Synthesis and Biocidal Activities of Polymer. IV. Antibacterial Activity and Hydrolysis of Polymers Containing Diphenyl Ether

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SYNOPSIS

The antibacterial monomer, 2,4,4'-trichloro-2'-acryloyloxydiphenyl ether (AcDP) was synthesized from 2,4,4'-trichloro-2'-hydroxydiphenyl ether (DP) and acryloyl chloride in the presence of dry THF at 20°C. Copolymers of AcDP with acrylic acid [poly(AcDP-*co*-AA)] or 2-hydroxyethyl methacrylate [poly(AcDP-*co*-HEMA)] were synthesized using BPO as a thermal initiator at 70°C. The synthesized poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) were identified by IR and ^{1}H-NMR spectra. The monomer reactivity ratios, r_1 (AcDP) and r_2 (AA), determined by the Kelen–Tüdös method, were 0.21 and 1.28, respectively. The number average molecular weights of poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) were 2400 and 3000, respectively. The glass transition temperatures of poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) were 87 and 50°C, respectively. The rate of hydrolysis decreased in the order of poly(AcDP-*co*-AA) > AcDP > poly(AcDP-*co*-HEMA) > poly(AcDP). The antibacterial activities of poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) were studied against *Staphylococcus aureus* by the shake flask test. The antibacterial activity of poly(AcDP-*co*-AA) was higher than that of poly(AcDP-*co*-HEMA). The trend of magnitude of the antibacterial activities for copolymers containing the AcDP unit was in agreement with that of the rate of hydrolysis for the copolymers. © 1996 John Wiley & Sons, Inc.

INTRODUCTION

Polymeric biocides prepared by chemically bonding the biocides on polymers have attracted much interest because of their long-lasting biocidal activities. A polymer-bound biocide may be slowly released from the polymer to serve its purpose or, alternatively, the polymer itself may exhibit biocidal properties. Polymeric bactericides can significantly reduce losses associated with volatilization, photolytic decomposition, dissolution, and transport. Moreover, increased efficiency, selectivity, and handling safety are additional benefits that may be realized. Therefore, it may be expected that polymeric bactericides offer great promise for enhancing the efficacy of some existing bactericides as well as reducing the environmental problems associated with others.

Apostolatos et al.[1] reported that the mixture of 2,4,4'-trichloro-2'-hydroxydiphenyl ether (DP) and 3,5,4'-tribromosalicylanilide was effective against both gram-positive and gram-negative bacteria. Finzi and Grimaldi[2] studied bactericidal power of DP against hospital-isolated bacteria. Carol and Rutherford[3] reported the antimicrobial effect for a mixture of DP with soap and acyl isethionate salts. They found that the antimicrobial activity of the DP-containing mixture was greater than that of soap itself. Viscose film[4] obtained from cellulose mixed with DP and a sodium hydroxide solution showed a clear bacteria-free zone against both *Staphylococcus aureus* SG 511 and *Escherichia*

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coli 92. Saito et al.[5] studied the insect repellent agent containing DP and vinyl polymers for household textiles. It repelled *Tyrophagus putrescentiae* effectively.

In this work, we synthesized 2,4,4′-trichloro-2′-acryloyloxydiphenyl ether (AcDP) by reacting acryloyl chloride (Ac) with 2,4,4′-trichloro-2′-hydroxydiphenyl ether (DP). DP was selected for its bactericidal activity against *Staphylococcus aureus*, existing in fiber, paper, latex, rubber, machine oil, leather, plastic, coatings, cosmetic articles, and packaging materials.[6–8] Copolymers of AcDP with acrylic acid (AA) or 2-hydroxyethyl methacrylate (HEMA) were synthesized. The copolymer compositions were analyzed quantitatively by elemental analysis or UV spectroscopy. The monomer reactivity ratios, r_1 (AcDP) and r_2 (AA) were determined by the Kelen–Tüdös method. The hydrolytic behaviors of monomer and polymers were studied by gas chromatography. The antibacterial activities of monomer and polymers were investigated against *Staphylococcus aureus* by the shake flask test.

EXPERIMENTAL

Materials

2,4,4′-Trichloro-2′-hydroxydiphenyl ether (DP; Ciba-Geigy) was recrystallized from *n*-hexane. Acryloyl chloride (Ac; Aldrich) was used without further purification. Triethylamine (Junsei) was refluxed with acetic anhydride and with KOH and finally distilled. Acrylic acid (AA; Junsei) was distilled from copper powder under reduced pressure. 2-Hydroxyethyl methacrylate (HEMA; Aldrich) was washed twice with 5% aq. NaOH and three times with water, then dried with Na_2SO_4 and distilled under nitrogen at reduced pressure. Benzoyl peroxide (BPO; Junsei) was dissolved in $CHCl_3$ and precipitated by adding an equal volume of methyl alcohol (MeOH; Junsei). Cyclohexanone (Junsei), *N,N*-dimethylformamide (DMF; J. T. Baker), tetrahydrofuran (THF; J. T. Baker), and other chemicals were purified by the standard procedures. Poly(ethylene-*co*-vinyl acetate) (EVA) having 40% of vinyl acetate (Intrinsic viscosity; 0.70 dL g^{-1}, Melt index; 57) was used as received from Aldrich. 2-*t*-Butyl-4-methylphenol (BMP) was used as received from Fluka. Beef extract (Difco), bacto-peptone (Difco), agar (Difco), tryptone (Aldrich), dextrose (Aldrich), potassium phosphate (Aldrich), and a bacteria, *Staphylococcus aureus* ATCC 6538P, were supplied from Pusan Urethane Co., Korea.

Instruments

IR spectra were taken on a Nicolet 710 FT-IR spectrophotometer using KBr pellet. ^{1}H-NMR spectra were recorded on a Jeol JSM-PMX 60SI spectrophotometer. UV spectra were taken on a Shimadzu 2100 spectrophotometer. Elemental analyses were performed by an elemental analyzer (EA; Carlo Erba Instruments, EA-1108). Gas chromatograms were recorded on a Hewlett–Packard 5890 Series II gas chromatograph (GC). Average molecular weight was determined by gel permeation chromatography (GPC; Waters, 150-C). Thermal properties were recorded on a Du Pont 910 differential scanning calorimeter (DSC) and on a Du Pont 951 thermogravimetric analyzer (TGA).

Synthesis of Monomer and Polymers

2,4,4′-Trichloro-2′-acryloyloxydiphenyl ether (AcDP)

AcDP was prepared by the reaction of 2,4,4′-trichloro-2′-hydroxydiphenyl ether (DP) and acryloyl chloride (Ac) in the presence of triethylamine. Details of synthesis and characterization procedure were reported in a previous paper.[9]

Poly(2,4,4′-trichloro-2′-acryloyloxydiphenyl ether-co-acrylic acid) [Poly(AcDP-co-AA)]

Copolymerization of AcDP with AA was carried out with BPO in cyclohexanone at 70°C. A series of copolymerizations, in which the feed ratios of AcDP (M_1) to AA (M_2) were varied in the range of 0.33 to 3.00, yielded copolymers over a wide range of compositions. The copolymerizations were stopped be-

Table I Reaction Parameters for the Copolymerization of AcDP (M_1) and AA (M_2) with BPO in Cyclohexanone at 70°C and Copolymer Composition

Exp. No.	Feed Ratio (M_1 : M_2)	Conversion (%)	M_1 in Copolymer by EA (mol %)
A-1	7.5 : 2.5	8.8	54.4
A-2	7 : 3	9.6	48.4
A-3	6 : 4	9.1	41.7
A-4	5 : 5	9.5	34.0
A-5	4 : 6	9.0	27.3
A-6	3 : 7	8.7	21.1
A-7	2.5 : 7.5	9.2	18.7

[M]: 9.72×10^{-2} mol/L, [BPO]: 2.46×10^{-4} mol/L.

Table II Characteristics of Polymers Used for Antibacterial Activity Test

Polymer	m_1[a]	$\bar{M}_w$	$\bar{M}_n$	$\bar{M}_w/\bar{M}_n$	T_g (°C)	T_d (°C)
Poly(AcDP-*co*-AA)[b]	40.0	4900	2400	2.04	87	232
Poly(AcDP-*co*-HEMA)[c]	53.8	6900	3000	2.30	50	321
Poly(AcDP)[d]	100	4600	2700	1.70	73	—

[a] Mol % of AcDP in polymer.
[b] Poly(2,4,4′-trichloro-2′-acryloyloxydiphenyl ether-*co*-acrylic acid), [AcDP] = 5.33×10^{-3} mol, [AA] = 2.19×10^{-3} mol, [BPO] = 3.84×10^{-5} mol.
[c] Poly(2,4,4′-trichloro-2′-acryloyloxydiphenyl ether-*co*-2-hydroxyethyl methacrylate)
[d] Poly(2,4,4′-trichloro-2′-acryloyloxydiphenyl ether), the data were taken from Ref. 13.

fore 10% conversion was reached. Taking one example as a typical copolymerization of $M_1/M_2 = 1$, both AcDP and AA solutions were prepared to 9.72×10^{-2} mol/L in cyclohexanone, respectively. Then, 5 mL of each solutions and 4.95×10^{-6} mol of BPO were introduced into a dry polymerization tube equipped with a magnetic stirring bar and a septa cap. The solution was deoxygenated by purging with purified N_2 gas. The tube was sealed and placed in a regulated thermostat bath at 70°C for fixed periods of time. The polymer solution obtained was precipitated in excess *n*-hexane. The precipitate was collected by filtration and dried under vacuum to constant weight.

Poly(2,4,4′-trichloro-2′-acryloyloxydiphenyl ether-co-2-hydroxyethyl methacrylate) [Poly(AcDP-co-HEMA)]

Copolymerization of AcDP (3.17×10^{-3} mol) with HEMA (1.19×10^{-3} mol) was carried out with BPO (2.23×10^{-5} mol) in 20 mL of cyclohexanone at 70°C. The polymerization procedure was the same as that of poly(AcDP-*co*-AA).

Characterization of Polymers

The compositions of poly(AcDP-*co*-AA) were determined by quantitative elemental analyses[10] based on the difference between the weight percents of oxygen in copolymers. The composition of poly(AcDP-*co*-HEMA) was determined by quantitative UV analysis[11] using DMF at 275.9 nm.

Molecular weights were determined by GPC using nonaqueous Microstyragel column and monodisperse polystyrene as a standard at 40°C. The concentrations of polymers were 0.1% or less.

Glass transition temperatures (T_g) were determined using a DSC on sample sizes averaging 10 mg under nitrogen at a heating rate of 10°C/min. Thermal stability was examined with a TGA at a scanning rate of 10°C/min under nitrogen atmosphere.

Hydrolysis of Monomer and Polymers

Sample preparation for release experiments was as follows: 100 mg of AcDP or its polymers and 5 mg of 2-*t*-butyl-4-methylphenol (BMP) as an internal standard for gas chromatograph analysis were placed

Table III Kelen–Tüdös Parameters for Determination of Monomer Reactivity Ratios for the Copolymerization of AcDP (M_1) and AA (M_2)

Exp No.	$X = \frac{M_1}{M_2}$	$Y = \frac{m_1}{m_2}$	X^2	$Y - 1$	$F = \frac{X^2}{Y}$	$G = \frac{X(Y-1)}{Y}$	$\alpha + F$	$\eta = \frac{G}{\alpha + F}$	$\xi = \frac{F}{\alpha + F}$
A-1	3.00	1.20	9.00	0.20	7.50	0.50	9.42	0.05	0.80
A-2	2.33	0.94	5.43	−0.06	5.78	−0.15	7.70	−0.02	0.75
A-3	1.50	0.72	2.25	−0.28	3.13	−0.58	5.05	−0.11	0.62
A-4	1.00	0.52	1.00	−0.48	1.92	−0.92	3.84	−0.24	0.50
A-5	0.67	0.37	0.45	−0.63	1.22	−1.14	3.14	−0.36	0.39
A-6	0.43	0.27	0.18	−0.73	0.67	−1.16	2.59	−0.45	0.26
A-7	0.33	0.23	0.11	−0.77	0.49	−1.10	2.41	−0.46	0.20

$\alpha = 1.92$, r_1 (AcDP) = 0.21, and r_2 (AA) = 1.28.

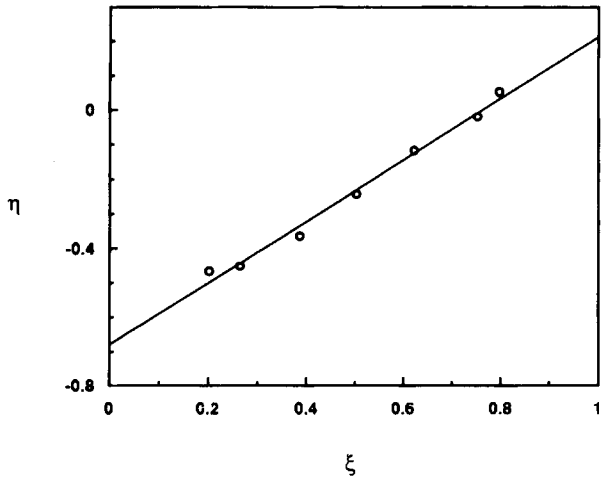

Figure 1 Kelen–Tüdös plot for the copolymerization of AcDP and AA: r_1 (AcDP) = 0.21, r_2 (AA) = 1.28.

in 25 mL of a round-bottom flask equipped with a magnetic stirring bar. After adding 14 mL of DMF and 1 mL of water, the flask was sealed with a septa cap and was let stand at 70°C. Periodically, 5 μL samples were withdrawn and analyzed by GC to determine the amount of products released from the monomer or its polymers.

All chromatography was conducted with a microprocessor-controlled Hewlett–Packard 5890 Series II gas chromatograph. The column was a Hewlett–Packard ultra-2 (0.32 mm i.d. × 25 m). All determinations were performed on 5 μL injections with column temperature programming from 100 to 250°C at a heating rate of 10°C/min and holding at 250°C for 10 min. Both injection and detection temperatures were 250°C. Both the pressure of carrier gas and air were 40 psi.

Accelerated Bacteria Growth Test

Preparation of Specimen, Buffer Solution, Nutrient Broth, Bacterial Culture, and Tryptone Glucose Extract Agar

Poly(AcDP-*co*-HEMA) and poly(AcDP-*co*-AA) were blended individually with poly(ethylene-*co*-vinyl acetate) (EVA; VA content, 40%) at 5 wt % concentration and dissolved in THF (5% solution). Then, test sample films of 0.1~0.13 mm thickness were prepared by casting the solutions on Petri dishes. The Petri dishes containing test samples were dried over 24 h at room temperature and dried under vacuum at 30°C to constant weight. The specimens were prepared by cutting the film into square-shape (5 × 5 cm).

Buffer solution was prepared by taking 1 mL from the mother solution, 34 g of potassium phosphate,

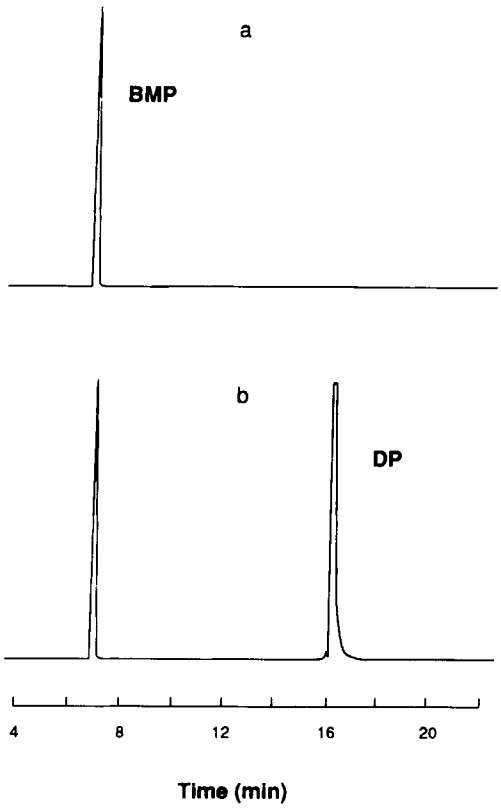

Figure 2 Gas chromatograms of poly(AcDP-*co*-AA) before (a) and after (b) hydrolysis in DMF-H_2O (14/1, v/v).

175 mL of 4% aq. NaOH solution, and 325 mL of sterile distilled water, into 799 mL of sterile distilled water.

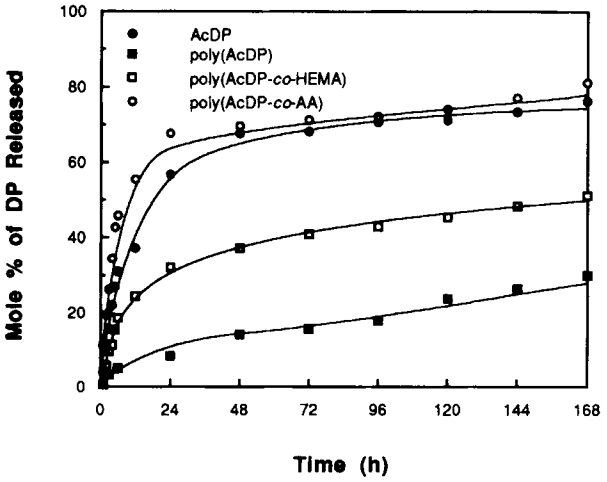

Figure 3 Hydrolysis of monomeric and polymeric bactericides containing DP moiety at 70°C in DMF-H_2O (14/1, v/v).

Nutrient broth was prepared from 3 g of beef extract, 5 g of peptone, and 1000 mL of sterile distilled water.

Bacterial culture was prepared as follows: freeze-dried ampoule of *Staphylococcus aureus* (ATCC 6538P) was opened, and a loopful of culture was smeared to give single colonies on nutrient agar and incubated at 37°C for 24 h. A representative colony was picked off with a wire loop and placed in a 10 mL of nutrient broth, which was then incubated with shaking at 37°C for 18 h. At this stage, the culture of *Staphylococcus aureus* contained ca. 10^8 cells/mL. By diluting with buffer solution, a culture of *Staphylococcus aureus* containing ca. 10^5 cells/mL was prepared.

Tryptone glucose extract agar was prepared from 3 g of beef extract, 5 g of tryptone, 1 g of dextrose, 15 g of agar, and 1000 mL of sterile distilled water.

Antibacterial Assessment

The details of shake flask test are found in the literature,[12] but a brief explanation can be described as follows: exposure of bacterial cells to specimen was started when 5 mL of the bacterial culture containing ca. 10^5 cells/mL was added to 200 mL of an erlenmeyer flask equipped with a screw cap containing 75 mL of buffer solution and/or specimen, which was preequilibrated at 37°C. At this stage, the culture of *Staphylococcus aureus* contained ca. 10^4 cells/mL. After shaking the above solution at 37°C for 1 h, decimal serial dilution was performed twice. Portions (1 mL) were removed and quickly mixed with 15 mL of tryptone glucose extract agar in a Petri dish. At this stage, the culture of *Staphylococcus aureus* contained ca. 10^2 cells/mL. After

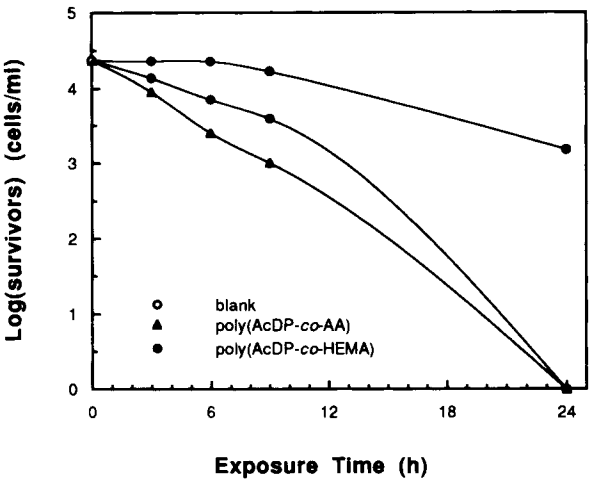

Figure 4 Plot of log(survivors) vs. exposure time for poly(AcDP-*co*-AA), poly(AcDP-*co*-HEMA), and blank against *Staphylococcus aureus*.

Table IV Results of Shake Flask Test on Poly(AcDP-*co*-HEMA) and Poly(AcDP-*co*-AA) against *Staphylococcus aureus* under Different Exposure Times

Sample	Concentration of Antibacterial Agent (wt %)	Exposure Time (h)	Number of Bacteria[a] (*Staphylococcus aureus* ATCC 6538P)	Reduction Percent of Bacteria	Living Cells/mL[b]
Blank	none	0	237	—	23700
		3	230	2.95	23000
		6	227	4.22	22700
		9	167	29.54	16700
		24	15	93.67	1500
Poly(AcDP-*co*-HEMA)[c]	5	3	137	42.19	13700
		6	71	70.04	7100
		9	39	83.54	3900
		24	0	100.00	0
Poly(AcDP-*co*-AA)[d]	5	3	90	62.03	9000
		6	25	89.45	2500
		9	10	95.78	1000
		24	0	100.00	0

[a] The average number of bacteria determined from three times tests of the inoculated solution for a given time.
[b] The living cells per mL is calculated by multiplying the number of colonies counted by the dilution factor.
[c] AcDP content; 53.8 mol % by UV analysis.
[d] AcDP content; 40.0 mol % by elemental analysis.

incubation at 37°C for 24 h, the colonies that were present on the surface of the tryptone glucose extract agar in the Petri dish were counted. The percent reduction of bacteria was calculated as follows:

$$\text{Percent reduction of bacteria} = (B - A)/B \times 100$$

where A is the number of bacteria recovered from the inoculated solution that contain the specimen in the flask and B (blank) is the number of bacteria recovered from the inoculated solution that does not contain the specimen in the flask.

The exposure time (shaking time) of the bacterial cells to buffer solution and the specimen was 0, 3, 6, 9, and 24 h. The living cells/mL was calculated by multiplying the number of colonies counted by the dilution factor:

$$\text{Living cells/ml} = \text{number of colonies} \times \text{dilution factor}$$

RESULTS AND DISCUSSION

Characterization of Poly(AcDP-*co*-AA) and Poly(AcDP-*co*-HEMA)

The IR spectrum of poly(AcDP-*co*-AA) indicated absorptions at 3427 (O—H, AA), 3093 (phenyl ring, AcDP), 1761 (C=O, AcDP), and 1711 (C=O, AA) cm^{-1} with disappearance of vinyl absorptions at 1633 (AcDP) and 1636 (AA) cm^{-1}. From the ^{1}H-NMR spectrum of poly(AcDP-*co*-AA) (solvent; acetone-d_6), several peaks were observed at 0.90~3.40 ($-CH_2CH-$), 6.33~7.50 ($C_{12}H_6$) and 7.90~8.73 (—COOH) ppm. The IR spectrum of poly(AcDP-*co*-HEMA) indicated absorptions at 3436 (O—H, HEMA), 3091 (phenyl ring, AcDP), 1765 (C=O, AcDP) and 1724 (C=O, HEMA) cm^{-1} with disappearance of vinyl absorptions at 1633 (AcDP) and 1637 (AA) cm^{-1}. From the ^{1}H-NMR spectrum of poly(AcDP-*co*-HEMA) (solvent; acetone-d_6), several peaks were observed at 0.57~1.47 (α—CH_3), 1.47~2.47 ($-CH_2-CH-$ and $-CH_2-C-$), 2.47~3.03 (—OH), 3.47~4.47 ($-O-CH_2-CH_2-O-$) and 6.60~7.67 ($C_{12}H_6$) ppm.

The compositions and molecular weights of poly(AcDP-*co*-AA) were listed in Table I.

Characterization results of poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) used for the estimation of antibacterial activity were listed in Table II.

Monomer Reactivity

The reactivity ratio of each monomer was estimated by the Kelen–Tüdös method.[14] Figure 1 shows a typical Kelen–Tüdös plot to determine monomer reactivity ratios, in which the ordinate η and the abscissa ξ are explained in Table III along with other several parameters.

The Kelen–Tüdös plot gives an r_1 value of 0.21 (AcDP) and r_2 value of 1.28 (AA). Since r_1 (k_{11}/k_{12}) is less than unity for the copolymerization of AcDP and AA, AcDP radical addition to the AA monomer occurs more readily than addition of the AcDP radical to the AcDP monomer. This is probably attributed to the steric hindrance of AcDP.

Hydrolytic Behavior of Monomer and Its Polymers

The amount of DP released from the sample was determined by quantitative GC analysis. The details of quantitative GC analysis are found in the literature[15] but a brief explanation can be described as follows: in the internal standard method a known weight ratio of DP and 2-*t*-butyl-4-methylphenol (BMP) as an internal standard was prepared and chromatographed. A straight-line calibration curve was obtained for peak area ratios against weight ratios of DP and BMP. From the calibration curve, the following equation is derived

$$A = 1.216W + 0.001$$

where A is the peak area ratio and W is the weight ratio (DP/BMP).

Considering that the samples before and after hydrolysis show different chromatograms, due to the hydrolysis cleavage of DP, the amount of DP released from monomer and polymers can be easily estimated by using GC. Figure 2 shows gas chromatograms as a typical example of poly(AcDP-*co*-AA) before (a) and after (b) hydrolysis of poly(AcDP-*co*-AA) in DMF-H_2O (14/1, v/v).

The amounts of DP released from AcDP, poly(AcDP),[13] poly(AcDP-*co*-HEMA) and poly(AcDP-*co*-AA) were calculated from the above equation. Figure 3 shows the hydrolytic behaviors of AcDP and its polymers. Polymers such as poly(AcDP) and poly(AcDP-*co*-HEMA) liberate DP more slowly than the corresponding monomer, indicating the effect of steric hindrance on the entropy term of reaction kinetics. Only poly(AcDP-*co*-AA) indicated a higher hydrolysis rate as compared with the

monomer. This fact may be due to the effect of the circumstances surrounding the reaction center. Thus, polar carboxyl groups in the copolymer molecules surrounding the ester linkage attached to DP moiety can increase the attack of water, as compared with the monomer that is not surrounded with such effective polar organic groups, thereby increasing the hydrolysis rate. This result is in agreement with the study of Kamogawa et al.[16] who stated that the rate of hydrolysis for copolymer, poly(2-phenethyl p-styrenesulfonate-*co*-N-vinyl-2-pyrrolidone), was higher than that for the corresponding monomer containing sulfonate ester group, 2-phenethyl p-styrenesulfonate, due to the participation of a neighboring polar pyrrolidone group. A first-order plot gave a straight line, and the values of rate constants, k_1, calculated were $1.70 \times 10^{-5}s^{-1}$, $2.44 \times 10^{-6}s^{-1}$, $9.03 \times 10^{-6}s^{-1}$, and $2.91 \times 10^{-5}s^{-1}$ for AcDP, poly(AcDP), poly(AcDP-*co*-HEMA), and poly(AcDP-*co*-AA), respectively.

It can be said that the hydrolysis of the esters both in the monomer and polymer states does take place with different rates for different chemical structures, thereby making the controlled release of bactericides possible.

Accelerated Growth Studies of Bactericidal Activity

In order to estimate the release behavior of the antibacterial agent from the specimen, the specimen containing 5 wt % of poly(AcDP-*co*-HEMA) or poly(AcDP-*co*-AA) was contacted with *Staphylococcus aureus*-inoculated solution in the flask for fixed periods of time.

All the antibacterial activity tests for samples were performed at least three times, and showed reproducibility within experimental errors. The results were summarized in Table IV. Figure 4 shows plot of log(survivors) vs. exposure time for poly(AcDP-*co*-HEMA) and poly(AcDP-*co*-AA) against *Staphylococcus aureus*. When the specimens were exposed for 3 h, the antibacterial activity of poly(AcDP-*co*-AA) was higher by about 1.5 times than that of poly(AcDP-*co*-HEMA). The trend of the magnitude of the antibacterial activities was in agreement with that of the release rate constant. The antibacterial activities of copolymers of AcDP with hydrophilic comonomers were very excellent compared to those of the blank. This result clearly indicates that the hydrophilicity of copolymer affects the antibacterial activity.

Furthermore, the antibacterial activities of copolymers were increased with increasing the exposure time against *Staphylococcus aureus*. This result clearly indicates that the antibacterial agent was gradually released from the specimen as was stated in the hydrolytic behaviors of polymers.

CONCLUSIONS

In this work, the antibacterial monomer, 2,4,4'-trichloro-2'-acryloyloxydiphenyl ether (AcDP), was synthesized. Poly(2,4,4'-trichloro-2'-acryloyloxydiphenyl ether-*co*-acrylic acid) [poly(AcDP-*co*-AA)] and poly(2,4,4'-trichloro-2'-acryloyloxydiphenyl ether-*co*-2-hydroxyethyl methacrylate) [poly(AcDP-*co*-HEMA)]were synthesized using BPO as a thermal initiator at 70°C, whose copolymer compositions were analyzed by elemental analysis or UV spectroscopy. The monomer reactivity ratios, r_1 and r_2 were determined by the Kelen–Tüdös method; r_1 (AcDP) = 0.21 and r_2 (AA) = 1.28. These values imply that the copolymerization was affected by the steric hindrance of the monomer containing 2,4,4'-trichloro-2'-hydroxydiphenyl ether (DP). Their molecular weights were observed to be low, being in the order of ca. 10^3. In hydrolytic behaviors of monomer and its polymers, a first-order plot gave a straight line, and the values of rate constants, k_1, calculated were $1.70 \times 10^{-5}s^{-1}$, $2.44 \times 10^{-6}s^{-1}$, $9.03 \times 10^{-6}s^{-1}$, and $2.91 \times 10^{-5}s^{-1}$ for AcDP, poly(AcDP), poly(AcDP-*co*-HEMA), and poly(AcDP-*co*-AA), respectively. The antibacterial activities of poly(AcDP-*co*-AA) and poly(AcDP-*co*-HEMA) were studied against *Staphylococcus aureus* by the shake flask test. The antibacterial activities of poly(AcDP-*co*-AA) was higher than that of poly(AcDP-*co*-HEMA). The trend of magnitude of the antibacterial activities was in agreement with that of the release rate constant.

REFERENCES

1. G. N. Apostolatos, J. C. Bohrer, and J. T. Inamorato, U.S. Pat. 3,989,827 (1976).
2. G. Finzi and G. Grimaldi, *Arch. Sci. Med.*, **137**(4), 775 (1980).
3. M. R. Carol and N. J. Rutherford, U.S. Pat. 4,832,861 (1989).
4. J. R. Geigy, Br. Pat. 1,024,022 (March 30, 1966).
5. K. Saito, M. Fujino, and S. Toyama, Jap. Pat. 63,303,901 (1988).

6. Y. Inoue, *Bactericide and Fungicide for a Comfortable Environment,* CMC, Tokyo, 1992.
7. Y. Inoue, *Technology and Market of Bactericide and Fungicide,* CMC, Tokyo, 1990.
8. K. Shibasaki, *Handbook of Bactericide and Fungicide,* Kihoudou, Tokyo, 1986.
9. S. T. Oh, C. S. Ha, and W. J. Cho, *J. Appl. Polym. Sci.,* to appear.
10. T. Otsu and M. Kinoshita, *Experimental Methods in Polymer Synthesis,* Kagaku Tounin Publishing Co., Ltd., Kyoto, 1985, p. 37.
11. E. J. Meehan, *J. Polym. Sci.,* **1**(3), 175 (1946).
12. AATCC Test Method 100-1981.
13. S. T. Oh, C. S. Ha, and W. J. Cho, *Polymer (Korea),* **18**(3), 309 (1994).
14. T. Kelen and F. Tüdös, *J. Macromol. Sci. Chem.,* **A-9**(1), 1 (1975).
15. J. F. Rabek, *Experimental Methods in Polymer Chemistry,* John Wiley and Sons, New York, 1980, p. 375.
16. H. Kamogawa, Y. Haramoto, Y. Misaka, Y. Asada, Y. Ohno, and M. Nanasawa, *J. Polym. Sci. Chem. Ed.,* **23,** 1517 (1985).

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