Cyclodextrins in polymer synthesis: Influence of methylated ß-cyclodextrin as host on the free radical copolymerization reactivity ratios of hydrophobic acrylates as guest monomers in aqueous medium

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Summary

Methylated ß-cyclodextrin (me-ß-CD) was used to complex the hydrophobic monomers n-butyl acrylate (**1**), n-hexyl acrylate (**2**) and cyclohexyl acrylate (**3**) yielding the corresponding water soluble host/guest complexes **1a-3a**. The complexes were copolymerized in water by free radical mechanism and the reactivity ratios were determined by measuring the monomer consumption by HPLC. The following reactivity ratios were found: copolymerization of **1a** and **2a**: $r_1 = 1.01 \pm 0.01$; $r_2 = 1.04 \pm 0.01$; copolymerization of **3a** and **2a**: $r_1 = 0.74$; $r_2 = 1.28$; copolymerization of **3a** and **1a**: $r_1 = 0.75 \pm 0.04$; $r_2 = 1.13 \pm 0.01$. In contrast to that, the copolymerization of the uncomplexed monomers **1-3** in organic medium (DMF/H$_2$O) leads to nearly ideal statistical copolymers in all cases.

Introduction

Cyclodextrins (CD) contain 6, 7 or 8 glucose-units (α, ß, γ) which are connected through α-glucosidic-1,4-bonds. The high number of hydroxy groups located on the hydrophilic outside of CD causes a high water-solubility of the ring molecule. The relatively hydrophobic cavity of CD predestinates it to include hydrophobic guest molecules like unsatured monomers[1-3].

In this connection we have investigated a new polymerization method in water dealing with CD-complexed hydrophobic monomers, recently[4-12]. We found that, during the free-radical polymerizations of the complexed monomers, the CD slips off from the monomer during chain propagation, the polymer precipitates while the CD remains in aqueous phase due to its high water-solubility[4-9]. In this connection we found that chain-transfer constants of mercaptans like the water-soluble N-acetyl-L-cysteine or the water-insoluble dodecanethiol differ strongly from the values obtained in organic solution in absence of CD[8,9]. As an interesting observation, we found that the reactivity ratios of the CD-complexed monomers isobornyl acrylate and butyl acrylate

($r_{\text{isobornyl acrylate/me-ß-CD}}$ = 0.3 ± 0.1, $r_{\text{butyl acrylate/me-ß-CD}}$ = 1.7 ± 0.1) differ significantly from the r-values of the corresponding uncomplexed isobornyl acrylate and butyl acrylate in organic solution ($r_{\text{isobornyl acrylate}}$ = 1.3 ± 0.1, $r_{\text{butyl acrylate}}$ = 1.0 ± 0.1)[7]. Up to now, systematic investigations dealing with the influence of side groups of acrylates have not been published. Therefore, in the present paper we wish to report our new investigations on the copolymerization behavior of various hydrophobic acrylate/methylated-ß-CD complexes in aqueous medium.

Results and discussion

Methylated ß-cyclodextrin (me-ß-CD) and the hydrophobic monomers n-butyl acrylate (**1**), n-hexyl acrylate (**2**) and cyclohexyl acrylate (**3**) were dispersed in water yielding the corresponding water-soluble host/guest complexes **1a-3a** after sonication for some minutes.

The characterization of the complexes is described elsewhere[7,12]. For kinetic studies, the complexed monomers **1a-3a** were copolymerized in water at various molar ratios using the free-radical initiator 2,2'-azobis (2-amidinopropane) dihydrochloride (**AAP**).

After several minutes of polymerization the compositions of the resulting copolymers were determined by measurements of the concentrations of residual monomers in the reaction medium using High Performance Liquid Chromatography (HPLC).

In order to evaluate these results with respect to the influence of me-ß-CD on the reactivity ratios, analogous copolymerizations of **1-3** were carried out in absence of me-ß-CD under similar conditions in a mixture of N,N'-dimethylformamide (DMF) and water (9:1 vol.). It has to be pointed out that, according to ^{1}H NMR, the initiator half-life time of decomposition was found to be nearly identical in both aqueous and organic media[7]. In all cases the monomer conversion was below 10 %.

The reactivity ratios for the radically initiated copolymerizations were derived from experimental results using the method of Kelen-Tüdös[3-15]. The arithmetic averages of the reactivity ratios r_A, r_B for two runs are shown in table. 1.

Table 1. Reactivity ratios of me-β-CD complexed monomers n-butyl acrylate (**1a**), n-hexyl acrylate (**2a**) and cyclohexyl acrylate (**3a**) in water and the corresponding uncomplexed monomers **1-3** in DMF/H$_2$O (9:1 vol.)

monomer A	monomer B	r_A	r_B
1a (1)	**2a (2)**	1.01 ± 0.01 (1.01 ± 0.01)	1.04 ± 0.01 (0.91 ± 0.03)
3a (3)	**2a (2)**	0.74 ± 0.01 (1.04 ± 0.04)	1.28 ± 0.01 (1.04 ± 0.08)
3a (3)	**1a (1)**	0.75 ± 0.04 (0.95 ± 0.02)	1.13 ± 0.01 (1.24 ± 0.04)
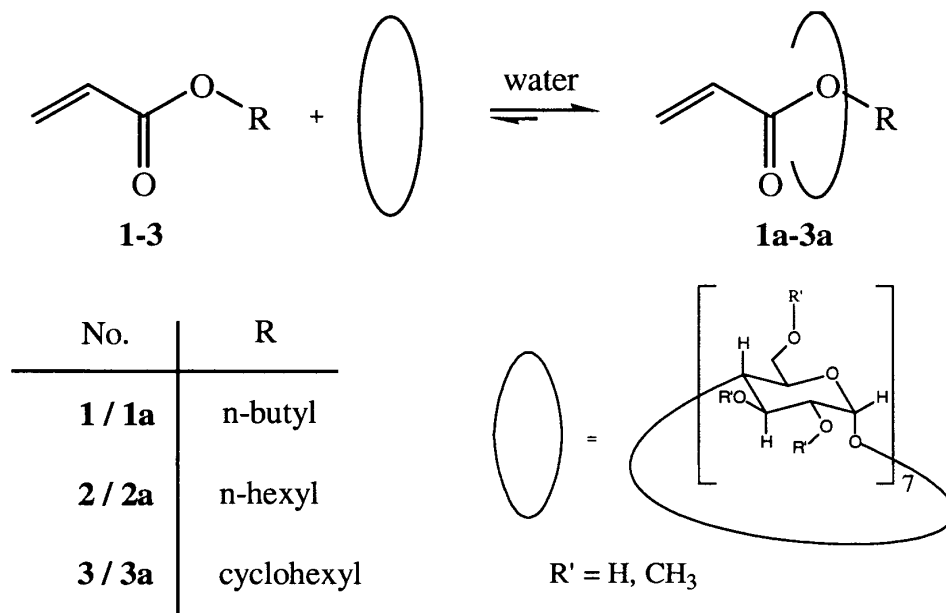
Scheme 1. Complexation of the acrylates **1-3** with me-β-CD in aqueous medium

Generally, the reactivity ratios of me-ß-CD complexes of cyclohexyl acrylate (**3a**) with n-butyl acrylate (**1a**) or n-hexyl acrylate (**2a**), respectively, indicate a preferred monomer addition of the linear acrylate monomers compared to retarded addition of the cyclic monomer (**3a**). The copolymerization of **1a** with **2a** leads to a nearly ideal statistical copolymer. In contrast to that, the series of copolymerizations of the unmodified monomers (**1-3**) in DMF/H₂O-solution lead to nearly ideal statistical copolymers in all cases. It seems that an influence of the sterical demand of the alkoxy groups of the monomers is not significant in absence of me-ß-CD with respect to the r-values. Additionally, the difference between each reactivity ratio is smaller than that of the copolymerization of the complexed monomers in water. Thus, relatively strong interactions between cyclodextrin (host) and monomer (guest) may control the copolymerization reactivity ratios. As mentioned above, a similar effect was also observed in case of the copolymerization of isobornyl acrylate and n-butyl acrylate[7]. From our new results it can be concluded, that the interactions between monomer and cyclodextrin are liable substantially for the control of copolymerization reactivity ratios. That means that, the better the guest monomer fits into the CD-cavity the lower the r-value.

Experimental part

Materials and methods

The monomers n-butyl acrylate (Fluka Chemie AG, Buchs, Switzerland, purity ≥ 99%), n-hexyl acrylate (Acros Organics N.V. / S.A., Geel, Belgium, purity ≥ 98 %) and cyclohexyl acrylate (Lancaster Synthesis GmbH, Mühlheim, Germany, purity ≥ 97 %) were distilled under reduced pressure. ß-Cyclodextrin (me-ß-CD) was obtained from Wacker-Chemie GmbH, Burghausen, FRG, with an average degree of

methylation of about 1.8 per glucose unit. 2,2'-azobis (2-amidinopropane) dihydrochloride was obtained from Wako Chemicals GmbH, Neuss, FRG. Water was demineralized before use. If not mentioned otherwise, all materials were used as received. The supersonic treatment was carried out by use of a Bandelin Sonorex RK 1028 Transistor.

HPLC measurements were performed by the use of a BIOTEC 525 system with a BIOTEC 540 diode array detector and a Knauer RI Detector with a ODS-2-Column (5μ 125 · 4.6 mm) and acetonitrile / water (1 : 1) as eluent. UV measurements were conducted with an UV 540 system of the company Unicam.

Complexation of monomers

117.6 g (88.3 mmol) of me-ß-CD were dissolved in 274 ml of water and 10.3 g of **1** (80.3 mmol) were added. The colorless dispersion was sonicated for 10 minutes yielding a clear colorless solution of the complexed monomer **1a**. The complexations of **2** and **3** were carried out analogously to **1**.

Copolymerization of the complexes 1a-3a

The complexed monomers **1a-3a** prepared as described above were mixed in different molar ratios (1 : 1, 1 : 1.5, 1 : 0.5, 1 : 0.77, 1 : 2 and 1 : 4). Under nitrogen, 5.5 mol-% of AAP with respect to monomer were added to each of the solutions. Under stirring all solutions were brought simultaneously to 80°C. After 6 minutes the solutions were poured into 100 g of cold water to stop polymerization and the precipitates were filtered off. The quantitative determination of the residual monomer concentrations was done by HPLC measurements.

Copolymerization of the uncomplexed monomers 1-3

The uncomplexed monomers **1-3**, dissolved in DMF/H_2O (9 : 1 vol.), were mixed in different molar ratios (as descripted above). Under nitrogen, 5.5 mol-% of AAP with respect to monomer were added to each of the solutions. Under stirring all solutions were brought simultaneously to 80°C. After 11 minutes the solutions were poured into 30 ml of cold water to stop polymerization. The precipitated polymers were filtered off and dried in vacuum. The quantitative determination of the concentrations of the non reacted monomers was done by HPLC measurements.

References

[1] Sänger, W. *Angew. Chem.* **1980**, *92*, 343
[2] Wenz, G. *Angew. Chem.* **1994**, *106*, 851
[3] Szejtli, J. *J. Mat. Chem.* **1997**, *7(4)*, 575
[4] Jeromin, J.; Noll, O.; Ritter, H. *Macromol. Chem. Phys.* **1998**, *199*, 2641
[5] Jeromin, J.; Ritter, H. *Macromol. Rapid Commun.*, **1998**, *19*, 377
[6] Casper, P.; Glöckner, P.; Ritter, H. *Macromolecules*, **2000**, *33(No. 12)*, 4361
[7] Glöckner, P.; Ritter, H. *Macromol. Rapid. Commun.*, **1999**, *20*, 602

[8] Glöckner, P.; Metz, N.; Ritter, H. *Macromolecules*, **2000**, *33(11)*, 4288

[9] Glöckner, P.; Ritter, H. *Macromol. Chem Phys.*, **2000**, *201*, 2455

[10] Reihmann, M.; Ritter, H. *Macromol. Chem. Phys.*, **2000**, *201*, 798

[11] Storsberg, J.; Ritter, H.; Pielartzik, H.; Groenendaal, L. *Adv. Mater.*, **2000**, *12(8)*, 566

[12] Bernhardt, S.; Glöckner, P.; Theis, A.; Ritter, H. *Macromolecules*, **in press**

[13] Kelen, T.; Tüdös, F. *J. Macromol.-Sci. Chem.*, **1975**, *A9(1)*, 1

[14] Kelen, T.; Tüdös, F.; Turcsányi, B. *Polym. Bull.*, **1980**, *2*, 71

[15] Kelen, T.; Tüdös, F.; Braun, D.; Czerwinski, W. K. *Macromol. Chem.*, **1990**, *191*, 1863