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A Novel Thermo-Sensitive Polymer . Poly(2- *iso*-propyl-2-oxazoline)

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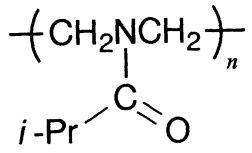
Poly(2-*iso*-propyl-2-oxazoline) (P*i*PrOZO), prepared by cationic ring-opening polymerization of *i*PrOZO, has been found to be a thermo-sensitive polymer. P*i*PrOZO possesses a cloud point (CP) around 36 °C. The CP changed by the addition of sodium chloride or a surfactant. For utilizing these characteristics, a new hydrogel was prepared by copolymerization of a P*i*PrOZO macromonomer with ethylene glycol dimethacrylate. The hydrogel swelled below the CP of P*i*PrOZO. Above the CP, on the other hand, the degree of swelling of the gel was very low.

Recently, there has been much attention to stimulus-sensitive polymers, which respond to external signals such as temperature, electric current, photoelectric, magnetic, and pH changes. Polymers which have a cloud point (CP) in an aqueous solution can be used as a thermo-sensitive polymer. For example, poly(vinyl methyl ether), hydroxypropyl cellulose, and poly(*N*-alkylacrylamide) are known to possess a CP, and some of them and their copolymers have been applied to several fields such as controlled release, enzyme activity control, and extraction.[1,2]

Cationic ring-opening polymerization of 2-alkyl-2-oxazolines is well known to be a convenient method to prepare linear poly(*N*-acylethylenimine)s (PROZO).[3,4] The polymerization is of highly living nature. PROZO becomes hydrophilic or hydrophobic by changing the nature of the acyl group; the hydrophilicity of the polymer decreases with increasing the carbon number of the acyl group. PMeOZO is highly hydrophilic; it is soluble in water and shows no CP in water. PEtOZO (M_W = 350 000) possesses a CP of 62 °C.[5] P*n*BuOZO is insoluble in water and shows a good hydrophobic nature in block-type poly(2-oxazoline) surfactants.[6] The present study deals with properties and applications of poly(2-*iso*-propyl-2-oxazoline) (P*i*PrOZO) as a novel thermo-sensitive polymer.



PiPrOZO

Cationic ring-opening polymerization of *i*PrOZO was performed using methyl tosylate as an initiator in acetonitrile, followed by reprecipitation (methanol - diethyl ether) to produce PiPrOZO (M_n=16 700, M_w/M_n=1.13).

Figure 1 shows relationship between the concentration of PiPrOZO and CP.[7] The CP decreased with increasing the concentration in the measured region. The effect of the additive on the CP of PiPrOZO is shown in Table 1. By the addition of sodium chloride to the PiPrOZO aqueous solution, the CP became lower. The higher the concentration of sodium chloride, the lower the CP of PiPrOZO. This is because sodium chloride removed hydrating water molecules from the polymer due to its stronger hydrogen bonding with water than that of the polymer. On the other hand, the CP increased by the addition of an ionic surfactant. It is well known that nonionic water-soluble polymers such as poly(ethylene oxide) and poly(*N*-vinylpyrrolidone) (PNVP) and surfactants form stable complexes in water.[8] In the present system, the increase of CP by the addition of the surfactant is probably due to the complex formation between PiPrOZO and the surfactant. The CP increase by the addition of sodium

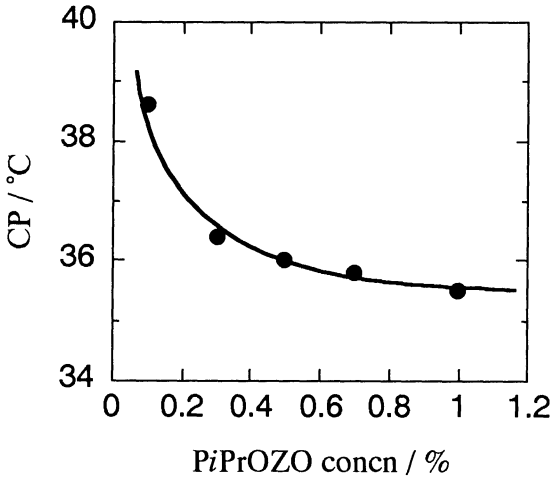


Fig. 1. Relationship between PiPrOZO concentration and CP.

Table 1. Effect of Additive on CP of PiPrOZO[a)]

Additive		CP
Compound	Concentration mol/l	°C
NaCl	0.1	35.6
NaCl	0.5	31.5
SDS[b)]	0.01	76.7
SDS[b)]	0.05	>100
DTMAC[c)]	0.01	38.4
DTMAC[c)]	0.05	60.5

a) PiPrOZO concentration = 0.5%. The CP of PiPrOZO in water = 36.0 °C

b) Sodium dodecylsulfate.

c) Dodecyltrimethylammonium chloride.

dodecylsulfate (SDS) was larger than that by dodecyltrimethylammonium chloride. A similar phenomenon was observed in the case of PNVP with ionic surfactants; the stronger complex from PNVP with SDS was formed than that with a cationic surfactant.[8]

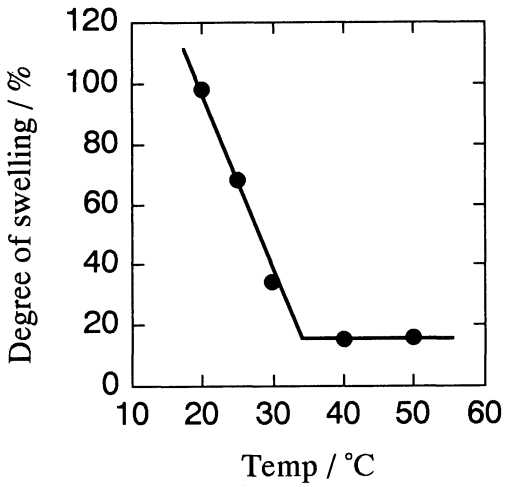


Fig. 2. Effect of temperature on the degree of swelling of the hydrogel.

One of possible applications of the present thermo-sensitive polymer is shown by properties of thermo-sensitive hydrogel of P*i*PrOZO. The hydrogel was prepared by the radical copolymerization of P*i*PrOZO macromonomer (**1**) (M_n = 3 500) possessing a polymerizable styryl group[9] with ethylene glycol dimethacrylate (**2**) (**1**:**2** = 70:30 wt%) in an aqueous methanol solution.[10] Fig. 2 shows the effect of temperature on the degree of swelling of the gel in water .[11] The degree of swelling of the gel is defined as the weight of the absorbed water per the weight of the dried gel. The gel swelled below the CP of P*i*PrOZO and the degree of swelling increased with decreasing temperature. Above the CP, on the other hand, the degree of swelling was very low. These data indicate that the hydrogel has the swelling transition point around the CP of P*i*PrOZO.

In summary, P*i*PrOZO has a CP around 36 °C in water and the CP changed by the additive and its concentration. The hydrogel of P*i*PrOZO showed a swelling transition around the CP of P*i*PrOZO. The CP of P*i*PrOZO is near the temperature of human beings, and hence, P*i*PrOZO and its hydrogel are expected to be applied to biomaterials having a thermo-sensitive function. Further investigations of applications of P*i*PrOZO to thermo-sensitive polymeric materials are now under progress in our laboratory.

References

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2) T. Okano, Y. H. Bae, H. Jacobs, and S. W. Kim, *J. Controlled Release*, **11**, 255(1990).

3) S. Kobayashi, *Prog. Polym. Sci.*, **15**, 751(1990).

4) S. Kobayashi and H. Uyama, *Polym. News*, **16**, 70(1991).

5) T. T. Chiu, B. P. Thill, and W. J. Fairchok, "Poly(2-ethyl-2-oxazoline): A New Water- and Organic Soluble Adhesive," in "Water Soluble Polymers," ed by J. E. Glass, A. C. S., (1986), p.425. To our knowledge, PEtOZO has not been used as thermo-sensitive polymers. This may be because CP of

PEtOZO is too high to design or prepare functional polymers possessing thermo-sensitivity.

6) S. Kobayashi, T. Igarashi, Y. Moriuchi, and T. Saegusa, *Macromolecules*, **19**, 535(1986).

7) The CP value was measured as follows. Aqueous solutions of P*i*PrOZO were placed in a test tube immersed in a polyethylene glycol bath which was heated at a rate of approximately 0.5 °C/min. The temperature at which the solution abruptly turned cloudy was readily detected by visual observation. The measurements were carried out at least three times and the average of these values was taken here as a CP value.

8) E. D. Goddard, *Colloid Surf.*, **19**, 255(1986).

9) S. Kobayashi, M. Kaku, S. Sawada, and T. Saegusa, *Polym. Bull.*, **13**, 447(1985).

10) The hydrogel was prepared as follows. Under argon, 2.8 g of P*i*PrOZO macromonomer (**1**), 1.2 g of ethylene glycol dimethacrylate, and 0.16 g of 2,2'-azobis(2,4-dimethylvaleronitrile) in a mixed solvent of 25.2 g of methanol and 10.8 g of water were incubated with shaking at a frequency of 150 times per min in a thermostat. The copolymerization was carried out for 48 h at 56 °C to give slightly opaque and stable dispersion. The hydrogel was isolated by ultrafiltration through a membrane (ADVANTEC Q0100, Mw cut-off 10 000). Yield 3.37 g (84%).

11) For the measurement of the degree of swelling, the hydrogel film was prepared by casting method; first the gel was again redispersed in methanol to the slightly opaque solution. The solution was cast on TEFLON sheet and kept for 2 days at 30 °C to evaporate the solvent. Then, the film was dried in vacuo at room temperature. The degree of swelling was determined as follows. The film was immersed in water at a desired temperature, taken out from the water and wiped with filter paper to remove excess water on the film surface. The polymer film was weighted at given time intervals until the weight value became constant.

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