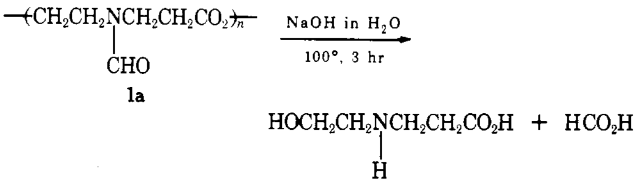
141-143° (lit.[3] mp 145-147°). *Anal.* Calcd for $C_5H_{11}NO_3$: C, 45.10; H, 8.33; N, 10.52. Found: C, 45.18; H, 8.31; N, 10.43.

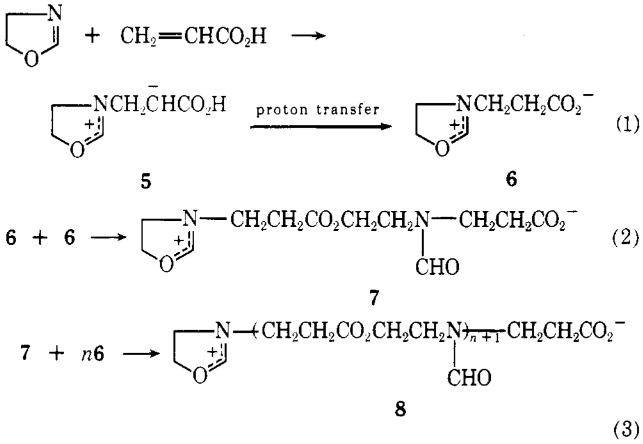


$$-(CH_2CH_2\underset{CHO}{N}CH_2CH_2CO_2)_n- \xrightarrow[100°,\ 3\ hr]{NaOH\ in\ H_2O} HOCH_2CH_2\underset{H}{N}CH_2CH_2CO_2H + HCO_2H$$

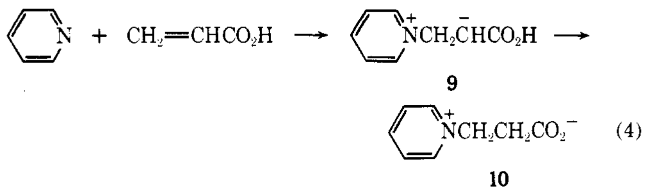
1a 4

Based on the above findings the structure of the OXZ-AA copolymer is expressed also by **1a**. Furthermore, it should be noted that pendant carboxyl groups were not detected in the copolymer; *i.e.*, the vinyl polymerization of AA did not occur during the copolymerization. A mixture of 0.163 g of the OXZ-AA copolymer and 1.86 g of *N,N*-dimethylformamide was allowed to stir at 50°. After 30 hr, the copolymer has completely solved in dimethylformamide. The molecular weight of the copolymer was even higher than that of the OXZ-BPL copolymer. It was measured by vapor pressure osmometry in dimethylformamide at 55° and found to be 13,200. This is interestingly compared with the OXZ-BPL copolymer, *i.e.*, the molecular weight of the latter copolymer was at most 4100.[2]

The OXZ-AA copolymerization can reasonably be formulated by eq 1-3. The Michael-type adduct **5** is first formed which is followed by the proton transfer to give the betaine **6**. Once **6** is formed in the reaction system the subsequent processes should be similar to those of the OXZ-BPL copolymerization.[2] In other words the betaine **6** is a common intermediate in the 1:1 alternating copolymerizations of both OXZ-AA and OXZ-BPL systems; 2 mol of **6** forms the dimeric zwitterion **7** in which the ring-opening isomerization of OXZ is involved as shown in eq 2. Then, successive attack of **6** to **7** takes place to give the macrozwitterion **8**. Thus, the propagation proceeds through the reaction of carboxylate end of the macrozwitterion **8** with the oxazolinium of the betaine **6**.



The OXZ monomer is a base like pyridine. The formation of a betaine **10** from AA and pyridine may relevantly be mentioned here for rationalizing the betaine intermediate **6**. A mixture of 7.5 mmol each of AA and pyridine in 2 ml of acetonitrile was kept at 80° for 7 hr. After work-up a betaine **10** was isolated in 44% yield as a white crystal, mp 131-132° (lit.[3] mp 132-134°). The structure of **10** was further confirmed by nmr analysis. The nmr spectrum of **10** in D_2O showed aromatic proton signals at δ 9.0∼7.8 due to the pyridinium (5 H), a triplet at δ 4.76 due to α-methylene protons (2 H) of nitrogen atom and a triplet at δ 2.94 due to α-methylene protons (2 H) of carboxylate group. The formation of **10** involves the proton transfer process of the adduct **9** (eq 4). The betaine **10** has been prepared from pyridine and BPL by Gresham *et al.*[3]



So far as we know this is the first example of the 1:1 alternating copolymerization between a cyclic monomer and a vinyl monomer.

Takeo Saegusa,* Shiro Kobayashi, and Yoshiharu Kimura
Department of Synthetic Chemistry, Faculty of Engineering
Kyoto University, Kyoto, Japan

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Hydrolysis of *p*-Nitrophenyl Acetate by a Bifunctional Nucleophilic Polymer Catalyst

The hydrolysis of phenyl esters catalyzed by imidazole-containing polymers has been studied extensively as models of esterolytic enzymes.[1] Apart from a few exceptional cases,[2] the efficiency of the imidazole catalysis is limited by the rate-determining acylation step.

The hydroxamate anion is one of the most powerful nucleophiles[3] and, therefore, its use as catalyst in the hydrolysis of phenyl esters should be quite interesting. This has been done to a limited extent in small-molecule systems,[4] and it was found that the catalytic efficiency was rather limited because of the slow decomposition of the acyl hydroxamate intermediate. It is expected from these results that high esterolytic efficiencies may be attained by combining these two complementary functions. For this purpose, we prepared a water-soluble copolymer containing the hydroxamate and imidazole functions and examined its catalytic efficiency in the hydrolysis of *p*-nitrophenyl acetate (PNPA), in comparison with that of a copolymer containing only the hydroxamate function.

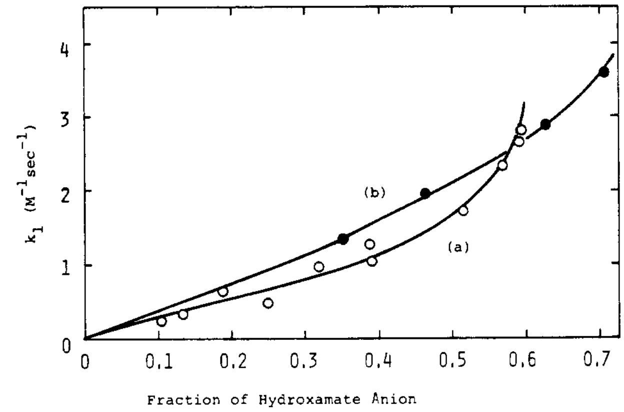

Figure 1. Acylation of hydroxamate copolymers by PNPA. Reaction condition: 30°, 0.1 *M* KCl, 28.9% (v/v) EtOH-H_2O; 0.15 *M* barbital buffer. Rate of acylation = $k_1[\text{PNPA}][\text{PHA}]_{\text{total}}$: (a) PHA-MIm-AAm copolymer, $[\text{PHA}]_{\text{total}} = 6.60 \times 10^{-4}$ *M*, [PNPA] = 1.12×10^{-2} *M*; (b) PHA-AAm copolymer, $[\text{PHA}]_{\text{total}} = 5.52 \times 10^{-4}$ *M*, [PNPA] = 4.02×10^{-5} *M*.

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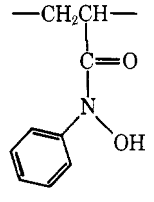
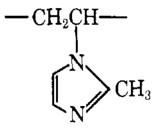
Table I
Copolymers

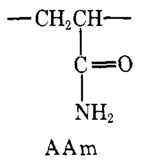
Polymer	Composition (%)[a] PHA	MIm	AAm		pK_a[b]	n'[b]	pK_{int}[b]	[η][c]
PHA-MIm-AAm	10	62	28	PHA unit	9.24	1.33	8.96	0.05
				MIm unit	6.60	1.64	7.22	
PHA-AAm	10		90		9.12	1.45	8.72	0.32

[a] Determined by uv and potentiometric titrations and by nmr spectroscopy. [b] 30°, 0.1 M KCl; 28.9% (v/v) EtOH–H_2O; pK_a = pH + n' log [(1 − α)/α], where α = fraction of the neutral species. pK_{int} = lim ($\alpha \rightarrow 1$) pK_a. [c] 30°; 0.1 M aqueous KCl.

A ternary copolymer (PHA-MIm-AAm) was prepared in CH_3CN at 70° with azobis(isobutyronitrile) as initiator from O-acetyl N-phenylacrylohydroxamate (bp 100 to 110° (0.08 mm)), 1-vinyl-2-methylimidazole, and acrylamide. The first monomer was synthesized by reaction of acetyl chloride and N-phenylacrylohydroxamic acid (mp 90 to 91°).[5] The acyl group in the copolymer was rather labile, and separation and purification of the original (no NH_2NH_2 treatment) copolymer always led to deacylation. The polymer was completely deacylated by treating in methanol with hydrazine at room temperature for 24 hr. A binary copolymer (PHA-AAm) was similarly prepared from O-acetyl N-phenylacrylohydroxamate and acrylamide. This copolymer was more resistant to hydrolysis than the ternary copolymer. The characterization of these copolymers was carried out by uv and potentiometric titrations and by nmr spectroscopy, as summarized in Table I.


PHA


MIm


AAm

The reaction of PNPA with the ternary copolymer was followed by determining the p-nitrophenolate anion released at 401 nm over the pH range of 7–9. Typical burst kinetics were observed with excess PNPA—the initial rapid liberation of p-nitrophenol due to acylation of the hydroxamate present and the subsequent slower release due to regeneration of the hydroxamate group through decomposition of the acyl intermediate. The kinetic data were analyzed by the method of Bender *et al.*,[6] and the rate constants of acylation (k_1) and deacylation (k_2) are plotted in Figures 1 and 2, respectively.

The reaction of PNPA with the binary copolymer showed similar kinetic characteristics. However, the second stage was too slow to determine the rate of deacylation accurately. Therefore, the deacylation was studied on the original copolymer of O-acetyl N-phenylacrylohydroxamate and acrylamide. This reaction was followed by the increase of the absorption at 300 nm due to the hydroxamate anion formed. The rate data given in Figure 2 were obtained by extrapolation to the zero buffer concentration.

The rate of acylation increased, as expected, with increase in the anionic form of the hydroxamic group (Figure 1), and it was quite similar between the two polymers. Therefore, it appears that the imidazole unit is not essentially involved in the acylation step of the ternary copolymer. The upward curvatures observed indicate that the nucleophilicity of the respective hydroxamate anion increases with the increasing degree of dissociation.

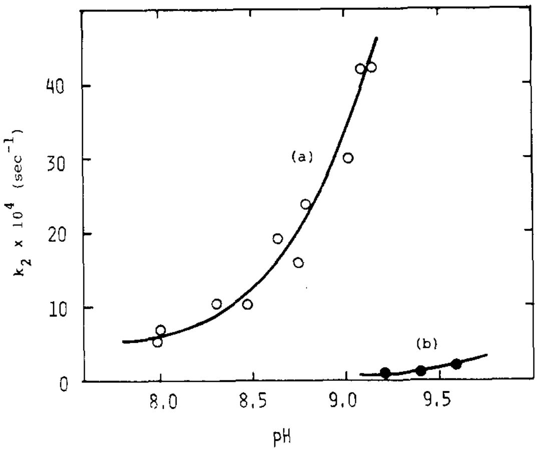


Figure 2. Deacylation of O-acetyl hydroxamates. Reaction condition: 30°, 0.1 M KCl, 28.9% (v/v) EtOH–H_2O; 0.05–0.2 M barbital buffer. The k_2 values were obtained by extrapolation to the zero buffer concentration: (a) ternary copolymer; the rate was determined from the burst kinetics of the reaction of PHA-MIm-AAm copolymer with PNPA; (b) binary copolymer; the rate was determined from the deacylation of the acylated PHA-AAm copolymer.

The rates of deacylation of the ternary copolymer were much greater than those of the binary copolymer. The rate difference amounted to approximately 40-fold at pH 9.1. Thus, the imidazole unit undoubtedly accelerated the deacylation process, and the overall catalytic efficiency of the ternary copolymer increased correspondingly. The imidazole unit may help deacylation either as a nucleophile or as a general base.

The rate of deacylation might be simply thought to be proportional to the content of the neutral imidazole unit. However, this is not the case. When the first-order rate constants of deacylation were plotted against the fraction of the neutral imidazole unit (α_{MIm}) in the polymer, it showed a steep rise as α_{MIm} approached 1.0. The deacylation assisted by the neutral imidazole unit may be more efficient when a tight polymer coil is formed by deprotonation of the imidazole unit. The increased efficiency of polymer catalysts based on the intramolecular aggregation has been mentioned in several cases.[7]

T. Kunitake,* Y. Okahata, and R. Ando
Department of Organic Synthesis, Faculty of Engineering
Kyushu University, Fukuoka, Japan

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