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A polymer onium acting as phase-transfer catalyst in halogen-exchange fluorination promoted by microwave

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Abstract

A polymerized quaternary ammonium salt polydiallyldimethylammonium chloride, exhibiting high stability to heat and base, was prepared and applied as phase-transfer catalyst (PTC) in halogen-exchange (Halex) fluorination of chloronitrobenzenes to give excellent yields of corresponding fluoronitrobenzenes. Dimethyl sulfoxide was found to be the best solvent when microwave was applied as heating resource.

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1. Introduction

Halogen-exchange (Halex) fluorination is an important method to prepare fluorinated aromatics. To accelerate the reaction between KF and substrates, phase-transfer catalyst (PTC) is often used. But quaternary ammonium salts containing β-H are prone to decompose to certain degree under Halex fluorination conditions [1]. At the same time, by-products derived from the decomposition would worsen the reaction greatly. To solve these problems, Yoshida grafted *N*-(2-ethylhexyl)-4-(*N*′,*N*′-dimethyl)aminopyridinium bromide on polystyrene to get a polymer PTC with a relative molecular weight of near 1000 $g{\cdot}mol^{-1}$ [2]. Subsequently, he and co-workers developed divinylbenzene across linked polystyrene supported tetraphenylphosphonium bromide and its modified analogue by replacing active hydrogen by methyl group [3]. The two polymers would not decompose obviously even at 210 °C. Herein, we report another efficient and stable polymer onium PTC to act as phase-transfer catalyst in halogen-exchange fluorination under the irradiation of microwave.

2. Results and discussion

As we know, efficient and stable PTC should have big relative molecular weight, stable structure and big polarity. So, we think it may be a polymer with cyclic structure. For the sake of convenience for preparation, polydiallyldimethylammonium chloride (**1**) was found to be the best candidate. It was prepared by polymerization of diallyldimethylammonium chloride according to reference [4] (Scheme 1).

As shown in Scheme 1, polymer **1** has a big density of catalytic active component. We reason that it should have high phase-transfer activity. At the same time, the catalytically active part is a five-membered ring, which provide it high stability. And fortunately these were proved by our experimental results.

1 is a very hygroscopic yellowish polymer with an average relative molecular weight of about $2 \times 10^5\ g{\cdot}mol^{-1}$. It would convert to a liquid when exposed to air for only 1 min. Furthermore, it is almost unsolvable in some polar aprotic solvents such as Me_2SO, sulfolane, $HCONMe_2$, $MeCONMe_2$ and *N*-methylpyrrolidone. So, the Halex reaction is a solid (**1**)–solid (KF)–liquid (solution of substrates) triphase procedure. To the best of our knowledge, it is the first time that **1** is used as PTC in Halex reaction. **1** is so hygroscopic that it is usually stored as solution in water; so, it is necessary to to dry it thoroughly before use. At first, its solution is dried at 100 °C in common oven,

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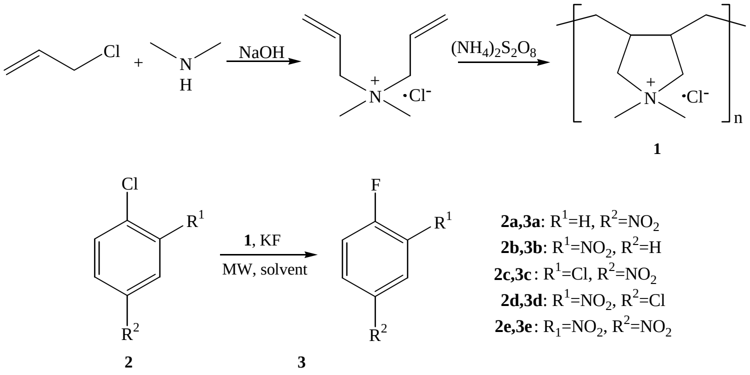


Scheme 1.

then grinded to fine powder and further dehydrated at 100 °C in vacuum for 10 h, and finally stored in desiccator. To examine its stability to heat, 0.33 g of **1** was added in 20 ml Me_2SO and refluxed for 6 h to find no obvious change. 2.19 g of KF was added in this system and refluxed for another 6 h to find almost the same phenomenon. So, **1** is very stable to heat and base. When **1** was used as phase-transfer catalyst in the halogen-exchange fluorination of *p*-chloronitrobenzene (PCNB), only 3 h was needed to complete the reaction and 90.1% *p*-fluoronitrobenzene (PFNB) was obtained. In a control experiment, only 86.8% PFNB yielded after 6 h and some tar appeared when cetyltrimethylammnoium bromide was used.

The application of microwave in organic synthesis was found its beginning by Gedye et al. [5] for esterization and have been developing very rapidly from then on. Some authors reported that the fluorination by radioactive elemental fluorine under microwave irradiation could be accelerated tremendously [6–8]. Kidwai et al. [9] got similar results when using KF and $(Me)_4NF$ as fluorinating agent. But they applied only in a very small scale and reacted in sealed tubes. In this work, microwave irradiation was applied to promote Halex fluorination in common scale.

Table 1
Preparation of PFNB catalyzed by **1** in 350 W microwave

Solvent	Time (h)	Yield (%)	Conversion (%)
Me_2SO	2	92.5	99.7
	1.5	90.3	99.0
$HCONMe_2$	2	6.0	7.2
$MeCONMe_2$	2	31.5	38.2
N-Methylpyrrolidone	2	40.6	61.9
Sulfolane	2	46.2	70.9

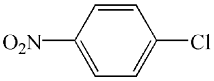
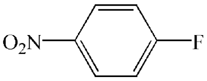
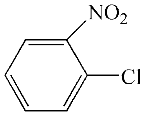
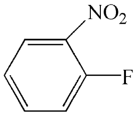
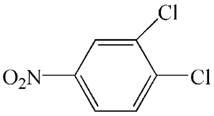
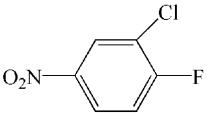
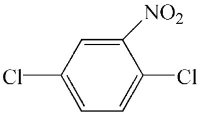
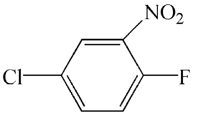
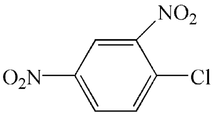
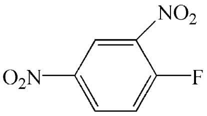
To our surprise, sulfolane and *N*-methylpyrrolidone, excellent solvents in traditional preparation, did not increase the conversion of PCNB but rather decreased it (Table 1). In fact, the final reaction mixture was viscous, filtered to get a saturated solid, washed twice by benzene and changed to brownish. The filtrate was distilled by steam to get nut-brown mother liquids with considerable amount of tar or dispersed black powder. It is known that superheating of liquid is sure to occur when microwave was used as heating resource [10], and so are these solvents according to this work (Table 2). The boiling point increment at the same conditions obviously followed linear plot against dielectric constant with a correlation coefficient of 0.998 (Fig. 1).

The superheating phenomenon made excessively high reaction temperature when sulfolane and *N*-methylpyrrolidone, which would promote the decomposition, were used as solvents. Some evidences were found in blank experiments that sulfolane and *N*-methylpyrrolidone would darken their color gradually to nut-brown and brown, respectively, when refluxed in microwave field. The former changed to black and obviously some fine black grit appeared at the bottom of the vessel after 2 h. Anhydrous fluoride is such a strong base in this system that it can extract proton from solvents, which is a main factor for the formation of a series of by-products [11]. To prove this, 3 g of KF was added in 20 ml of fresh sulfolane and refluxed in 700 W microwave for 2 h. A black, viscous and effluvial system was gotten and some one fifth

Table 2
Superheating phenomenon of some solvents (50 ml) heated by microwave

Solvents	Dielectric constant	bp in oil (°C)	bp in microwave (°C)	bp increment (°C)
$HCONMe_2$	36.71	153	161	8
$MeCONMe_2$	37.78	166	174	8
Me_2SO	48.9	189	199	10
Sulfolane	43.3	287	296	9
N-Methylpyrrolidone	32.0	204	211	7

Table 3
Preparation of Ar–F catalyzed by **1**

Entry	Substrate (2)	Heating resource	Solvent	Time	Product (3)	Yield (%)
a		350 W (MW)	Me_2SO	2 h		92.5
b		200 °C (oil bath) 300 W (MW)	Me_2SO Me_2SO	3 h 3 h		90.1 60.5
c		200 °C (oil bath) 350 W (MW)	Me_2SO Me_2SO	5 h 10 min		51.1 94.5
d		200 °C (oil bath) 350 W (MW) 190 ° (oil bath)	Me_2SO Me_2SO Me_2SO	1 h 15 min 30 min		88.6 58.0 41.2
e		200 W (MW) 110 °C (oil bath)	Acetonitrile Acetonitrile	2 h 10 h		89.2 80.5

of total mixture solidified to coke-like thing. It was obvious that decomposition was reinforced by KF. It seemed that the decomposition of solvents changed to be the main reaction at elevated boiling point since much lower conversion of substrates were resulted in comparison with Me_2SO (Table 1). In a word, Me_2SO is the best solvent for microwave-promoted Halex reaction.

In order to identify its catalytic activity, **1** was used to catalyze the preparation of a series of fluoronitrobenzenes from corresponding chloronitrobenzenes (Table 3).

The results shown in Table 3 illustrated that **1** was an efficient and stable PTC for Halex reaction, and the application of microwave irradiation accelerated the reaction rate for several times and the yields of products were also elevated. At the same time, very small tar and light color of reaction system were observed in experiments. "Non-heat effect" has being presumed to be the reason for the rate enhancement by a great number of authors. And we have also found the kinetic functions of common and microwave-promoted fluorination following different reaction orders in our further research. But, it is beyond the scope of this paper.

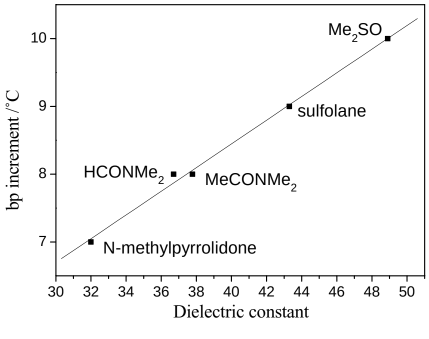


Fig. 1.

3. Conclusion

A stable polymerized quaternary ammonium salt polydiallyldimethylammonium chloride was developed to act as efficient and stable phase-transfer catalyst in halogen-exchange fluorination to prepare fluoronitrobenzenes with good yields. The application of microwave enhanced the reaction rate several times. Superheating phenomenon showed that sulfolane and *N*-methylpyrrolidone, excellent solvents for traditional fluorination, were not fit for microwave-promoted fluorination any longer.

4. Experimental

4.1. General

Spray-dried KF was further dried in vacuum at 150 °C for 15 h before use. All solvents were subjected to re-distillation and dried over 4A molecular sieve for at least 1 week.

Sanle WHL07S-1 chemistry-oriented microwave oven, designed by the author, was made in Nanjing Sanle Microwave Technology Development Co. Ltd., and the temperature was measured by Reytek® infrared thermometer.

Products were inspected by Varian 3700 gas chromatograph, Varian Saturn 2000 GC/MS chromatograph and Bomenn MB1543 FT-IR chromatograph (KBr). The IR and MS spectra of products were identical with authentic standard spectra.

4.2. Preparation of polydiallyldimethylammonium chloride (*1*)

To a mixture of 30 ml of dimethylamine (35.8 wt.%) and 37 ml of allyl chloride was added 22.4 g of solution of NaOH (40%) at 15 °C with agitation; after 10 min, the system was heated to 40 °C and maintained for 6 h. The final mixture was filtered and 6 ml of water was added, and finally distilled under reduced pressure to get rid of volatile by-products. Consequently, the residue was diluted by water to 48.4 g to get a solution of diallyldimethylammonium chloride. At 60 °C in N_2 atmosphere, 33 g of solution of $(NH_4)_2S_2O_8$ (4%) in water was added evenly into the above solution within 2 h and reacted for further 6 h. **1** was recovered by a yield of 92.3%.

4.3. Typical experimental procedure for the preparation of fluoronitrobenzenes

4.3.1. Preparation of ***3a–d*** from ***2a–d***

To a solution of 25 mmol of chloronitrobenzenes (**2a–d**) in 20 ml of Me_2SO was added 0.33 g of **1** and 37.5 mmol of KF, then heated by microwave with violently stirred for certain time, cooled down to less than 40 °C and filtered; the residue was washed by 2 × 10 ml of benzene, filtrate and lotion were combined to undergo steam distillation. Organic layer was separated and water layer extracted by 3 × 20 ml of benzene. The organic layer and extraction were combined and benzene was removed by simple distillation. Pure products was obtained by rectification under reduced pressure. Traditional heating reaction was all the same except for being heated by oil bath.

4.3.2. Preparation of 2,4-dinitrofluorobenzene(***3e***) from 2,4-dinitrochlorobenzene (***2e***)

4.05 g of 2,4-dinitrochlorobenzene, 0.37 g of **1**, 1.75 g of KF and 0.28 g of urotropine, acting as polymerizing inhibitor, were added in 20 ml acetonitrile, heated by 200 W microwave for 2 h, then cooled down to room temperature and filtered. The filtrate was examined by GC directly. Traditional reaction was all the same except that the mixture was refluxed in oil bath.

References

[1] J. Clark, D.K. Smith, Chem. Soc. Rev. 28 (1999) 225–231.

[2] Y. Yoshida, Y. Kimura, Tetrahedron Lett. 30 (1989) 7199–7202.

[3] Y. Yoshida, Y. Kimura, M. Tomoi, Chem. Lett. (1990) 769–772.

[4] W.C. Qu, Master's degree dissertation, Nanjing University of Science & Technology, Nanjing, 1998, p.12.

[5] R. Gedye, F. Smith, K. Westaway et al., Tetrahedron Lett. 27 (1986) 279–282.

[6] O.R. Hwang, S.M. Moerlein, L. Lang, J. Chem. Soc., Chem. Commun. 21 (1987) 1799–1801.

[7] S. Stone-Elander, N. Elander, Appl. Radiat. Isot. 42 (1991) 885–887.

[8] S. Stone-Elander, N. Elander, Appl. Radiat. Isot. 44 (1993) 889–893.

[9] M. Kidwai, P. Sapra, K. Ranjan, Indian J. Chem. 38B (1999) 114–115.

[10] Z. Wang, Research on Behavior of Gas, Liquid and Solid in Microwave Field, PhD Dissertation, Jilin University, Cangchu, 1994, p. 51.

[11] D.V. Adams, J.H. Clark, D.J. Nightingale, Tetrahedron 55 (1999) 7725–7738.