

# Effect of organic electrolyte on chloromethylation of 2-bromoethylbenzene in micellar catalytic system

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## Abstract

A small amount of organic electrolyte tetrabutylammonium bromide (TBAB) was added into the micellar catalysis system in which chloromethylation reaction of 2-bromoethylbenzene (BrEtBz) was carried out, and the effect of TBAB on the catalytic reaction was investigated. The decrease in critical micelle concentration (CMC) and the increase in solubilization of BrEtBz in the micelles formed by surfactant and TBAB were observed. The chloromethylation reaction of BrEtBz exhibited higher conversion and higher selectivity for mono-chloromethylation in the surfactant micelles containing TBAB than in the single surfactant micelle. The mechanism of chloromethylation reaction and the synergistic mechanism between organic electrolyte (TBAB) and three types of surfactants were discussed.

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**Keywords:** Organic electrolyte; Micellar catalysis; 2-Bromoethylbenzene; Chloromethylation

## 1. Introduction

2-Bromoethylbenzyl chloride (BEBC), especially the para-isomer, is a promising key intermediate for fine-chemicals, pharmaceuticals, polymers, etc. [1–5], because of its easy transformation to many chemicals. BEBC is mainly prepared by chloromethylation of 2-bromoethylbenzene (BrEtBz) in the presence of chloromethyl methyl ether and/or bis-chloromethyl ether (or reagent combinations which can result in the formation of these ethers) and Lewis acid [6–8]. Selectivity and yield of the mono-chloromethyl derivatives are determined by the consecutive formation of the polychloromethylation byproducts, and the formation of diphenylmethane derivatives and other byproducts, because of the Friedel–Crafts alkylation catalyzed by the same Lewis acid [9], and are often not so high [7]. Moreover, the hazards associated with these chloromethylethers are apparently so severe that classical procedures for the direct or indirect chloromethylation under Friedel–Crafts conditions are essentially no longer used, and other methods have been employed in order to develop alternative procedures which do not utilize extremely hazardous materials, but with no real success

[10]. Micelles composed of surfactant molecules are the simplest of the aggregates to locally concentrate both lipophilic and hydrophilic reactants near them by micellar solubilization and electrostatic forces, often resulting in dramatic increases in reaction rates [11–13]. In addition, micellar catalysis can make reaction conditions gentle, can effectively avoid side reactions to occur, and enhance the efficiency of organic synthesis. At present, micellar catalysis has been applied in various organic syntheses, such as electrophilic substitution reaction, nucleophilic substitution reaction, oxidation reaction, hydrolysis and so on [14–22]. The objectives of the present work are to perform chloromethylation of BrEtBz catalyzed by micelles in aqueous surfactant solutions to avoid the formation of carcinogenic chloromethylethers [23], and to compare the effect in the presence and the absence of organic electrolyte on chloromethylation of BrEtBz in the micellar catalytic system.

## 2. Experimental

### 2.1. Materials

Tetrabutylammonium bromide (TBAB), cetyltrimethylammonium bromide (CTAB), sodium dodecyl sulfonates (SDS) and nonylphenol polyoxyethylene ether (NP-10) purchased from Aldrich Chemical Co., Inc. were of analytical grade and

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used without further purification. 2-Bromoethylbenzene and other reagents employed were commercial samples (ACS grade) and used without further purification. Distilled water was used for all the reactions.

## 2.2. Determination of critical micelle concentration

While a small amount of electrolyte was added into aqueous surfactant solutions, the critical micelle concentration (CMC) was determined by the ring method [24] with a JZHY-180 surface tension meter with the temperature kept constant (15 °C). The break point which indicated CMC was obtained by plotting the surface tension  $\gamma$  against the surfactant concentration. With the electrolyte concentration changed, the same experiments as the aforementioned one were repeated, and the curves of CMC versus the electrolyte concentration were plotted.

## 2.3. Measurements of 2-bromoethylbenzene solubilization

The solubilization of BrEtBz in aqueous surfactant solution in the presence or the absence of TBAB was measured after equilibrium was reached using a UV-2602 ultraviolet–visible spectrophotometer at 259 nm. When BrEtBz was fully solubilized, the aqueous surfactant solution became cloudy. The break point was obtained by plotting absorbance against BrEtBz volume. With the surfactant concentrations changed, the same experiments as the aforementioned one were repeated, and the solubilization curves of BrEtBz were plotted.

## 2.4. Chloromethylation experiment

The chloromethylation reactions were carried out in a 250 mL round flask with a mechanical stirrer. A typical reaction procedure was as follows: BrEtBz, surfactant, 36.5% aqueous formaldehyde and 36% aqueous hydrochloric acid were added into the flask and the mixture was stirred. Then  $\text{PCl}_3$  was added dropwise when the temperature reached to 80–82 °C. At the end of the experiment the organic products were extracted with chloroform (3  $\times$  200 mL) and dried over anhydrous  $\text{Na}_2\text{SO}_4$ . The solvent was removed in vacuo and organic residue was analyzed by HPLC using Waters 600 E  $\varphi$ 4.5  $\times$  250 mm.

## 3. Results and discussion

### 3.1. Effect of adding electrolyte on the critical micelle concentration

Fig. 1 shows the changes of CMC with the addition of TBAB or NaBr into ionic surfactants (CTAB and SDS).

At the beginning, CMC decreased sharply and there was a lowest point in the curve. The decrease in CMC was connected with the synergistic effect of electrolyte and surfactant [25], which was named “nonideality” or “negative deviation from ideality” [26]. When cation  $\text{TBA}^+$  or  $\text{Na}^+$  was inserted into the surfactant (SDS) micelle, the charge of anionic hydrophilic groups was partly counterbalanced. This would cause the increase in the micelle size and the reduction of the electri-

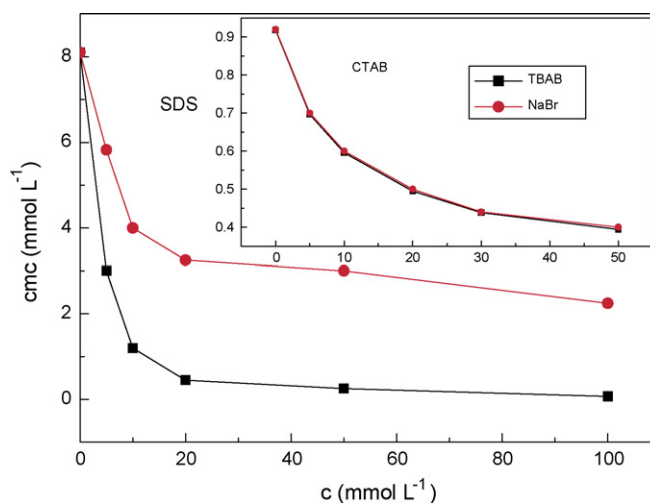


Fig. 1. Effect of adding electrolyte on the critical micelle concentrations of ionic surfactants.

cal repulsion in the Stern layer of the micelle [12,27]. In other words, the charge density at the micelle surface decreased, and thereby the absolute value of the electrical potential was also reduced [12]. This charge separation effect would be more favorable for the formation of the micelle at lower concentrations of anionic surfactant (SDS). In addition to electrostatic forces, another contribution to nonideality was due to the hydrophobic interaction [28] between hydrophobic groups of SDS and additive TBAB. It can be concluded that there must be hydrophobic interaction between hydrophobic groups of nonionic surfactant (NP-10) and TBAB. However, for cationic surfactant (CTAB), the effect of TBAB on CMC was the same as that of NaBr because there was only electrostatic interaction between cationic hydrophilic groups and  $\text{Br}^-$  and no hydrophobic interaction between hydrophobic groups of CTAB and TBAB.

### 3.2. Solubilization of 2-bromoethylbenzene in micelle

The solubilization capacity of BrEtBz in the aqueous solutions of three types of surfactants at 15 °C in the presence or the absence of TBAB is shown in Fig. 2. The curves in Fig. 2 are plots of the solubilization capacity of BrEtBz versus logarithm of surfactant concentrations. All the aqueous solutions containing surfactant but no TBAB could not make BrEtBz solubilize when surfactant concentrations were below CMC; once their concentrations reaching to CMC, BrEtBz could be solubilized in the micellar solutions significantly, and the solubilization capacity increased with the increasing surfactant concentrations rapidly. The solubilization abilities of the surfactant micelles were distinctly different at the same concentration, and decreased in the order: NP-10 > CTAB > SDS in accordance with the general rule of solubilization abilities of different types of surfactants for different organic reagents [25]. The difference should be attributed to the different compact extents of the surfactant micelles and the different CMC of these surfactants.

When a small amount of organic electrolyte (TBAB) was added into the solution containing ionic surfactant (SDS or CTAB), the solubilization capacity of BrEtBz was higher in

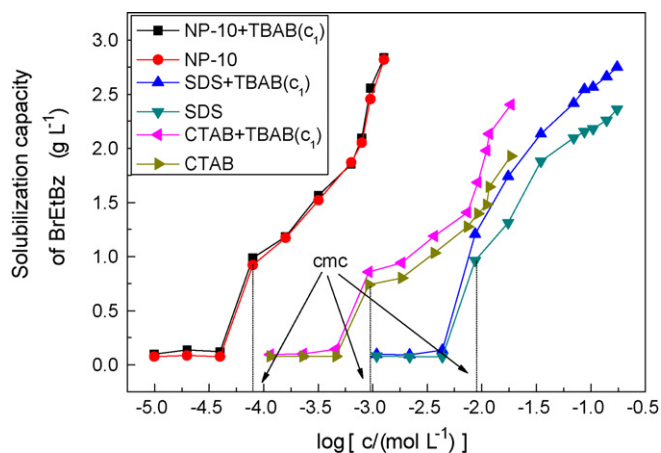


Fig. 2. Solubilization of 2-bromoethylbenzene in aqueous surfactant solutions in the presence of or the absence of TBAB,  $c_1 = 0.01 \text{ mol L}^{-1}$ .

both micellar solutions containing TBAB than in the single CTAB or SDS micellar solution. The results were connected with the strong electrostatic interaction between the ionic surfactant and TBAB which would lead to larger negative deviation from ideality [26]. The decrease in CMC in the ionic surfactant solution containing TBAB would result in the formation of more micelles under the same surfactant concentration and thus the total amount of BrEtBz solubilization in micelle would increase. However, for NP-10, the solubilization ability remained almost unchanged, because the effect of adding a small amount of organic electrolyte on CMC and the aggregate number ( $N_{\text{agg}}$ ) was very small [25].

### 3.3. Chloromethylation

Micellar catalysis for the chloromethylation reaction of BrEtBz was carried out in the aqueous solutions containing surfactant but no organic electrolyte. Fig. 3 shows the conversion of BrEtBz varied with the change of the surfactant concentration at the same temperature ( $82^\circ\text{C}$ ) and reaction time (8 h), and Fig. 4 shows the conversion varied with the change of the reaction

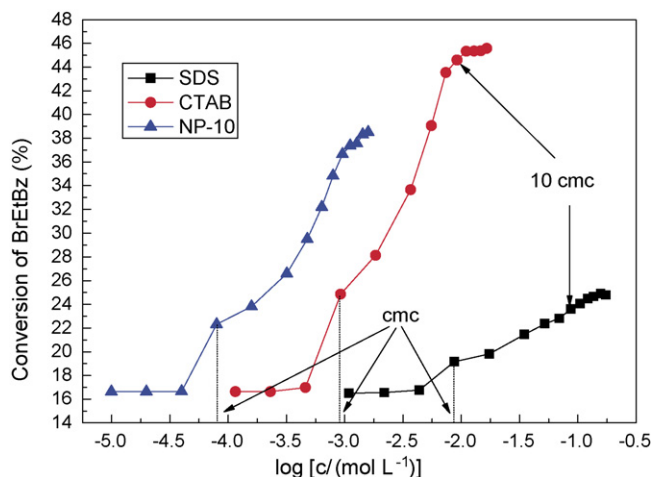


Fig. 3. Relationship between conversion and concentration of three types of surfactants. Reaction temperature:  $82^\circ\text{C}$ ; reaction time: 6 h.

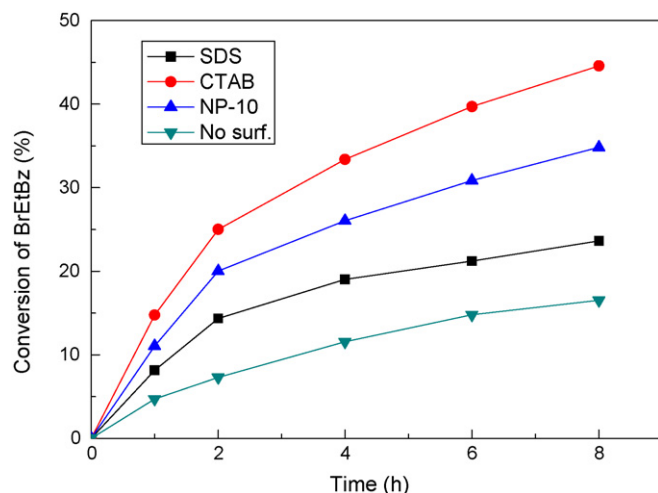


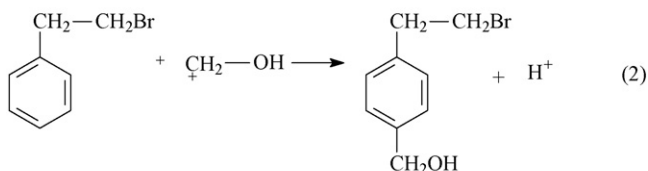
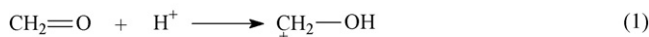
Fig. 4. Relationship between conversion and reaction time for three types of surfactants. Reaction temperature:  $82^\circ\text{C}$ ; concentrations of surfactants: 10-fold CMC.

time at the same temperature ( $82^\circ\text{C}$ ) and with a concentration of 10CMC when different types of surfactants (NP-10, CTAB and SDS) were used alone. As seen in Figs. 3 and 4, when surfactants were not used or their concentrations were below CMC, the conversion of BrEtBz after 8 h was ca. 16%, and hardly varied with surfactant concentration. However, the conversion increased with an increase in the surfactant concentration higher than CMC, and leveled off after the surfactant concentration reaching to 10CMC (for ionic surfactants). The facts indicate that chloromethylation of BrEtBz has happened effectively in the micellar catalysis system. When no surfactants were used or surfactant concentration was below CMC, the reaction system was a suspension with two phases and the interface area between oil phase and water phase was very small, so the reaction rate was quite low and the conversion of BrEtBz was not so high. However, when surfactant micelles were formed, BrEtBz was solubilized into the micelles, the interface area of oil phase/water phase was magnified suddenly and the rate of chloromethylation reaction occurred at the interface of oil phase/water phase was accelerated abruptly, so the conversion showed a break point at CMC. Above CMC, the number of micelles increased with the increasing surfactant concentration, so the rate of chloromethylation reaction speeded up and the conversion was enhanced. An optimum surfactant concentration is observed.

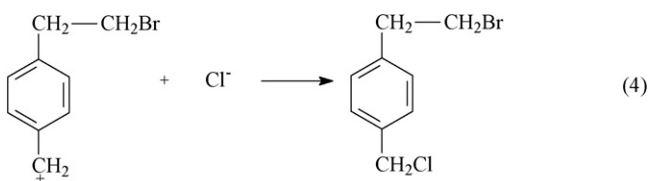
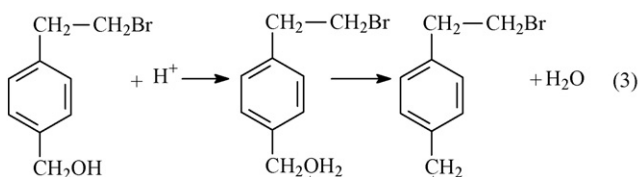
On comparison of different surfactants in Fig. 4, it was observed that the conversion of BrEtBz was dependent on the cationic, nonionic, and anionic micelles. The conversion was highest for the cationic surfactant (CTAB) system, lower for the nonionic surfactant (NP-10), and much lower for the anionic surfactant (SDS). The different catalytic abilities of surfactants, on the one hand, should be attributed to their different solubilization abilities. CTAB, NP-10 and SDS have various CMC, as described in Section 3.2. The lower CMC leads to more micelles at the same concentration causing more BrEtBz to be solubilized into micelles and greater encounter probability [29] between BrEtBz and reactive species. On the other hand, the different catalytic abilities of surfactants suggest the chloromethylation

reaction among BrEtBz, hydrochloric acid, formaldehyde and surfactant has a particular mechanism, and it possibly consists of two steps: electrophilic substitution reaction and nucleophilic substitution reaction, which can be expressed as follows:

Electrophilic substitution reaction:



Nucleophilic substitution reaction:



Which is the rate-controlling step of the two types of reactions? The answer can be obtained by comparing the catalytic effects of different types of surfactants on the overall reaction.

In Figs. 3 and 4, it can be found that the conversion of BrEtBz catalyzed by CTAB micelles was much higher than that catalyzed by SDS micelles, the plausible reason of which is that the effects of the electrophilic substitution reaction and the nucleophilic substitution reaction on the overall reaction rates are different; probably, the rate of the electrophilic substitution reaction is faster, but the nucleophilic substitution reaction is slower. So it can be assumed that the nucleophilic substitution reaction is the rate-controlling step. When CTAB was used, the cationic head groups which were outside the micellar shells strongly attracted the anions  $\text{Cl}^-$  by electrostatic interaction, so that anions  $\text{Cl}^-$  were concentrated around micelles, the nucleophilic substitution reaction was accelerated, and the overall reaction rates speeded up. However, when SDS was used, the anionic head groups which were outside the micellar shells strongly repelled the anions  $\text{Cl}^-$ , so that SDS micelles played an inhibition role in the nucleophilic substitution reaction, which resulted in a slow rate of the overall reaction. These conditions can also be explained by Fig. 4. The micellar catalysis effect of CTAB was much stronger than that of SDS at the concentration of 10CMC. Thereby, cationic surfactant is more suitable for the chloromethylation of BrEtBz. Besides, the inhibition action of anionic surfactant on the nucleophilic substitution reaction can also be analyzed further by comparing the catalytic effects of NP-10 and SDS on the overall reaction rates shown

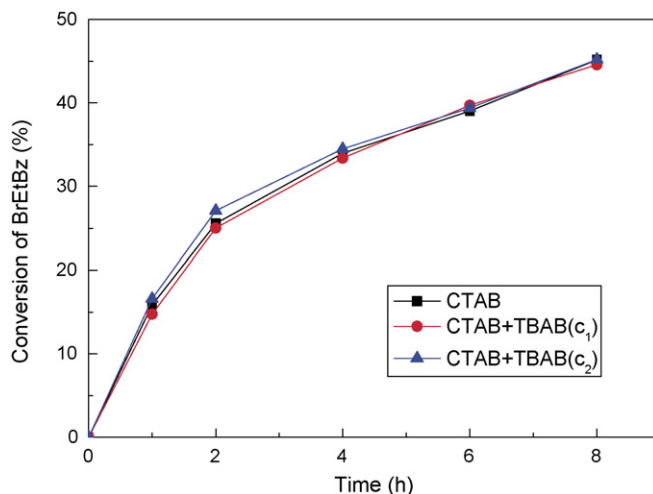


Fig. 5. Relationship between conversion and reaction time for CTAB system in the presence of TBAB. Reaction temperature:  $82^\circ\text{C}$ ; concentrations of CTAB: 10-fold CMC;  $c_1 = 0.01 \text{ mol L}^{-1}$ ,  $c_2 = 0.03 \text{ mol L}^{-1}$ .

in Figs. 3 and 4. It can be observed that the micellar catalysis effect of NP-10 on the chloromethylation of BrEtBz was much stronger than that of SDS because there was no repellent action between the NP-10 micellar shells and anions  $\text{Cl}^-$  and no inhibition action on the nucleophilic substitution reaction.

In conclusion, the solubilization for BrEtBz is facilitated in the three types of surfactant micelles by hydrophobic interaction. However, the primary difference in the behavior between the three surfactants may be owing to the different availability of anions  $\text{Cl}^-$  at the rate-determining step, which is in turn determined mostly by electrostatic interactions. For CTAB, electrostatic attraction favors the presence of anions  $\text{Cl}^-$  around the micelles. For SDS, charge repulsion removes the  $\text{Cl}^-$  ions from the micelles. For neutral NP-10, anions  $\text{Cl}^-$  may diffuse into the micelles. Thus, the observed rate and conversion of chloromethylation reaction is  $\text{CTAB} > \text{NP-10} > \text{SDS}$ .

#### 3.4. Effect of adding organic electrolyte on chloromethylation

The effect of adding a small amount of organic electrolyte (TBAB) on the reaction rate and the conversion is compared for different types of surfactant systems in Figs. 5–7. The addition of a small amount of TBAB has a negligible effect on the cationic surfactant system but does improve the conversion for SDS systems and enhances the conversion greatly for the NP-10 system. It is obvious that the effects of TBAB in the three systems are different and it should be analyzed according to the reaction mechanism and on the basis of the structures of the three-type surfactants. In solutions containing cationic surfactant micelles, the positive ions  $\text{TBA}^+$  cannot get close to the positively charged micelle surface owing to electrostatic repulsion, so the addition of TBAB hardly influences the total rate. On the other hand, the reactive anions  $\text{Cl}^-$  are locally concentrated by electrostatic interactions at the micelle surface. This effect is sufficient for catalytic purposes. So the reaction rate and the conversion show no distinct variation.

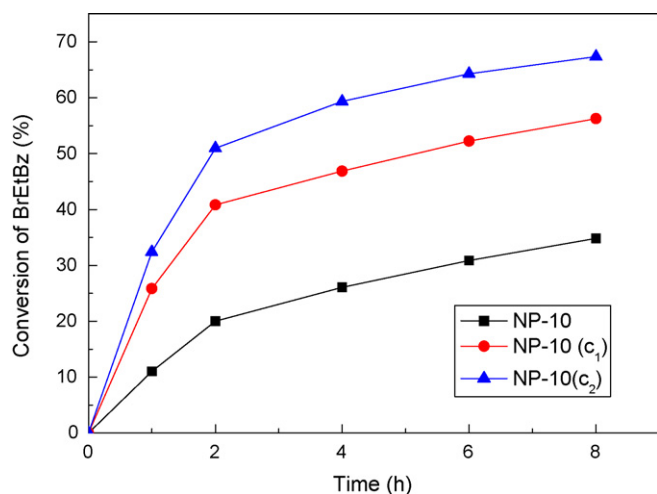


Fig. 6. Relationship between conversion and reaction time for NP-10 system in the presence of TBAB. Same condition as Fig. 5, except with concentration of NP-10: 10-fold CMC.

For solutions containing NP-10, there is no inhibition action for the nucleophilic substitution reaction as described in Section 3.3. Furthermore,  $TBA^+$  may be combined on the surface of NP-10 micelles by hydrophobic interaction between butyl groups of  $TBA^+$  and hydrophobic groups of NP-10, so that NP-10 micelle surface charged positively accelerates distinctly the nucleophilic substitution reaction leading to the sharp enhancement of the total reaction rate, which improves the conversion of BrEtBz indeed; higher solubilization abilities of NP-10 micelles containing TBAB is another factor resulting in higher conversion. The effect of TBAB is most pronounced for SDS, one reason is the decrease in CMC of SDS and the increase in BrEtBz solubilization in the micellar solution; another is that  $TBA^+$  may be inserted into micelles owing to the synergistic effect of electrostatic attraction and hydrophobic interaction between butyl groups and the hydrocarbon chains of SDS, reducing the net charge on the micelle surface, so that the inhibiting effect of anionic head groups of SDS on the rate-

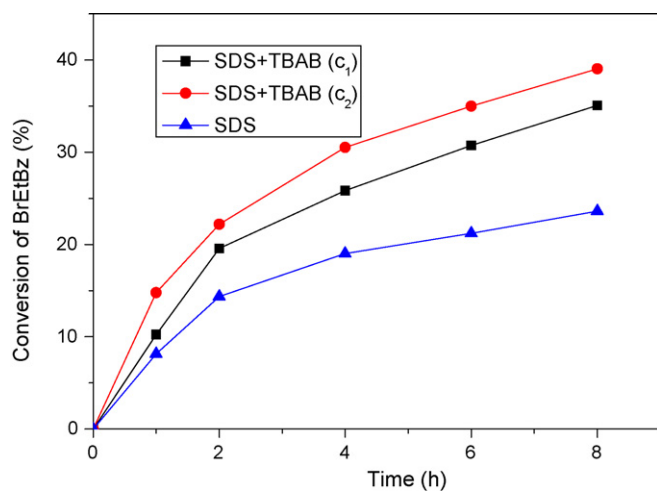


Fig. 7. Relationship between conversion and reaction time for SDS system in the presence of TBAB. Same condition as Fig. 5, except with concentration of SDS: 10-fold CMC.

Table 1

Selectivity for mono-chloromethylation of BrEtBz in the presence of surfactants

Surfactant	Reaction time, 1 h	Reaction time, 6 h
CTAB	87.7	82.8
NP-10	86.4	78.3
SDS	85.2	73.1
No surfactant	76.3	64.7

Reaction temperature: 82 °C; concentrations of surfactants: 10-fold CMC.

Table 2

Selectivity for mono-chloromethylation of BrEtBz in the presence of surfactants and TBAB

Surfactant	TBAB (mol L <sup>-1</sup> )	Reaction time, 1 h	Reaction time, 6 h
CTAB	0.01	92.3	89.7
	0.03	92.9	90.0
NP-10	0.01	93.2	91.8
	0.03	96.1	94.5
SDS	0.01	90.8	85.6
	0.03	91.5	86.1

Same condition as Table 1, except with addition of TBAB.

controlling step is weakened, resulting in speeding up of the total reaction.

### 3.5. Selectivity

It is well known that micellar catalysis can be used to enhance the selectivity for intermediate products. In our micellar catalytic system, surfactant micelles can provide a high surface area between the oil phase and the water phase, which might improve the selectivity for mono-chloromethylation. Tables 1 and 2 show the experimental results. When neither surfactant nor TBAB was used, the selectivity was very low and decreased from 76.3% to 64.7%; however, the selectivity was distinctly improved in the presence of surfactant, especially in the presence of surfactant and TBAB. The highest selectivity for mono-chloromethylation at 32.4% conversion after 1 h was 96.1% when the NP-10 concentration and the TBAB concentration were  $9.2 \times 10^{-3}$  mol L<sup>-1</sup> and 0.03 mol L<sup>-1</sup> which decreased to 94.5% at 67.4% conversion after 8 h. This decrease in the selectivity with an increase in the conversion is likely to be due to subsequent chloromethylation of mono-chloromethyl BrEtBz to polychloromethylation byproducts. Chloromethylation in solution of other surfactants such as CTAB and SDS gave similar decrease in the selectivity with an increase in the conversion as shown in Tables 1 and 2.

## 4. Conclusion

In this paper the chloromethylation of BrEtBz has been carried out successfully in a micellar catalysis system. The mechanism of chloromethylation reaction consists of electrophilic substitution reaction and nucleophilic substitution reaction, and the nucleophilic substitution is the rate-controlling step, so cationic surfactant (CTAB) is more suitable for the chloromethylation of BrEtBz. Adding a small amount of elec-

trolyte into micellar solutions in which non-ionic surfactant NP-10 or anionic surfactant SDS was used can speed up obviously the chloromethylation reaction, especially in the nonionic surfactant system the acceleration was more distinct. For cationic surfactant system, adding organic electrolyte TBAB cannot speed up the rate of chloromethylation reaction of BrEtBz. The selectivity for mono-chloromethylation was remarkably improved in the micellar solutions. Further aspects of the micellar catalysis and the application to organic syntheses and practical chemical processes are under investigation.

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