Pergamon

Tetrahedron Letters 44 (2003) 981–983

TETRAHEDRON
LETTERS

Selective alkylation of phenol with *tert*-butyl alcohol catalyzed by [bmim]PF_6

Hao-Yu Shen,* Zaher M. A. Judeh and Chi Bun Ching

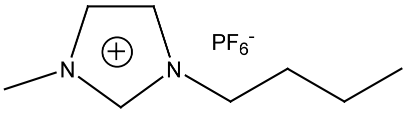
Chemical and Process Engineering Centre, National University of Singapore, 10 Kent Ridge Crescent, Singapore 117576

Received 1 November 2002; revised 22 November 2002; accepted 29 November 2002

Abstract—Alkylation of phenol with *tert*-butyl alcohol (TBA) in a room temperature ionic liquid, 1-butyl-3-methylimidazoliumhexafluorophosphate ([bmim]PF_6), has been investigated. The effects of various parameters such as reaction temperature, reaction time, reactant ratio (mol ratio of phenol to that of TBA), and the amount of the ionic liquid used were studied. The [bmim]PF_6 ionic liquid was found to catalyze the reaction with high conversion and good selectivity. © 2003 Elsevier Science Ltd. All rights reserved.

1. Introduction

The alkylation of phenol with *tert*-butyl alcohol is of both industrial importance and academic relevance. The alkylated phenol products are used as raw materials for the manufacture of a variety of resins, durable surface coatings, varnishes, wire enamels, printing inks, surface-active agents, rubber chemicals, antioxidants, fungicides and petroleum additives.[1–5] Investigation of both homogeneous and heterogeneous catalysts for this typical Friedel–Crafts alkylation reaction resulted in different selectivities and activities based mainly on the acidity of the catalysts employed. Catalysts used for this reaction include Lewis acids, Brønsted acids,[6] montmorillonite,[7] cation-exchange resins,[8] mesoporous materials,[1] zeolites,[2,3] molecular sieves,[5] as well as supercritical and near-critical water.[4] Room temperature ionic liquids (ILs)[9] such as [bmim]PF_6 **1** are finding growing applications as alternative reaction media for separations and organic transformations.[10–13] The desirable advantages of ionic liquids such as lack of vapor pressure, wide liquid range and thermal stability have made them exceptional reaction media and environmentally benign solvents. They are especially promising solvents for catalysis where activity, selectivity, and stability of catalysts are enhanced (Scheme 1).



[bmim]PF_6 **1**

Scheme 1. [bmim]PF_6 **1**.

The alkylation reaction of phenol with *tert*-butyl alcohol is an acid-catalyzed reaction. The product selectivities are largely dependent on the acidity and the temperature of the reaction system. Weakly acidic catalysts lead to mainly oxygen alkylated products (phenyl alkyl ether, *t*-BPE). The presence of the phenolic hydroxyl group (–OH) on the aromatic ring kinetically favours *o*-alkylation (*o*-isomer, e.g. *o*-TBP). However, due to steric hindrance, the thermodynamically unfavoured *o*-isomer (*o*-TBP) readily isomerizes into the less hindered, *p*-isomer (*p*-TBP), especially under moderate acidic conditions. When strong acidic catalysts are used, 2,4-DTBP is predominant. Strong acidic catalysts or high reaction temperatures produce *m*-TBP, which is formed by the secondary isomerization of the initially formed *o*- and/or *p*-isomers. It is interesting to note that [bmim]PF_6 is an acidic ionic liquid, which is expected to be advantageous for the chosen reaction.[9]

In this paper we report an efficient preparation of *tert*-butyl phenols through alkylation of phenol with TBA catalyzed by [bmim]PF_6 **1** ionic liquid. The effects of some important variables, like reaction temperature, reactant ratio and the amount of the ionic liquid used on the activity and selectivity are investigated. The present work revealed that ionic liquid [bmim]PF_6 **1** has potential applications in the synthesis of *tert*-butyl phe-

---

Keywords: phenol; alkylation; ionic liquid; *o*-TBP; *p*-TBP; 2,4-DTBP.

* Corresponding author. Tel.: +65-8744217; fax: +65-68734805; e-mail: shen_haoyu@ices.a-star.edu.sg

PII: S0040-4039(02)02740-5

nols with excellent conversion and good selectivity towards 2,4-DTBP.

2. Results and discussion

The alkylation experiments were carried out in sealed tubes at a given temperature. At the end of the reaction the tubes were cooled, the products were extracted from the ionic liquid using light petroleum and quantified (mol%) by gas chromatography (GC, HP-6890).

In the present study, alkylation of phenol with *tert*-butyl alcohol in [bmim]PF_6 gave a mixture of *o*-TBP, *p*-TBP and 2,4-DTBP. No phenyl ethers or *m*-TBP were produced even at high phenol conversions. Phenyl ethers and *m*-TBP were produced when CCl_4 was used as a solvent for this reaction.[14] A major advantage for the use of an ionic liquid for this reaction is that the phenol conversion was higher than those reported in the literature.[1–5] In the present study, 2,4-DTBP was isolated as the major product with selectivity greater than 75%. The results suggested that the medium for this reaction is strongly acidic.

Figure 1 shows the relative activity and product selectivity in ionic liquid as a function of reaction time for the alkylation of phenol with TBA at 60°C with a molar ratio of phenol to TBA of 1:2 (based on phenol). Figure 1 also shows clearly that the catalyst activity and product selectivity reached an equilibrium level after 4 h. Therefore, all the experimental data were obtained within the initial 4 h of the reaction.

The effect of temperature change on the conversion of phenol was studied in the temperature range of 40–80°C. At temperatures lower than 40°C, no products were observed. As can be seen from Figure 2, the conversion of phenol increased with an increase in temperature from 50 to 70°C. In contrast, at reaction temperatures above 70°C, a decrease in phenol conversion was observed. Therefore, the suitable reaction temperature range was inferred to be from 50 to 70°C. As the temperature was raised from 40 to 70°C, a decrease in the selectivity for the *o*- and *p*-TBP was observed. Interestingly, an increase in the selectivity for 2,4-DTBP was observed. Considering the phenol conversion and product distribution, the optimum reaction temperature was inferred to be 60°C. At this reaction temperature, the selectivity for 2,4-DTBP is the highest at high phenol conversions.

A series of reactions were carried out to establish the effect of reactant ratio on the conversion and selectivity under exactly the same conditions (at 60°C for 4 h using 0.5 ml of ionic liquid per 10 mmol phenol) except using variable amounts of TBA (5, 10, 20, 30, 40 mmol) while keeping the amount of phenol constant at 10 mmol. The results are shown in Figure 3. It was observed that as the amount of TBA increases, the conversion of phenol and selectivity for 2,4-DTBP passed through a maximum, while the selectivity for *o*- and *p*-TBP passed through a minimum. The maximum phenol conversion was observed when three times the TBA concentration based on phenol was used. However, the highest selectivity for 2,4-DTBP was observed when the mol ratio of phenol:TBA was 1:2. In order to achieve the highest selectivity for 2,4-DTBP without compromising the high conversion of phenol, all further experiments were carried out with the mol ratio of phenol to TBA being 1:2, i.e. 20 mmol TBA per 10 mmol phenol.

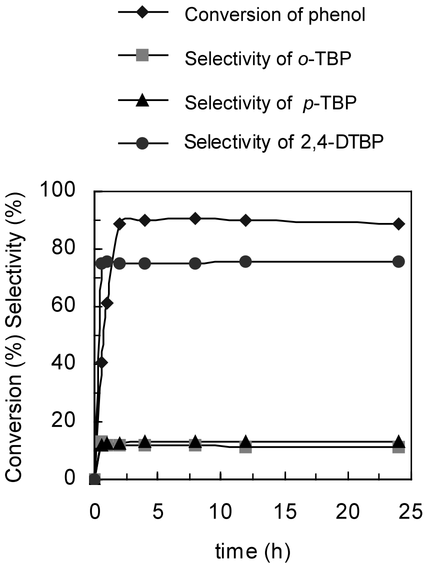


Figure 1. Phenol conversion and product selectivity versus reaction time. *Conditions*: phenol:TBA (1:2) mol ratio; 60°C, 0.5 ml ionic liquid (10 mmol phenol).

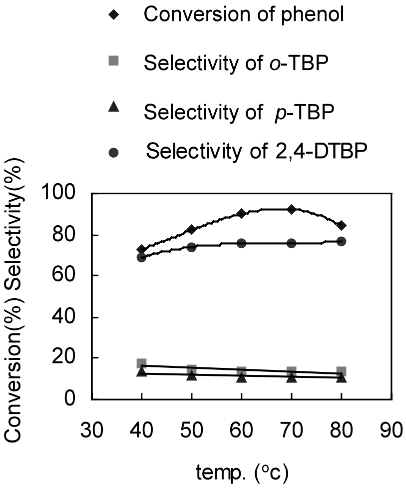


Figure 2. Phenol conversion and product selectivity versus reaction temperature. *Conditions*: phenol:TBA (1:2) mol ratio; 4 h, 0.5 ml ionic liquid (10 mmol phenol).

The effect of the amount of ionic liquid on the reaction was studied by varying the quantity of ionic liquid (0.1, 0.25, 0.5, 0.75, 1.0 1.5 ml/10 mmol phenol). The reactions were carried out under similar reaction conditions as described previously. As shown in Figure 4, it was observed that with an increase in the proportion of

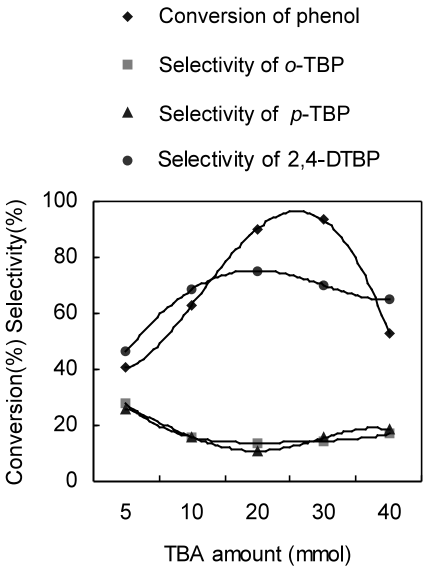


Figure 3. Phenol conversion and product selectivity versus amount of TBA added. *Conditions*: 60°C; 4 h, 0.5 ml ionic liquid (10 mmol phenol).

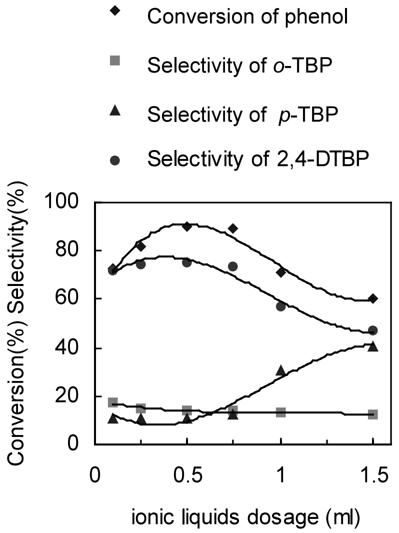


Figure 4. Phenol conversion and product selectivity versus amount of ionic liquid. *Conditions*: phenol:TBA mol ratio, 1:2; 60°C; 4 h.

ionic liquid, the conversion of phenol and selectivity for 2,4-DTBP passed through a maximum and then decreased as the usage of ionic liquid was increased. However, the selectivity for *o*-TBP also decreased slightly. Interestingly, when more than 0.5 ml of ionic liquid was used, the selectivity for *p*-TBP increased rapidly. The highest conversion of phenol and the best selectivity for 2,4-DTBP were obtained when the amount of ionic liquid used was 0.5 ml per 10 mmol phenol.

In conclusion, alkylation of phenol with *tert*-butyl alcohol in an ionic liquid was successful. The optimum reaction conditions for this reaction were a molar ratio of 1:2 of phenol to *tert*-butyl alcohol, 0.5 mmol ionic liquid per 10 mmol phenol, 60°C for 4 h. The present study shows that ionic liquid has a potential application in the production of *tert*-butyl phenols with high activity and 2,4-DTBP selectivity.

It should be noted that the decomposition of $[PF_6]^-$ in the presence of water produces HF. In this case issues such as safety and corrosion should be taken into account.[15] Also, additional efforts and costs should be considered to avoid the liberation of toxic and corrosive HF into the environment.

Acknowledgements

We would like to thank the National University of Singapore (NUS) and the Agency for Science, Technology and Research (A*STAR) for financial support.

References

1. Sakthivel, A.; Badamali, S. K.; Selvam, P. *Micropor. Mesopor. Mater.* **1985**, *39*, 457–463.
2. Krishnan, A. V.; Ojha, K.; Pradhan, N. C. *Org. Proc. Res. Dev.* **2002**, *6*, 132–137.
3. Zhang, K.; Zhang, H.; Xua, G.; Xiang, S.; Xu, D.; Liu, S.; Li, H. *Appl. Catal. A: Gen.* **2001**, *207*, 183–190.
4. (a) Chandler, K.; Deng, F.; Dillow, A. K.; Liotta, C. L.; Eckert, C. A. *Ind. Eng. Chem. Res.* **1997**, *36*, 5175–5179; (b) Sato, T.; Sekiguchi, G.; Adschiri, T.; Arai, K. *Chem. Commun.* **2001**, *17*, 1566–1567.
5. Sumbramanian, S.; Mitra, A.; Satyanarayana, C. V. V.; Chakrabarty, D. K. *Appl. Catal. A: Gen.* **1997**, *159*, 229–240.
6. Sartori, G.; Bigi, F.; Casiraghi, G.; Carnati, G.; Chiesi, L.; Arduini, A. *Chem. Ind.* **1985**, *22*, 762–763.
7. Tateiwa, J.; Hayama, E.; Nishimura, T.; Uemura, S. *Chem. Lett.* **1996**, *1*, 59–60.
8. Chandra, K. G.; Sharma, M. M. *Catal. Lett.* **1993**, *19*, 309–317.
9. Wasserscheid, P.; Keim, W. *Angew. Chem., Int. Ed.* **2000**, *39*, 3772–3789.
10. (a) Judeh, Z. M. A.; Ching, B. C.; Bu, J.; McCluskey, A. *Tetrahedron Lett.* **2002**, *43*, 5089–5091; (b) Judeh, Z. M. A.; Shen, H. Y.; Chi, B. C.; Feng, L. C.; Selvasothi, S. *Tetrahedron Lett.* **2002**, *43*, 9381–9384.
11. Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457–2483.
12. Chauvin, Y.; Olivier, H.; Mubmann, L. FR 95/14,147, 1995, 9.
13. DeCastro, C.; Sauvage, E.; Valkenberg, M. H.; Holderich, W. F. *J. Catal.* **2000**, *196*, 86–94.
14. Corma, A.; Garcia, H.; Primo, J. *J. Chem. Res.* **1988**, *1*, 40–41.
15. Wasserscheid, P.; Van Hal, R.; Bösmann, A. *Green Chem.* **2002**, *4*, 400–404.