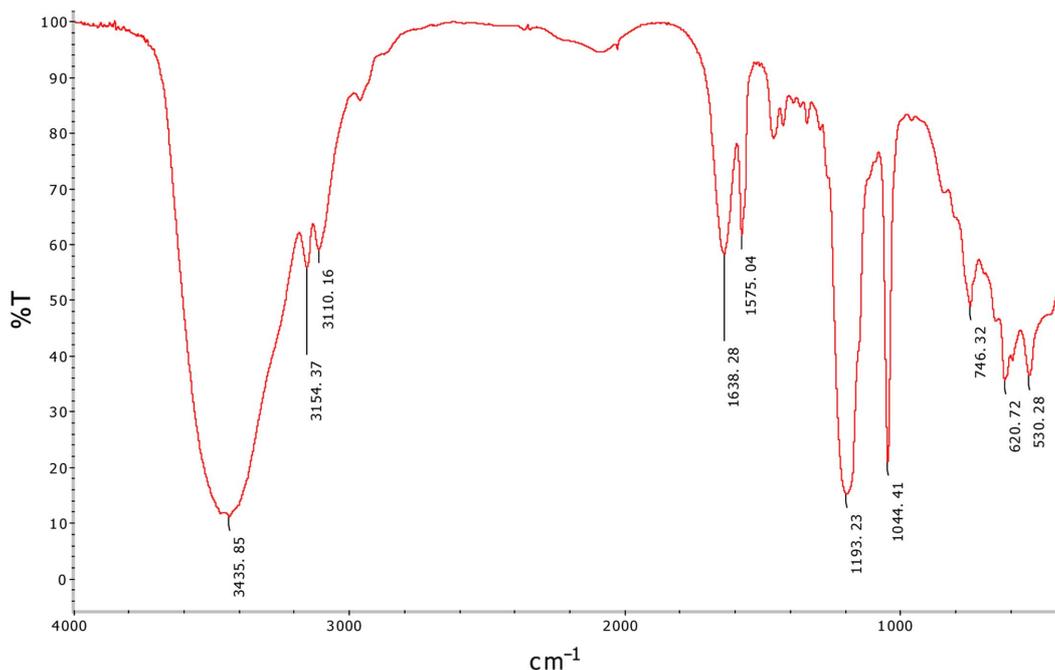


Fig. 4. The IR spectra of [HSO₃pmim]Br.

Analysis of 1,7-dibromoheptane

The purity of 1,7-dibromoheptane is analyzed by gas chromatograph. During the analysis, the chromatographic conditions are as follows:

- Instrument type: GC9800TFP
- Classification No.: 070321
- Column temperature: 170 °C
- Column pressure: 0.43 MPa
- Vaporization temperature: 270 °C
- Hydrogen pressure: 0.25 MPa
- Measured temperature: 270 °C
- Atmospheric pressure: 0.03 MPa
- Instrument attenuation: 1/1
- Detector: FID
- Sample: 1,7-dibromoheptane
- Sensitivity: 2
- Concentration: 0.05 μL
- Aux gas: 0.04 MPa
- Class of carrier gas: N₂

Gas chromatographic column: SE-54 30 m×0.53

RESULTS AND DISCUSSION

Comparison of yields under different conditions

Synthesis of 1,7-dibromoheptane under different reaction conditions was studied. During the synthesis, different brominating agents, such as PBr₃, HBr, [HSO₃pmim]Br and [HSO₃bmim]Br were used; different catalysts, such as H₂SO₄, hexadecyl trimethyl ammonium bromide (CTAB), [HSO₃pmim]Br, [HSO₃bmim]Br and CTAB-Nafion/MCM-41 mesoporous molecular sieve were also used; different solvents, such as H₂O, [HSO₃pmim]Br and [HSO₃bmim]Br was chosen. CTAB could be chosen as the catalyst, because the reaction of synthesizing 1,7-dibromoheptane was a nucleophilic substitution reaction, and cationic surfactants could increase the reaction rate.⁹ CTAB-Nafion/MCM-41 mesoporous molecular sieve was selected as the catalyst, mainly for its strong acidity and the lower cor-

Table 1. The comparative yields of 1,7-dibromoheptane under different reaction conditions

No.	brominating agent	catalyst	solvent	yield, %
1	PBr ₃	-	-	76
2	HBr	-	H ₂ O	74
3	HBr	H ₂ SO ₄	H ₂ O	90
4	HBr	CTAB	H ₂ O	76
5	HBr	H ₂ SO ₄ +CTAB	H ₂ O	95
6	HBr	Nafion-CTAB/MCM-41	H ₂ O	83
7	[HSO ₃ pmim]Br	[HSO ₃ pmim]Br	[HSO ₃ pmim]Br	95
8	[HSO ₃ bmim]Br	[HSO ₃ bmim]Br	[HSO ₃ bmim]Br	93

Note: All reactions were conducted at 100, reaction time was 2 h, 3 equivalent of brominating agent, plus 1 equivalent of 1,7-heptanediol.

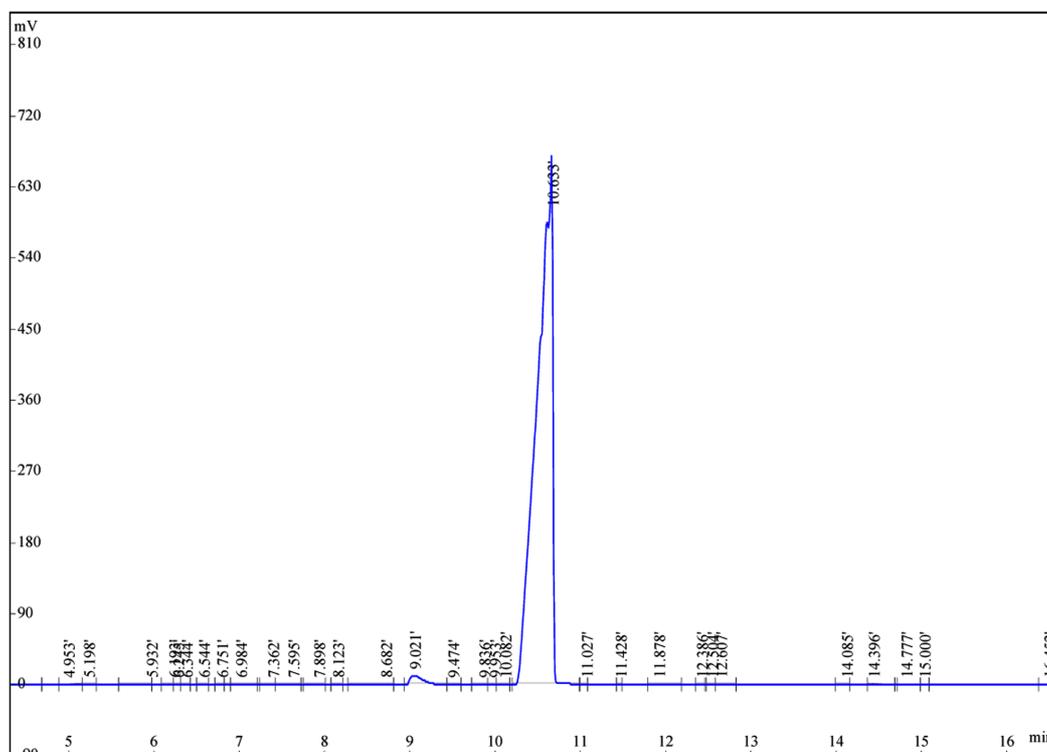
rosion. Then the comparative yields of 1,7-dibromoheptane under different reaction conditions are shown in *Table 1*.

It can be seen from *Table 1* that novel ionic brominating agents have a stronger reactive ability than ordinary covalent ones, which indicates Br⁻ of novel ionic brominating agents have a greater nucleophilic ability. From the experimental results of No.3 to No.6, it is shown that in the halogenated reaction of primary alcohol, the hydroxyl group is firstly protonated, because strong acids benefit removal of the hydroxyl group, thus, strong acids can be used as the catalysts.¹⁰ Then a nucleophilic substitution reaction is performed, in which cationic surfactants can

also enhance the reaction rate. Moreover, in the halogenated reaction of primary alcohol, the novel ionic liquid [HSO₃Rmim]Br serves as bromination agent and catalyst as well as solvent; therefore both the reaction rate and the yield can be increased greatly.

Analysis of 1,7-dibromoheptane

Gas chromatogram of 1,7-dibromoheptane: Standard gas chromatogram of 1,7-dibromoheptane and the gas chromatogram of 1,7-dibromoheptane we synthesized can be seen in *Fig. 5* and *Fig. 6* respectively. By comparing the areas of peaks as well as the locations of peaks, the product obtained is obviously high in purity.

**Fig. 5.** Gas chromatogram of 1,7-dibromoheptane standard.

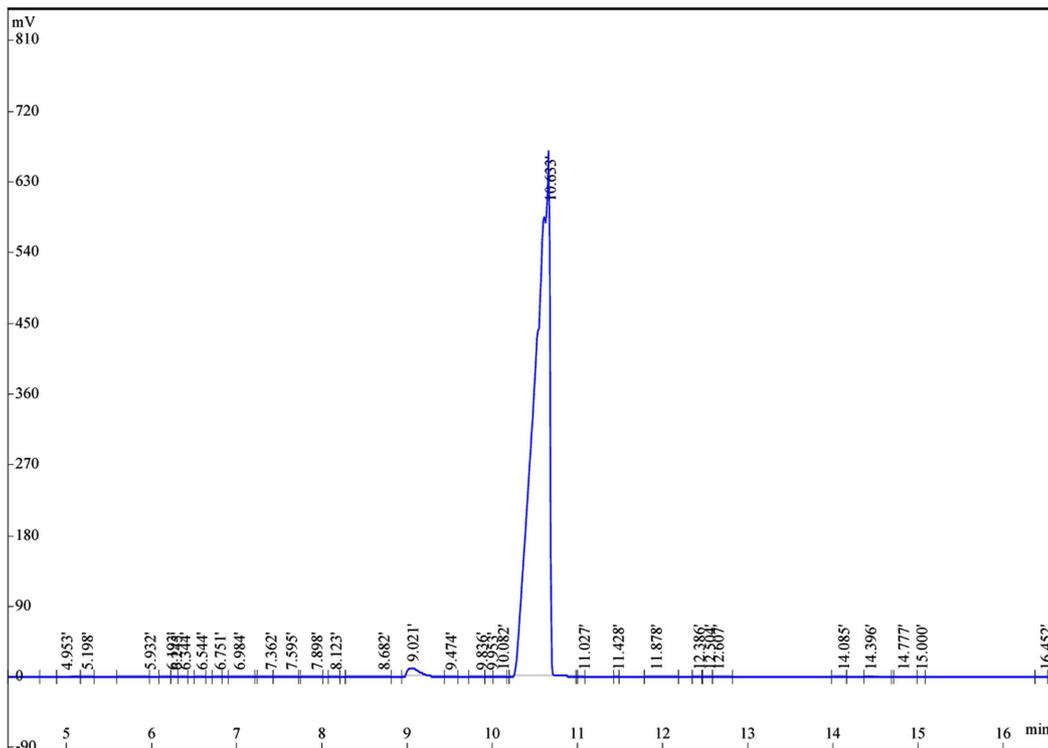


Fig. 6. Gas chromatogram of 1,7-dibromoheptane product.

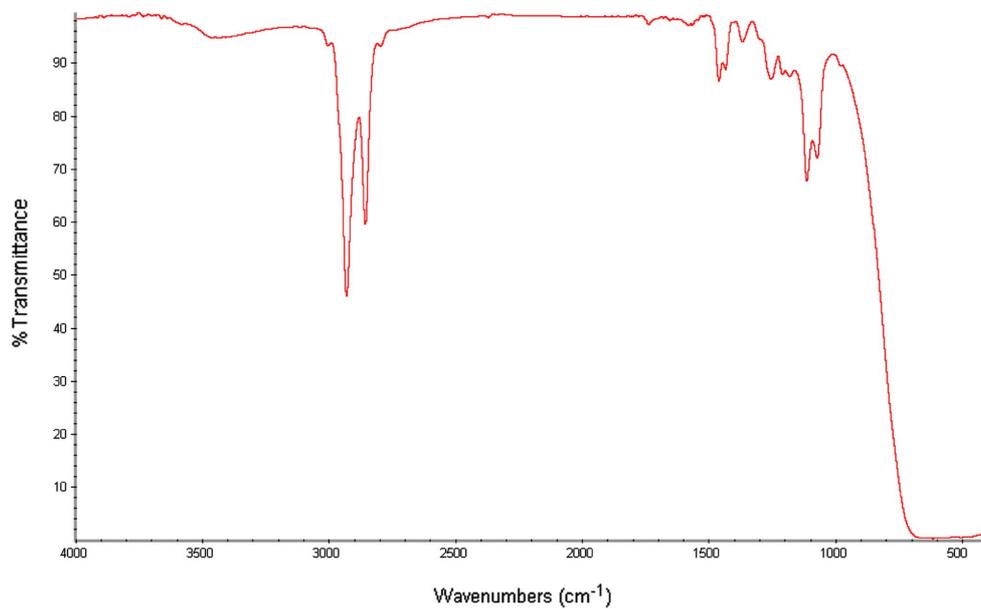


Fig. 7. The IR spectrum of 1,7-dibromoheptane prepared with ionic liquids.

IR spectrum of 1,7-dibromoheptane: The IR spectrum of 1,7-dibromoheptane is shown in Fig. 7. As seen in Fig. 7, wave 2930 cm^{-1} indicates the asymmetric stretching vibration of methylene, while wave 2858 cm^{-1} indicates the symmetric stretching vibration of methylene. Waves

1460 cm^{-1} and 1230 cm^{-1} are the flexural vibration of methylene and carbon-hydrogen bonds in $-\text{CH}_2\text{-Br}$ respectively.

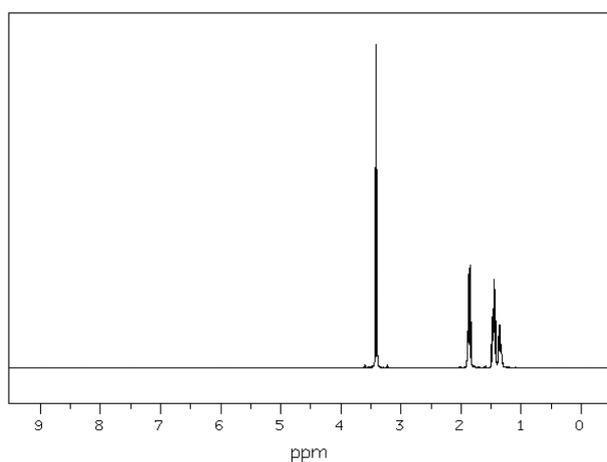


Fig. 8. ^1H NMR spectrum of prepared 1,7-dibromoheptane with ionic liquids.

Table 2. The analysis results of ^1H NMR spectrum for the prepared 1,7-dibromoheptane

Characteristic functional groups	Chemical Shift δ , ppm
A	3.41
B	1.86
C	1.45
D	1.35

In Table 2, what do "A, B, C and D" stand for are as follows:

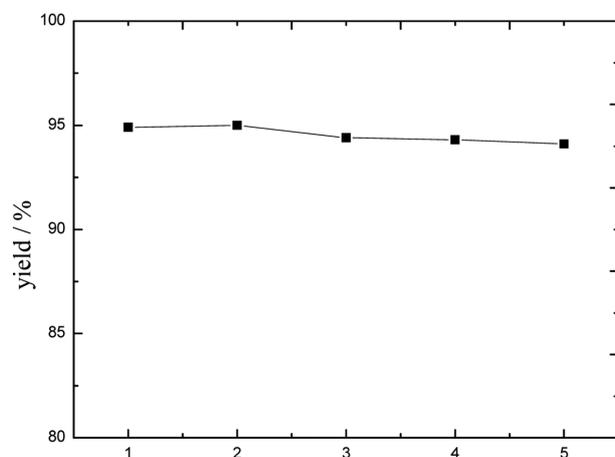
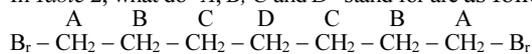


Fig. 9. The effect of the recycled catalysts on the brominating reaction.

^1H NMR spectrum of 1,7-dibromoheptane: ^1H NMR spectrum of the prepared 1,7-dibromoheptane is shown in Fig. 8, and the spectrum analysis results are shown in Table 2.

Recycling of ionic liquids

Under optimum conditions, the recycling of catalyst $[\text{HSO}_3\text{pmim}]\text{Br}$ is studied, and the results are shown in Fig. 9. As seen in Fig. 9, the yield of 1,7-dibromoheptane

decreases from 95% to 94% after the catalyst was recycled five times, which indicates that catalysts still maintain good selectivity and activity after recycling.

CONCLUSIONS

Novel ionic liquid, 1-(ω -sulfonicacid)alkyl-3-methylimidazolium bromide $[\text{HSO}_3\text{Rmim}]\text{Br}$, can serve as a nucleophilic reagent in the brominating reaction, because it has higher reactive activity and lower corrosion than the traditional brominating agents, namely, it is a stable and environmentally friendly catalyst.

Novel ionic liquid, 1-(ω -sulfonicacid)alkyl-3-methylimidazolium bromide $[\text{HSO}_3\text{Rmim}]\text{Br}$, serves a brominating agent, a catalyst and a solvent in the brominating reaction.

Novel ionic liquid, 1-(ω -sulfonicacid)alkyl-3-methylimidazolium bromide $[\text{HSO}_3\text{Rmim}]\text{Br}$, serves as a green solvent. It can also greatly simplify the 1,7-dibromoheptane separation process, because the solution becomes two phase after reaction, then the organic phase containing 1,7-dibromoheptane can be separated by simple phase separation, and the aqueous phase which contains 1-(ω -sulfonates)propyl-3-methylimidazolium and unreacted $[\text{HSO}_3\text{pmim}]\text{Br}$ is chemically treated to recycle $[\text{HSO}_3\text{pmim}]\text{Br}$.

Novel ionic liquid, 1-(ω -sulfonicacid)alkyl-3-methylimidazolium bromide $[\text{HSO}_3\text{Rmim}]\text{Br}$, can be recycled, the yield of 1,7-dibromoheptane remains constant after the catalyst is recycled five times, which indicates that catalysts still maintain good selectivity and activity after recycling.

REFERENCES

- Wang, Q. A. *Advanced Organic Chemistry*; Chemical Industry Press: Beijing, 2004; p 158.
- Vogel, A. *Textbook of Practical Organic Chemistry*, 4th ed.; Longman Group Limited, London, 1978; pp 391-384.
- Arbuzov, A. E. *J. Russ. Phys. Chem. Soc.* **1906**, 38, 687.
- Nicholas, E. L.; Hanna, M. T. *Tetrahedron* **2003**, 59, 2253.
- Nguyen, H. P.; Plamen, K., *et al. Journal of Molecular Catalysis A: Chemical* **2004**, 218, 41.
- Ren, R. X.; Wu, J. X. *Organic Letter* **2001**, 3, 3727.
- Tong, J.; Sun, J.; *et al.* Method of converting primary alcohol and cyclohexanol into alkyl halide in acid ionic liquid $[\text{Hmim}]^+\text{X}^-(\text{X}=\text{Cl}, \text{Br}, \text{I})[\text{P}]$. CN:1440958, 2003-9-10.
- Cole, A. C.; Jensen, J. L. *J. Am. Chem. Soc.* **2002**, 124, 5962.
- Pine, S. H. *Organic Chemistry*; McGraw-Hill: New York, 1980, 108.
- Zhao, Z. Z. *The Catalysis of Emulsion and Micelle*; Chemical Industry Press: Beijing, 2006; p 10.