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SHORT COMMUNICATION

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Preparation of temperature-sensitive polymer particles having different lower critical solution temperatures

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Abstract Preparation of temperature-sensitive core-shell composite polymer particles was carried out by seeded emulsion copolymerization of dimethylaminoethyl methacrylate and ethylene glycol dimethacrylate with submicron-sized polystyrene seed particles as core. The lower critical solution temperature (LCST) of the core-shell composite was about 35 °C, while the LCST could be controlled toward higher or lower temperatures by copolymerizing the shell layer with hydrophilic/hydrophobic vinyl comonomer.

Key words Temperature-sensitive – LCST – core-shell – particle – emulsion polymerization

Introduction

Currently, temperature-sensitive polymer particles are attracting more attention because of their suitability as a carrier for biomolecules in the biomedical field [1–4]. In previous articles, we reported the preparation of a new type of temperature-sensitive core-shell composite polymer particles with lower critical solution temperature (LCST) at around 35 °C by seeded emulsion copolymerization of dimethylaminoethyl methacrylate (DM) and ethylene glycol dimethacrylate (EGDM) with submicron-sized polystyrene (PS) seed particles [5, 6]. The composite particles consisting of DM-EGDM copolymer shell layer which swelled at temperature below the LCST and shrank above the LCST. The EGDM content in the shell layer had no effect on the LCST [7].

Many researchers reported the preparations of N-isopropylacrylamide based copolymer gels having different LCST values [8–11], but to our knowledge there is no report on the preparation of core-shell composite polymer particles having different LCST values. This article describes LCST changes of PS/P(DM-EGDM) composite particles by copolymerizing with hydrophilic/hydrophobic vinyl comonomer in the shell layer.

Experimental

Materials

Styrene (S), butyl acrylate (BA), ethyl acrylate (EA), methyl methacrylate (MMA), acrylic acid (AA) and methacrylic acid (MAA) were distilled under reduced pressure in a nitrogen atmosphere. 2,2′-Azobis(isobutyronitrile) (AIBN) was purified by recrystallization. DM and EGDM were of reagent grade and used as received. 2,2′-Azobis(2-amidinopropane) hydrochloride (V-50) and polyoxyethylene sorbitan monooleate (Tween-80) were also of reagent grade. Deionized water was distilled with a Pyrex distillator. Other chemicals used were of analytical grade.

Preparation of copolymers

A series of copolymer was prepared by solution copolymerization carried out in toluene using AIBN as initiator.

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Table 1 Preparation of PS seed particles by emulsion polymerization[a)]

Ingredients		
Styrene	(g)	64
Tween 80	(g)	0.16
V-50	(g)	0.256
Water	(g)	300

[a)] 60 °C, 24 h, N_2, 100 rpm.
Abbreviations: Tween 80, polyoxyethylene sorbitan monooleate; V-50, 2,2′-azobis(2-amidinopropane) hydrochloride.

Table 2 Preparation of temperature-sensitive composite particles[a)]

Sample No.		1	2	3
PS[b)]	(g)	18.98	18.98	18.98
DM	(g)	0.599	0.599	0.599
MAA	(g)	0.0325	–	–
Styrene	(g)	–	–	0.016
EGDM	(g)	0.0183	0.0183	0.0183
V-50	(g)	0.4	0.4	0.4
Water	(g)	150	150	150

[a)] 60 °C, 8 h, N_2, 100 rpm.
[b)] Number average diameter, 0.2 μm; solid content, 158 g/l.
Abbreviations: PS, Polystyrene; DM, dimethylaminoethyl methacrylate; MAA, methacrylic acid; EGDM; ethylene glycol dimethacrylate; V-50, 2,2′-azobis (2-amidinopropane) hydrochloride.

The produced copolymers were precipitated from the solution and then washed repeatedly before use. Hereafter copolymer of “A” and “B” will be expressed as “P(A–B)”. Terpolymers will be also expressed in the same way.

Preparation of PS seed particles

Emulsion polymerization of S was carried out in the presence of nonionic emulsifier at 60 °C for 24 h under a nitrogen atmosphere at a stirring rate of 100 rpm in a round-bottomed, four-necked flask under the conditions listed in Table 1.

Preparation of temperature-sensitive composite polymer particles

Three types of temperature-sensitive core-shell composite particles were prepared. One was prepared by seeded emulsion copolymerization of DM and EGDM with 0.2 μm-sized PS seed particles and the other two were prepared by the seeded emulsion terpolymerizations of DM, EGDM and S/MAA with the same PS seed particles. S and MAA contents in the shell layers were maintained at 3.8 and 8.8 mol%, respectively. The conditions have been detailed in Table 2. The composite particles were washed repeatedly by serum replacement to remove any soluble oligomer.

The hydrodynamic diameters (*Dh*) of particles at 40 and 25 °C were measured by dynamic light scattering (DLS).

Results and discussion

Figure 1 shows transmission electron microscopic (TEM) photographs of PS seed, PS/P(DM-EGDM), PS/P(DM-MAA-EGDM) and PS/P(DM-S-EGDM) composite particles prepared under the conditions listed in Tables 1 and 2, which were not purified. The TEM photographs suggest that no copolymer particle was byproduced during each seeded emulsion copolymerization.

Figure 2 shows the change of turbidity temperature of aqueous solutions of copolymers of DM with various vinyl comonomers ranging from hydrophobic S to hydrophilic MAA as a function of comonomer content. The polymer concentration was fixed at 10 g/l in all measurements. The polydimethylaminoethyl methacrylate (PDM) had a turbidity temperature at around 37 °C. On copolymerizations of DM with various comonomers the turbidity temperature deviated gradually from 37 °C. This deviation was dependent on both the concentration and the type of comonomers. In the cases of hydrophilic AA and MAA monomers the turbidity temperatures were higher than that of PDM and increased further with increases in the comonomer contents. Whereas in the cases of other hydrophobic monomers the turbidity temperature decreased gradually with increases in the comonomer contents and in the hydrophobicity. For example, at the comonomer content of 10 mol%, P(DM-S) had the lowest to be 14 °C and P(DM-MAA) had the highest to be 43 °C. On the basis of these results, in order to prepare temperature-sensitive composite particles having different LCST values, the introductions of S and MAA into the shell layer of PS/P(DM-EGDM) core-shell composite particles were, separately, tried by their copolymerizations.

Figure 3 shows the variations of *Dh* of purified PS seed, PS/P(DM-EGDM), PS/P(DM-MAA-EGDM) and PS/P(DM-S-EGDM) composite particles at pH 9. PS/P(DM-EGDM) composite particles had the LCST at around 35 °C, whereas PS/P(DM-S-EGDM) and PS/P(DM-MAA-EGDM) composite particles had the LCST values at around 28° and 41 °C, respectively. In the case of PS/P(DM-S-EGDM) composite particle deswelling took place gradually with an increase in the temperature at around the LCST, as compared to the other two composite particles. This may be due to the formation of

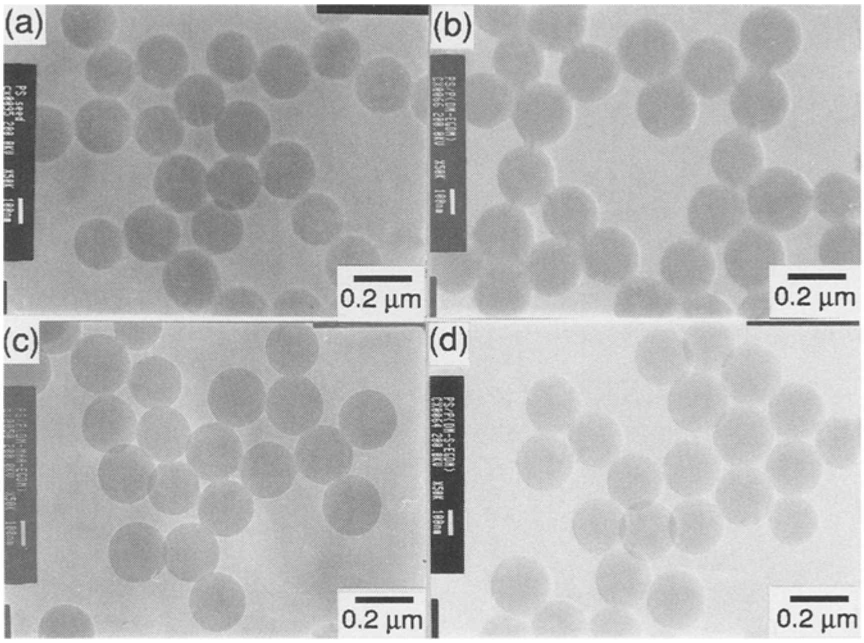

Fig. 1 Transmission electron microscopic photographs of PS seed (a), PS/P(DM-EGDM) (b), PS/P(DM-MAA-EGDM) (c), and PS/P(DM-S-EGDM) (d) composite particles

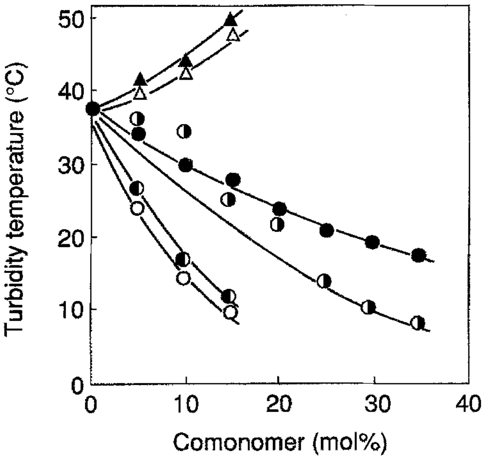

Fig. 2 Change of turbidity temperature of aqueous solutions (10 g/l) of copolymers of DM with various vinyl comonomers as a function of comonomer content: ○, P(DM-S); ◐, P(DM-BA); ◑, P(DM-EA); ●, P(DM-MMA); △, P(DM-AA); ▲, P(DM-MAA)

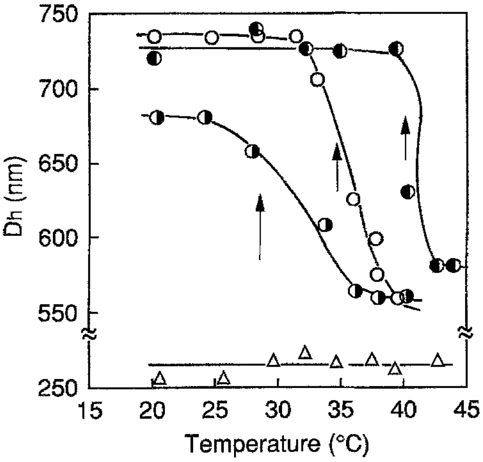

Fig. 3 Variations of hydrodynamic diameters (*Dh*) of PS seed (△), (PS/P(DM-EGDM) (○), PS/P(DM-MAA-EGDM) (◐), and PS/P(DM-S-EGDM) (◑) composite particles with temperature at pH 9. Arrow indicates LCST

collapsed polymeric skin at the outer surface of shell in the process of deswelling around the LCST, which blocks the rapid water release from the inner hydrated shell layer [10]. This effect should be more pronounced due to the presence of hydrophobic S component in the shell layer. The swelling/deswelling phenomenon was reversible for all composite particles.

These results suggest that it is possible to prepare temperature-sensitive composite polymer particles having different LCST values. The composite particles having low LCST may be useful as a carrier for the separation of biomolecules which have poor heat stability.

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References

1. Bae YH, Okano T, Hsu R, Kim SW (1987) Makromol Chem Rapid Commun 8:481
2. Hoffman AS, Afrassiabi A, Dong LC (1986) J Control Release 4:213
3. Hoffman AS (1987) J Control Release 6:297
4. Kawaguchi H, Fujimoto K, Mizuhara Y (1992) Colloid Polym Sci 270:53
5. Okubo M, Ahmad H (1995) Colloid Polym Sci 273:817
6. Okubo M, Ahmad H (1996) Colloid Polym Sci 274:112
7. Okubo M, Ahmad H (1996) J Polym Sci Poly Chem Ed in press
8. Chen G, Hoffman AS (1995) Macromol Rapid Commun 16:175
9. Wu XS, Hoffman AS, Yager P (1993) Makromol Chem Rapid Commun 14:314
10. Yu H, Grainger DW (1993) J App Poly Sci 49:1553
11. Tailor LD, Cerankowski LD (1975) J Polym Sci Poly Chem Ed 13:2551