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Improvement Method for Synthesis of *p-tert*-butylthiacalix[*n*]arenes; Effect of Using Base Catalyst with Carboxylic Acid

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Abstract

The improved method for synthesis of *p-tert*-butylthiacalix[*n*]arenes (TC*n*As) by using precursor which is sulfur-bridged oligomer of *p-tert*-butylphenol with acetic acid and terephthalic acid as a template in a combination with base catalyst such as NaOH and NaH gave much better yields for TC6A (10.6 %) and TC8A (7.8 %), respectively. Such stronger base NaH than NaOH could bring down a reaction temperature for synthesis of TC8A.

Introduction

Considerable attention has been recently focused on *p-tert*-butylthiacalix[*n*]arenes (TC*n*As) because of their predominantly versatile capability than those of *p-tert*-butylcalix[*n*]arenes (C*n*As) (Figure 1) [1]. By contrast native CnAs cannot bind with metal cations, TC*n*As, linked via sulfide bridges in stead of methylene units, which itself can make host–guest complexation with metal cations [2]. Sone *et al.* first synthesized TC4A by acid catalyzed cyclization of an acyclic tetramer [3]. After that, Kumagai *et al.* described the simple one-step synthesis of TC4A in satisfactory yield [4]. Since then, Iki *et al.* reported a synthesis of TC*n*As from a sulfur-bridged acyclic dimer of *p-tert*-butylphenol, in which the synthetic yield was not improved [5]. Recently, we have reported the synthesis of TC8A by the terephthalate-induced cyclization of a mixture of acyclic oligomers, which was obtained by the reaction between *p-tert*-butylphenol and sulfur with CaO in ethylene glycol/diphenyl ether system in a poor yield [6]. To appreciate the synthetic yields of TC*n*As, we studied particulars about the synthetic condition. We report here the improved synthetic method for TC*n*As in much better yields, in which acetic acid and terephthalic acid are used as a template in the presence of base such as NaOH and NaH catalyst for TC6A and TC8A, respectively.

Experimental

In a typical run (run 5 in Table 2), under nitrogen a mixture of precursor (30 g) [6], terephthalic acid (2.35 g, 14.1 mmol) and NaH as base catalyst (3.99 g, 99.9 mmol) in diphenyl ether (100 ml) was stirred and heated to 100 °C at which sulfur (2.14 g, 66.6 mmol) was added. The temperature was raised at 170 °C in an hour and kept 12 h. After cooling to 70 °C, 2 N sulfuric acid (100 ml) was slowly added to the resulting dark-red viscous material. The organic layer on the acidic aqueous layer was stirred with *n*-heptane (100 ml) at 50 °C for 30 min. Insoluble fraction was filtered and the organic layer was separated from an aqueous layer, which was washed with water three times and organic layer was evaporated *in vacuo* to give viscous material. This fraction was used to calculate each yield of TC*n*As by ^{1}H-NMR analysis. This material was treated with acetone (100 ml) in resulting to give precipitates. Thus obtained precipitates, which consisted of TC8A, TC6A and TC4A, were filtered. The precipitates were resolved in a small amount of toluene. Pure TC8A was firstly isolated as a white powder and the second was TC6A, finally TC4A came out from the mother liquid. Those isolated white powder were recrystallized from toluene for a couple of times to give a pure compound. Calculated Yield: TC4A (2.10 g, 20.1%), TC6A (1.09 g, 8.8%), TC8A (0.17 g, 7.8%), TLC (Hexane: Acetone = 2:1); R_f (TC4A): 0.53, (TC6A): 0.35, (TC8A): 0.45

Results and discussion

Synthetic yields of TC*n*As were calculated by ^{1}H-NMR analysis. After completion of the reaction of TC*n*As, the organic layer of the reaction mixture was evaporated and dried *in vacuo* to result in obtaining viscously material which was taken in ^{1}H-NMR analysis in $CDCl_3$. It is possible to determine of each yield of

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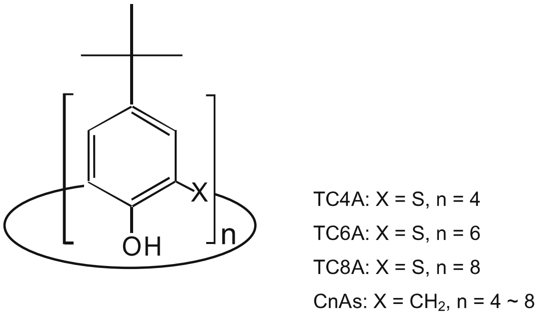

Figure 1. Structural formulas of TC*n*As and C*n*As.

TC*n*As (n = 4, 6 and 8) by ^{1}H-NMR analysis because hydroxyl groups attributed for TC4A, TC6A and TC8A appeared clearly at 9.6, 9.1 and 8.6 ppm as well as aromatic-H attributed for TC4A, TC6A and TC8A appeared at 7.61, 7.57, and 7.54 ppm, respectively. The numbers of *tert*-butyl groups attributed for TC*n*As can be available because the total volume of *tert*-butyl group attributed for starting precursor and TC*n*As are invariable before or after a reaction. The yields for TC*n*As were calculated from Equation (1). The Equation (1) is $A/A_0 \times 100$, it was recognized that the isolated yields for TC*n*As were almost same as calculated yields. Where A is integral value of hydroxyl group attributed for each TC*n*A×9, and A_0 is total integral values of *tert*-butyl groups attributed for starting precursor and TC*n*As.

As described above, we have succeeded to synthesize TC8A using terephthalic acid in the presence of NaOH as a base catalyst [6] even in low yield. To investigate a preparation condition for TC*n*As, we tried to use a couple of carboxylic acids as a template as shown in Table 1. It is shown that acetic acid works as the most advantageous template to provide 10.6 % yield for TC6A. It is interesting that larger size carboxylic acid such as phthalic acid can improve a yield of TC4A in 64.2%, regardless not isolation of TC6A and TC8A. Terephthalic acid, isophthalic acid, and phenol can work as an excellent templates, because all kinds of TC*n*As were synthesized. It is supposed that carboxylic acid works better as a template, because the yield of TC4A using the mono-carboxylic acids such as benzoic acid as a template, was 13.3–24.2%, and the di-carboxylic acids such as a terephthalic acid except for isophthalic acid was 41.5–64.2%. In the case of using di-carboxylic acid as a template, the yield of TC4A was about double yield than the using of mono-carboxylic acid as a template. It suggested that the sodium carboxylate, which could have interaction such as a metal coordination with hydroxyl group of precursors, have something effect on cyclization of precursor in the reaction mixture. It seems that the isophthalic acid, which is *metha*-dicarboxylic acid as a template, could work only one carboxylic acid moiety for an effect of steric hindrance for cyclization of precursor, as shown in Figure 2. In the case of non-aromatic carboxylic acids such as glutaric and acetic acid were used, it is probably different template effect is working, because those carboxylic acids can be locating at center of precursors as shown in Figure 3, because there is no steric constraint of aromatic ring. As shown in Table 1, the yields of TC8A are ranging from 0 to 1.6%, which are still in poor yield. It is reported that the molecular mitosis in a synthesis of calix[*n*]arenes proceeds such as cyclic octamer transforms to the cyclic tetramer with the higher boiling diphenyl ether rather than xylene [7]. It means lower temperature is much favorable condition to elaborate larger ring size of calix[*n*]arenes such as C6A and C8A. To prepare TC*n*As, which is replaced CH_2 groups of C*n*As by S; reaction temperature should be raised up at least 140 °C, because the activation temperature of elemental sulfide is over 140 °C [8]. To improve the yields of TC6A and TC8A, the reaction conditions including reaction temperature, kinds of base catalyst and reaction time are investigated in detail. As shown in Table 2, NaH works effectively at 170 °C to synthesize TC8A in a 7.8% yield, which is five times up than that of NaOH was used. This result suggested that base catalyst should be much stronger than NaOH as a template.

When the reaction temperature was raised up at 230 °C and the reaction time was prolonged for 12 h, the yield of TC8A was down to 0.1% as well as down to 5.7% for TC4A. On the contrary, the yield of TC4A was kept up at 18.1% in a such as shorter reaction time as 4 h, which means a degradation of TC4A was originated

Table 1. Effect of templates for synthesis of TC*n*As

Run	Template	Yield (%)		
		TC4A	TC6A	TC8A
1	Terephthalic acid	41.9	5.2	1.6
2	Phthalic acid	64.2	0	0
3	Isophthalic acid	12.6	3.6	0.8
4	Benzoic acid	24.2	9.1	0
5	Glutaric acid	41.5	5.9	0
6	Acetic acid	13.3	10.6	0
7	Phenol	25.2	3.4	0.5
8	No template	20.7	2.0	0

Temperature: 230 °C, Reaction Time: 4 h, Catalyst: NaOH.

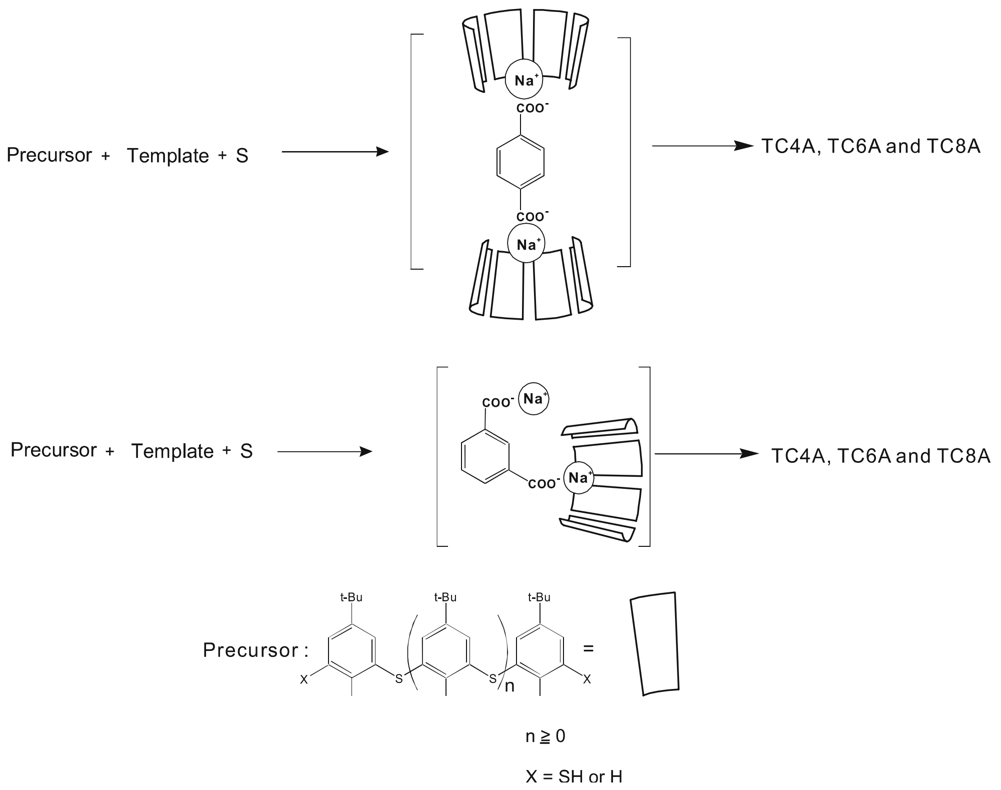

Figure 2. The estimated synthetic mechanism of TC*n*As with dicarboxylic acid as template.

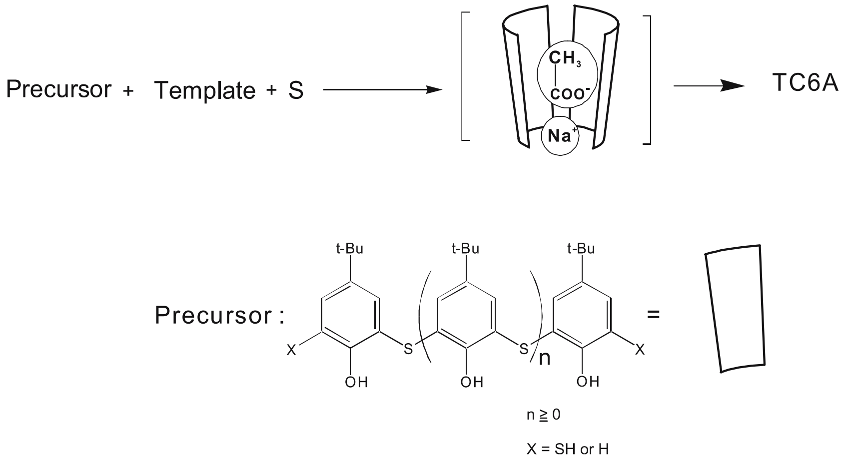

Figure 3. The estimated synthetic mechanism of TC*n*As with mono carboxylic acid as templates.

Table 2. Effect of catalyst and temperate for synthesis of TC*n*As

Run	Template	Catalyst	Temperature (°C)	Time (hr)	Yield (%)		
					TC4A	TC6A	TC8A
1	Terephthalic acid	NaOH	230	4	41.9	5.2	1.6
2	Terephthalic acid	NaOH	170	4	0	0	0
3	Terephthalic acid	NaH	230	12	5.7	0	0.1
4	Terephthalic acid	NaH	230	4	18.1	0	0
5	Terephthalic acid	NaH	170	12	20.1	8.8	7.8
6	Terephthalic acid	NaH	150	12	0.8	0	0
7	Terephthalic acid	NaH	170	4	1.9	0	0
8	Acetic acid	NaOH	230	4	13.3	10.6	0
9	Acetic acid	NaH	170	12	6.0	5.7	0

out over an extended time. Shorten reaction time of 4 h with a low reaction temperature at 170 °C gave only 1.9% yield of TC4A together with no isolation of TC6A and TC8A.

Conclusion

In this study, appreciably reaction condition for a preparation of a larger ring size of TC*n*As such as TC6A and TC8A was established. The combination of terephthalic acid and NaH works as induced cyclization of a mixture of acyclic oligomers to yield TC6A and TC8A in good yield. On the other hand, the combination of acetic acid and NaH instead of NaOH is not advantage for the synthesis of TC6A. It is the first example to synthesize TC8A using NaH as base catalyst in a lower reaction temperature condition.

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