Synthesis of Chloromethylstyrene-tetraethyleneglycol Dimethacrylate Copolymer Beads Having Various Phenolic Derivatives Immobilized via Amide Bond and Their Antioxidation Activity

Takamasa Nonaka, Shuuji Maeda, Tomonari Ogata, Satoko Nakashima, Tomonori Kawasaki, Seiji Kurihara

Department of Applied Chemistry & Biochemistry, Faculty of Engineering, Kumamoto University, Kurokami 2–39-1, Kumamoto 860-8555, Japan

ABSTRACT: Resins having phenolic derivatives were prepared by treating a resin (RAS-4G), having benzylamino groups, with benzoic acids containing phenolic hydroxyl groups. The RAS-4G was prepared by treating macroreticular chloromethylstyrene-tetraethyleneglycol dimethacrylate (4G) copolymer beads with potassium phthalimide in *N,N*-dimethylformamide, followed by reflux in an ethanol/hydrazine monohydrate mixture. 4-Hydroxy benzoic acid, (2,4-, 3,4-, and 3,5-)dihydroxy benzoic acids, 3,4,5-trihydroxy benzoic acid, etc., were used as benzoic acids with phenolic hydroxyl groups. The antioxidation ability of the resins having phenolic derivatives was investigated against the generation of 1,4-dioxane hydroperoxide. The resins showed high inhibition ability against the generation of hydroperoxide. In particular, the resin (RAS-4G-3,4-DHBA) having two phenolic hydroxyl groups had the highest inhibition ability. The resins were found to act as radical scavengers during the generation of 1,4-dioxane hydroperoxide by UV irradiation in the presence of oxygen. © 2005 Wiley Periodicals, Inc. J Appl Polym Sci 97: 2097–2104, 2005

Key words: antioxidants; functionalization of polymers; high performance polymers; resins; hydroperoxide; radical scavenger

INTRODUCTION

Many kinds of peroxides are known to be influential in industrial chemistry or in our life. For example, peroxides, such as hydrogen peroxide or benzoylperoxide, are used as sterilizers or initiators for polymerization. Recently, many researchers have paid much attention to active oxygen sources from which hydrogen peroxide, super oxide ion, or hydroxyradicals are made in our human body, because they are considered to cause cancer or geriatric diseases.[1–4] It is also known that most aliphatic ethers contain small amounts of their hydroperoxides, which are made by UV irradiation in the presence of oxygen during storage.[5,6] Such hydroperoxides are explosive materials. Therefore, careful attention is required during purification of ethers by distillation. Moreover, it is also known that fats and oils are subject to polymerization or to generation of lipid hydroperoxide by light irradiation in the presence of oxygen during storage. This means that fats or oils are denatured by oxidation.

It has been reported that denaturation of organic compounds, due to oxidation, occurs via the formation of peroxide radicals.[7] On the other hand, phenolic compounds, such as catechol, hydroquinone, or 4-methoxyphenol, have been reported to act as inhibitors of radical chain reactions during the autoxidation of such organic compounds.[3,8–12]

Previously, we have reported on the synthesis of insoluble copolymer beads having phenolic derivatives and their antibacterial activity against *Escherichia coli* (*E. Coli*) or *Staphylococcus aureus* (*S. aureus*), even in salt aqueous solutions.[13] If the resins having phenolic derivatives have antioxidant ability, the generation of peroxides can be prevented by the presence of such resins and they can be easily reused many times after separating them by filtration. A purification process, such as distillation, for the elimination of peroxides is not necessary; and the denaturation of organic compounds, such as ethers, fats, or oils, during storage must be prevented.

In this study, we prepared resins having phenolic derivatives from macroreticular chloromethylstyrene (CMS)-tetraethyleneglycol dimethacrylate (4G) copolymer beads by amination; and following reaction with various benzoic acids with phenolic hydroxyl groups, we investigated the inhibition ability against the gen-

Correspondence to: T. Nonaka.

eration of 1,4-dioxane hydroperoxide in the presence of oxygen by UV irradiation. The relationship between the inhibition ability and the structure of immobilized phenolic derivatives is also discussed.

EXPERIMENTAL

Materials

4-Chloromethylstyrene (CMS) was purchased from Tokyo Kasei Co. (Tokyo, Japan) and was purified by elimination of inhibitors by treating with 1 mol/dm^3 sodium hydroxide solution and distillation under reduced pressure (82–83°C/7mmHg). α,α'-Azobisisobutylonitrile (AIBN) was purified by recrystallization from ethanol. N,N-Dimethylformamide (DMF) was purified by distillation under reduced pressure (50°C/12mmHg) after drying it overnight in the presence of a molecular sieve (Wako Chemical Co. Osaka, Japan). 1,4-Dioxane was purchased from Wako Chemical Co. and passed through an activated alumina column to eliminate hydroperoxides. Other chemical compounds were of reagent grade and used as received.

Preparation of the RCS-4G copolymer beads

Macroreticular CMS–tetraethyleneglycol dimethacrylate (4G) copolymer beads (RCS-4G) were prepared by suspension copolymerization in water using cyclohexane as a diluent. A solution of CMS (0.38mol) and 4G (0.038mol), cyclohexane (72cm^3) (120 vol % to total monomers), and AIBN (5.3mmol) as an initiator was poured into an autoclave with 500cm^3 of 0.2% (w/v) hydroxyethyl cellulose aqueous solution. The mixture was stirred until the monomer solution was dispersed as fine droplets. Then, the suspension was heated to 70°C. Polymerization was carried out at 70°C for 4.5h under stirring. After polymerization, the product was filtered off, washed with hot water (80°C) several times, and immersed in methanol overnight. After drying, copolymer beads with the desired diameter (32–60 mesh) were selected. The content of the chloromethyl group in the copolymer beads was determined by measuring chlorine content in the copolymer beads by the combustion method.[14]

Introduction of benzylamino groups into RCS-4G

RCS-4G (10g) and potassium phthalimide (0.054mol) (2.5M ratio to chloromethyl groups in copolymer beads) were stirred in anhydrous DMF at 100°C for 5h. The intermediate product was filtered off and washed with deionized water and ethanol. After drying, the intermediate product was immersed in a hydrazine monohydrate ethanol solution (ethanol/hydrazine monohydrate = 4/1(v/v)), and the mixture was refluxed at 100°C for 6h to hydrolyze the intermediate

product. After reflux, the product (RAS-4G) was alternately washed several times with ethanol and deionized water, and then purified by Soxhlet extraction with methanol for 12h. The introduction of benzylamino groups was confirmed by infrared spectra and elemental analysis.

Measurement of pore structure

Specific surface areas of the resins obtained were measured on a Yuasa surface area apparatus (BET method). Pore volume and radius of the resins were determined on a Carlo-Erba mercury porosimeter (Model 220) (Italy).

Measurement of anion exchange capacity

In a glass-stoppered Erlenmeyer flask was placed 0.25g of the resin, followed by an addition of 50 cm^3 of 0.1mol dm^{-3} HCl solution. The mixture was shaken at 30°C for 15h, and the resin was filtered off. 2mol dm^{-3} NaHCO$_3$ solution and 5cm^3 of 2% (w/v) starch solution were added to 10cm^3 of the supernatant. Then the anion exchange capacity was determined by titrating chloride ions in the supernatant with 0.1 mol dm^{-3} AgNO$_3$ solution using Fluorescein as an indicator. The value of anion exchange capacity obtained indicated the content of benzylamino groups in the copolymer beads.

Introduction of phenolic derivatives into copolymer beads

RAS-4G (2g) and benzoic acids having phenolic hydroxyl groups(1.2M ratio to the benzylamino groups) were added into 30cm^3 of DMF and stirred at 0–5°C for about 30 min. An amount of N,N'-dicyclohexylcarbodiimide (DCC), equal to that of the phenolic derivatives and dissolved in DMF, was added dropwise to the above mixed solution over 3 min at 0–5°C. After addition, the mixture was stirred at 0–5°C for 2 h, then at 20°C for 2 h, and further at 60°C for 4 h. After removal of the urea derivative formed, by decantation, the resins were filtered off, washed with methanol several times, and then purified by Soxhlet extraction with methanol for 24h. After drying, the resins having phenolic derivatives were obtained. The content of phenolic derivatives, introduced into the resins, was calculated by the difference of anion exchange capacity of the resins before and after introduction of phenolic derivatives into copolymer beads.

Measurements of inhibition ability of the resins against the generation of 1,4-dioxane hydroperoxide

About 0.1g of the resins was placed into a quartz tube, and 10cm^3 of pure 1,4-dioxane containing no hydroper-
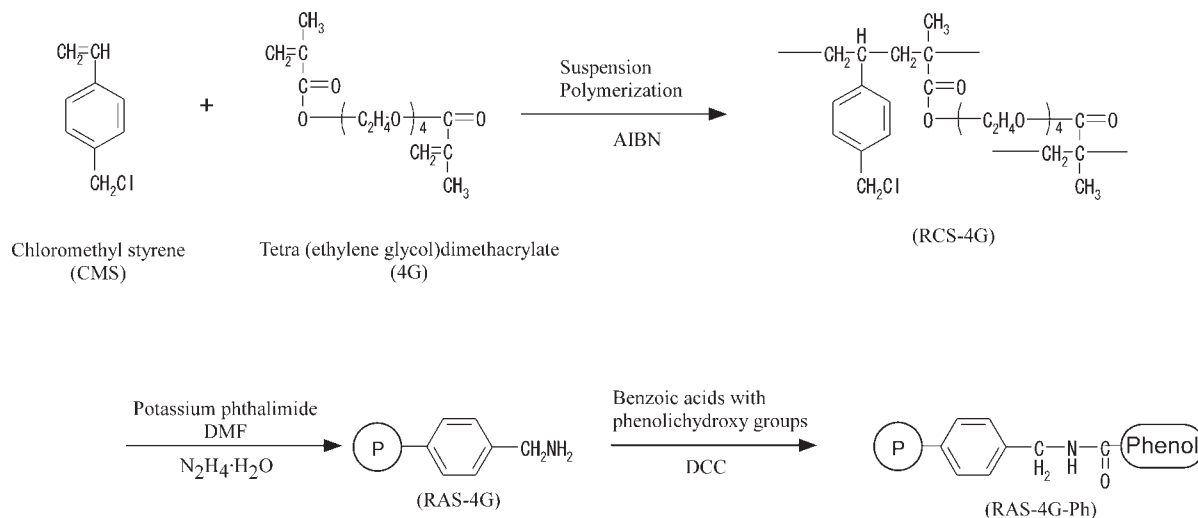
Figure 1 Synthesis of resins containing benzylamino groups or phenolic derivatives.

oxide was added. After oxygen was bubbled into 1,4-dioxane for 5 min in the dark at 25°C, the tube was sealed and UV light (>300nm) (High pressure mercury lamp; SHL-100UVQ2; Toshiba Co., Tokyo, Japan; *c.a.* 5mW/cm^2) was used to irradiate the tube from a 20 cm distance with magnetic stirring. The hydroperoxide content of the 1,4-dioxane generated was determined by iodometry as follows:[15] After irradiation, the resin was removed by decantation, and 0.12mol dm^{-3} FeCl$_3$ acetic acid solution and 0.2cm^3 of saturated KI solution was added to 5cm^3 of the 1,4-dioxane containing hydroperoxide under N$_2$ atmosphere. 10cm^3 of deionized water was added and titrated with 0.02mol dm^{-3} sodium thiosulfate solution using 1 wt % starch solution as an indicator. A blank test was performed using the same procedure. The concentration of hydroperoxide was calculated using eq. (1):

Concentration of hydroperoxide in 1,4-dioxane

$$= (a - b)X(N)/2(\text{mmol/dm}^3) \quad (1)$$

where a, b, and N are the volumes (cm^3) of 0.02mol/dm^3 sodium thiosulfate solution in the presence of the resins and in the absence of the resins, and the factor of 0.02mol/dm^3 sodium thiosulfate solution, respectively.

Radical scavenging ability of the resins having phenolic derivatives

2,2-Diphenypicrylhydrazil (DPPH) is known as a metastable radical bearing a radical electron stabilized by resonance. A solution of DPPH is dark purple, due to the maximum absorption peak at 520nm, and this absorption disappears when the radical is lost. Therefore, the radical scavenging ability of the resins having phenolic derivatives was evaluated by measuring the

change in the absorption intensity at 520nm, after the toluene solution of DPPH was shaken with the resins in the presence of the resins for a prescribed time.

RESULTS AND DISCUSSION

Preparation of the resins having phenolic derivatives

The scheme of the synthesis of the resins having phenolic derivatives is shown in Figure 1.

First, macroreticular copolymer beads (RCS-4G) (CMS:4G = 90:10M ratio) were prepared by suspension copolymerization of CMS and 4G using AIBN as an initiator, as described before.[13] The RCS-4G had 1.1 cm^3/g of pore volume, 500Åof average pore radius, and 30 m^2/g of specific surface area. Next, the RCS-4G was treated with potassium phthalimide in DMF at 100°C for 5h, followed by reflux at 100°C for 6h in an ethanol-hydrazine monohydrate mixture. The RCS-4G had chlorine content of about 5.0 mmol/g, and the aminated resin (RAS-4G) had residual chlorine content of about 0.4 mmol/g. This indicates that about 92% of the chloromethyl groups in the RCS-4G were converted to benzyl amino groups. The introduction of phenolic derivatives was brought about by the reaction of benzylamino groups in the RAS-4G with carboxyl groups in various benzoic acids having phenolic hydroxy groups. In this study, we used various benzoic acids having different amounts of phenolic hydroxyl groups to introduce phenolic derivatives to the resin (RAS-4G) via amide bond. 4-Hydroxybenzoic acid (4-HBA), 2,4-dihydroxybenzoic acid (2,4-DHBA), 3,4-dihydroxybenzoic acid (3,4-DHBA), 3,5-dihydroxybenzoic acid (3,5-DHBA), 3,4,5-trihydroxybenzoic acid (3,4,5-THBA), 3,5-di-*tert*-butyl-4-hydroxy-benzoic acid (D-*t*-BHBA), tannic acid (TA), and 6-hydroxy-2,5,7,8-tetramethyl chroman-2-carboxylic acid (HTMCA) were used as
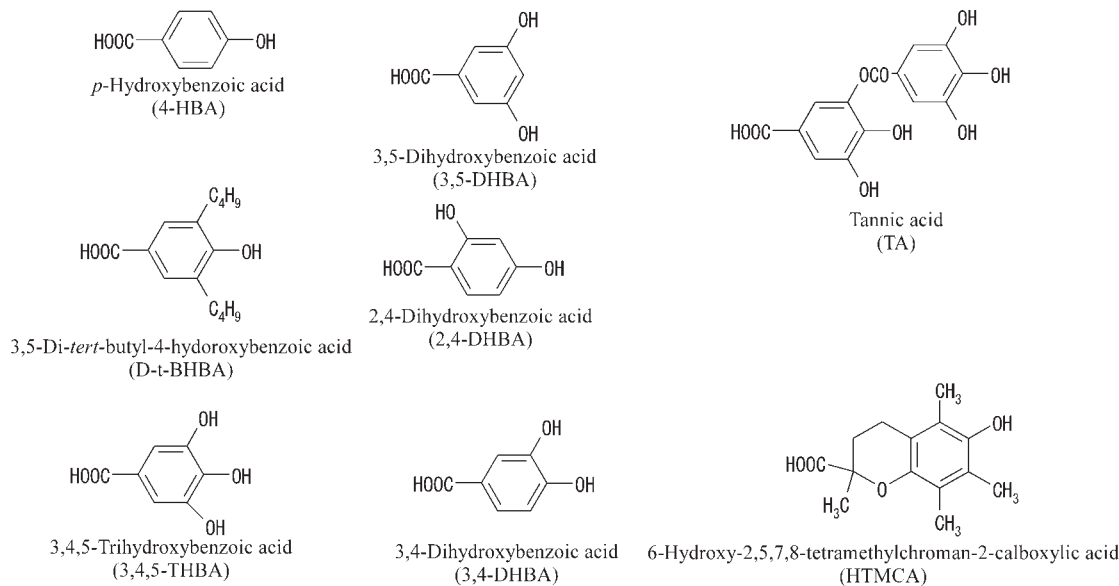
Figure 2 Structures of benzoic acids with phenolic hydroxyl groups introduced into the resin.

the benzoic acids having phenolic hydroxyl groups. The structures of these benzoic acids are shown in Figure 2.

The amount of introduced phenolic derivatives is shown in Table I, together with abbreviations for the resins. All phenolic derivatives were introduced into the resins by the reaction of benzylamino groups more than 80% in the RAS-4G with various benzoic acids having phenolic hydroxyl groups. Table I also suggests that a small amount of benzylamino groups still remains in the resins having phenol derivatives. The infrared spectra of the RCS-4G, RAS-4G, and RAS-4G-3,5-DHBA are shown in Figure 3. The reduced absorption band at 1260 cm^{-1} is due to -CH$_2$Cl, and new absorption bands, at 3400 and 1710 cm^{-1} due to -NH$_2$ groups, were observed in the RAS-4G. The absorption peak at 3300 cm^{-1} due to OH groups became broad because of the introduction of phenolic hydroxyl groups, and a new absorption peak at 1650 cm^{-1} due to amide II appeared in the RAS-4G-3,5-DHBA. These
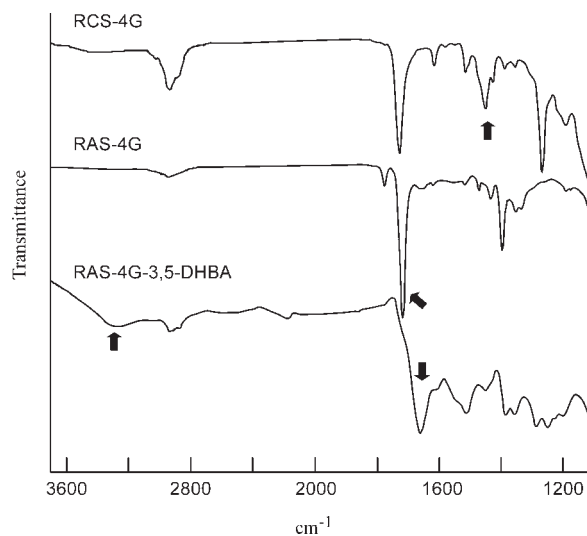
results indicate the introduction of benzylamino groups into the RCS-4G and of 3,5-DHBA into the RAS-4G via the amide bond.

Generation of 1,4-dioxane hydroperoxide by UV irradiation in the presence of oxygen

Most organic compounds have a tendency to autoxidize by light irradiation in the presence of oxygen during storage.[16,17] In particular, it is reported that ethers autoxidize easily and become ether hydroperoxides; we can make 1,4-dioxane hydroperoxide from purified 1,4-dioxane by UV irradiation in the presence of oxygen.[18] Figure 4 shows the time line of the con-

TABLE I
Content of Amino Groups and Phenolic Derivatives Introduced in the Resins

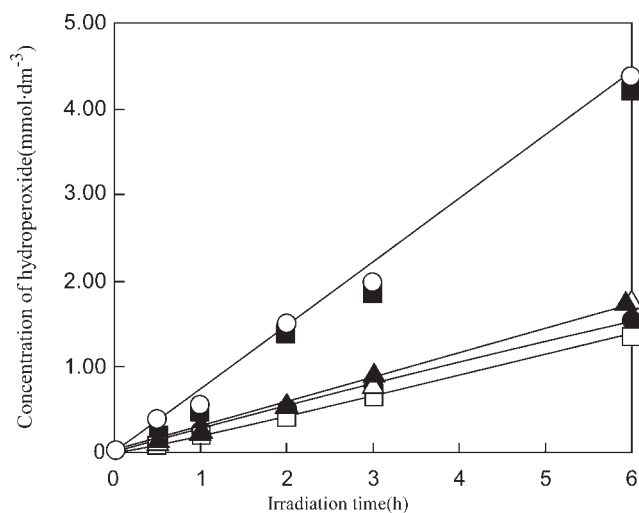| Resin	Amino groups/ phenolic derivatives (mmol/g-R)	Phenolic OH group (mmol/g-R)
RAS-4G	4.6/0	0
RAS-4G-4-HBA	0.4/4.2	4.2
RAS-4G-2,4-DHBA	0.7/4.1	8.2
RAS-4G-3,4-DHBA	0.2/4.6	9.2
RAS-4G-3,5-DHBA	0.6/4.0	8.6
RAS-4G-3,4,5-THBA	0.5/4.1	12.3
RAS-4G-TA	0.8/3.8	19.0
RAS-4G-D-t-BHBA	0.5/4.1	4.1
RAS-4G-HTMCA	0.3/4.3	4.3

**Figure 3** IR spectra of the RCS-4G, RAS-4G, and RAS-4G-3,5-DHBA.

centration of 1,4-dioxane hydroperoxide generated in 1,4-dioxane saturated with oxygen by UV irradiation in the absence or in the presence of the resins. The open circles in Figure 4 show the results in the case of the absence of the resins; the amount of 1,4-dioxane hydroperoxide generated in 1,4-dioxane increased significantly with increasing irradiation time of UV light. Generation of 1,4-dioxane hydroperoxide was hardly observed when nitrogen was introduced instead of oxygen into purified 1,4-dioxane for 10 min at room temperature (24–25°C). Thus, it was found that 1,4-dioxane hydroperoxide could easily be generated in 1,4-dioxane saturated with oxygen by UV irradiation at room temperature within several hours.

Inhibition of the generation of 1,4-dioxane hydroperoxide with resins having phenolic derivatives

Figure 4 also shows the time line of the concentration of 1,4-dioxane hydroperoxide generated in 1,4-dioxane saturated with oxygen by UV irradiation in the presence of the resins (RAS-4G-4-HBA, RAS-4G-3,5-DHBA, and RAS-4G-3,4,5-THBA) having various phenolic derivatives with different numbers of phenolic hydroxyl groups. It was found that the increase of 1,4-dioxane hydroperoxide with increasing time was suppressed with the resins having phenolic derivatives. The RCS-4G, having only chloromethyl groups, had no inhibition ability against the generation of 1,4-dioxane hydroperoxide. This result indicates that all the resins having phenolic derivatives have inhibition ability against the generation of 1,4-dioxane hydroperoxide. The order of inhibition effect of the resins is as follows:

Figure 4 Formation of 1,4-dioxane hydroperoxide by UV irradiation in the absence or in the presence of resins having phenolic derivatives or amino groups: (○)in the absence of resins, (△)RAS-4G-4-HBA, (□)RAS-4G-3,5-DHBA, (●)RAS-4G-3,4,5-THBA, (▲)RAS-4G, (■)RCS-4G.
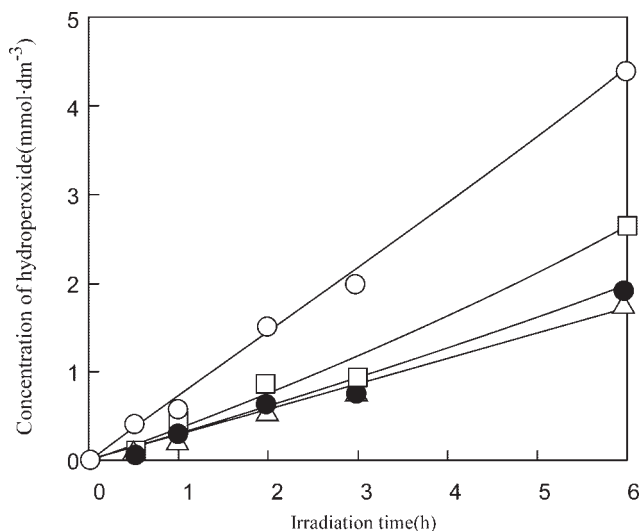
Figure 5 Formation of 1,4-dioxane hydroperoxide by UV irradiation in the absence or in the presence of resins having phenolic derivatives: (○)in the absence of resins, (△)RAS-4G-4-HBA, (□)RAS-4G-D-*t*-BHBA, (●)RAS-4G-HTCMA.

RAS-4G-3,5-DHBA > RAS-4G-3,4,5-THBA > RAS-4G-4-HBA > RAS-4G-TA.

However, the difference of the inhibition ability between these resins was very small.

This result indicates that the order of the magnitude of the inhibition ability of the resins does not always correspond with the number of phenolic hydroxyl groups in the resins.

Figure 4 also shows the time line of the concentration of 1,4-dioxane hydroperoxide generated in the presence of the RAS-4G having benzylamino groups, but no phenolic derivatives. The RAS-4G also suppressed the generation of 1,4-dioxane hydroperoxide, but the inhibition ability of the RAS-4G was a little bit lower than that of the RAS-4G-3,5-DHBA and the RAS-4G-3,4,5-THBA, and almost the same as that of the RAS-4G-4-HBA. The inhibition mechanism of those resins against the generation of 1,4-dioxane hydroperoxide will be mentioned later.

Next, the generation of 1,4-dioxane hydroperoxide was investigated in the presence of the resins (RAS-4G-4-HBA, RAS-4G-D-*t*-BHBA, and RAS-4G-HTCMA) having various phenolic derivatives, which have no alkyl groups or two different alkyl groups at *ortho*-positions of hydroxyl groups in the benzene ring. Figure 5 shows the time line of the concentration of 1,4-dioxane hydroperoxide generated in 1,4-dioxane saturated with oxygen by UV irradiation in the presence of the resins. All those resins also suppressed the generation of 1,4-dioxane hydroperoxide, and the order of the magnitude of the inhibition ability was as follows:

RAS-4G-4-HBA > RAS-4G-HTMCA > RAS-4G-D-*t*-BHBA.

Thus, electron-donating alkyl groups at the *ortho*-position to hydroxyl groups in the benzene ring did not increase the inhibition ability against the generation of 1,4-dioxane hydroperoxide. From Figures 4 and 5, it was found that the RAS-4G-3,5-DHBA, having two phenolic hydroxyl groups, exhibited the highest inhibition ability against the generation of 1,4-dioxane hydroperoxide.

Next, the inhibition ability of the resins having two phenolic hydroxyl groups at different positions in the benzene ring was investigated. The RAS-4G-2,4-DHBA and RAS-4G-3,4-DHBA were used, besides the RAS-4G-3,5-DHBA, for this experiment. The results are shown in Figure 6. All these RAS-4G-DHBA resins having two phenolic hydroxyl groups at different positions in the benzene ring exhibited high inhibition ability against the generation of 1,4-dioxane hydroperoxide. The order of the magnitude of the inhibition ability was as follows:
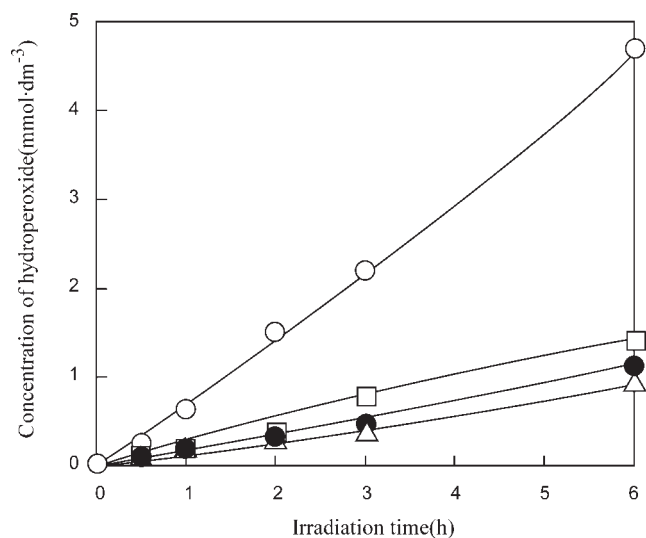
RAS-4G-3,4-DHBA > RAS-4G-2,4-DHBA > RAS-4G-3,5-DHBA.

However, the difference of the inhibition ability was very small.

The inhibition ability of the resins having various phenolic derivatives and the RAS-4G having benzylamino groups are compared in Table II, which shows the inhibition (%) of the resins used in this study. The inhibition (%) was calculated by using eq. (2):

$$\text{Inhibition}(\%) = (C_0 - C)/C_0 \times 100 \qquad (2)$$

where C_0 and C are the concentration of hydroperoxide in the absence and in the presence of the resins after UV irradiation for 6h, respectively.

TABLE II
Inhibition Ability of the Resins Having Phenolic Derivatives or Benzyl Amino Groups

Resin	Inhibition (%)
?RAS-4G-4-HBA	60.2
RAS-4G-2,4-DHBA	76.9
RAS-4G-3,4-DHBA	80.0
RAS-4G-3,5-DHBA	69.7
RAS-4G-3,4,5-THBA	65.3
RAS-4G-TA	48.3
RAS-4G-D-t-BHBA	39.4
RAS-4G-HTMCA	56.8
RAS-4G	63.9

Thus, the RAS-4G-DHBAs, having two phenolic hydroxyl groups in the benzene ring, had higher inhibition ability than the other resins. In particular, the RAS-4G-3,4-DHBA exhibited the highest inhibition ability against the generation of 1,4-dioxane hydroperoxide. The reason for the difference in the inhibition ability of these resins will be clarified by further investigation.

Inhibition mechanism of the resins having phenolic derivatives against the generation of 1,4-dioxane hydroperoxide

In previous work, we have reported that resins having amino groups decomposed 1,4-dioxane hydroperoxide, giving RO radicals, and that the radicals initiated the polymerization of vinyl monomers, such as methyl methacrylate or butyl methacrylate in a 1,4-dioxane water mixture.[5,6]

To clarify the inhibition mechanism of the resins having phenolic derivatives, against the generation of 1,4-dioxane hydroperoxide, first the decomposition of 1,4-dioxane hydroperoxide with the RCS-4G, RAS-4G, and RAS-4G-3,5-DHBA was investigated. The resins were placed into 1,4-dioxane containing a certain amount of 1,4-dioxane hydroperoxide, and the change in the concentration of 1,4-dioxane hydroperoxide with time was measured in their presence. The results are shown in Figure 7. A clear decrease in the concentration of 1,4-dioxane hydroperoxide was observed only with the RAS-4G, and little change in the concentration of 1,4-dioxane hydroperoxide was observed with the RCS-4G and RAS-4G-3,5-DHBA. This indicates that only the RAS-4G, having benzylamino groups, decomposed 1,4-dioxane hydroperoxide, and the RCS-4G and RAS-4G-3,5-DHBA did not decompose 1,4-dioxane hydroperoxide. In the previous report,[6] we mentioned that 1,4-dioxane hydroperoxide was decomposed by reaction with resins having amino groups as shown below and RO generated initiated the polymerization of vinyl monomers such as MMA or BMA.

Figure 6 Inhibition of the generation of 1,4-dioxane hydroperoxide by UV irradiation in the presence of resins having phenolic derivatives with two phenolic hydroxyl groups at different positions: (○) in the absence of resins, (△)RAS-4G-3,4-DHBA, (□)RAS-4G-3,5-DHBA, (●)RAS-4G-2,4-DHBA.
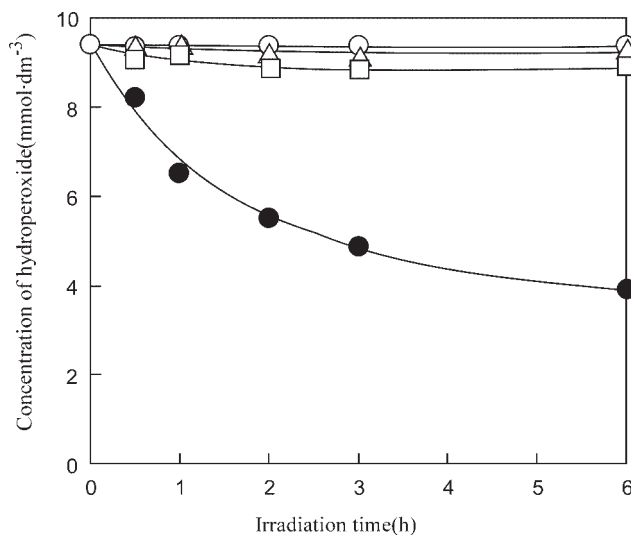
Figure 7 Decomposition of 1,4-dioxane hydroperoxide with the RCS-4G, RAS-4G, and RAS-4G-3,5-DHBA: (○) in the absence of resins, (△)RCS-4G, (●)RAS-4G, (□)RAS-4G-3,5-DHBA.

Figure 8 Time dependencies of the residual DPPH by the reaction of DPPH with resins containing phenolic derivatives or amino groups: (○) in the absence of resins, (△)RAS-4G-4-HBA, (□)RAS-4G-3,5-DHBA, (●)RAS-4G-3,4,5-THBA, (▲)RAS-4G-D-*t*-BHBA, (◇)RAS-4G, (■)RCS-4G.

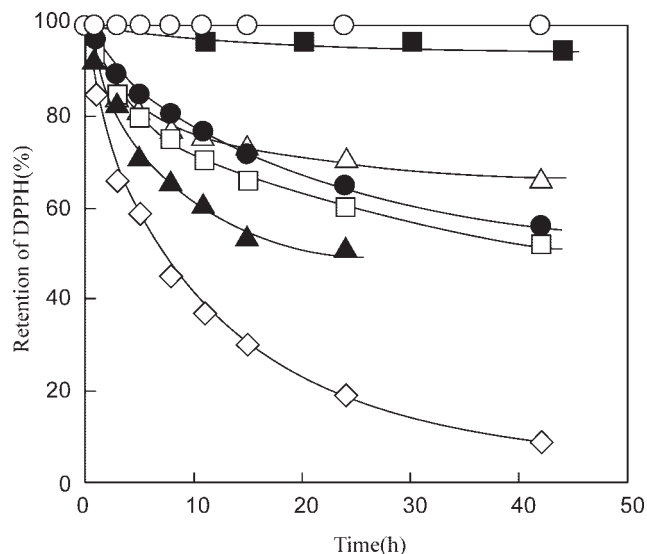$$ROOH + R\text{-}NH_2 \rightarrow RO\cdot + OH^- + R + NH_2^+$$

Accordingly, it is considered that the inhibition mechanism of the RAS-4G-3,5-DHBA, having phenolic hydroxyl groups, must be different from that of the RAS-4G, having only benzylamino groups.

Recently, it has been reported that phenolic compounds, such as catechol, hydroquinone, or 4-methoxyphenol, act as inhibitors of radical chain reactions during the autoxidation of organic substrates. So we considered that inhibition ability of the resins having phenolic derivatives was brought about by scavenging the radicals generated during the oxidation of 1,4-dioxane. Therefore, we investigated the radical scavenging ability of the RCS-4G, RAS-4G, RAS-4G-4-HBA, RAS-4G-3,5-DHBA, RAS-4G-3,4,5-THBA, and RAS-4G-D-*t*-BHBA against the DPPH radical. DPPH is known to be a metastable radical bearing a radical electron stabilized by resonance. Figure 8 shows the time course of the changes in the concentration of DPPH in the absence or in the presence of the resins. It was found that all the resins having phenolic derivatives exhibited radical scavenging ability against DPPH. It is known that amines also work as inhibitors for radical polymerization of vinyl monomers. Figure 8 also shows that the RAS-4G, having only benzylamino groups, exhibited radical scavenging ability against DPPH. The order of the scavenging ability of the resins was as follows:

RAS-4G-D-t-BHBA ≫ RAS-4G > RAS-4G-3,5-DHBA > RAS-4G-3,4,5-THBA > RAS-4G-4-HBA.

The RCS-4G hardly exhibited any scavenging ability against DPPH. The results indicate that both resins having phenolic derivatives and the RAS-4G having only benzylamino groups have radical scavenging abil-

ity. However, the order of the scavenging ability of the resins against the DPPH radical is not in agreement with that of their inhibition ability against the generation of 1,4-dioxane hydroperoxide shown in Table II.

It has been reported that hydroperoxides of ethers are formed by UV irradiation of ethers in the presence of oxygen via reaction I, II, and III, as shown in Figure 9.[16] The generation of hydroperoxides is explained as follows: AH in Figure 9 denotes 1,4-dioxane. First, A radical is generated by abstraction of H radical from 1,4-dioxane (AH) by UV irradiation (reaction I). Next, AOO radical is generated by the reaction of A radical with oxygen (reaction II). A radical is generated again by the reaction of AOO radical with AH (reaction III). A radical reacts again with oxygen and AOO radical is generated again (reaction II). Accordingly, 1,4-dioxane
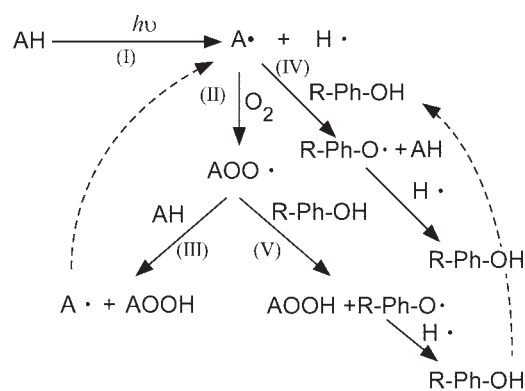
Figure 9 Tentative inhibition mechanism of 1,4-dioxane hydroperoxide with resins having phenolic derivatives.
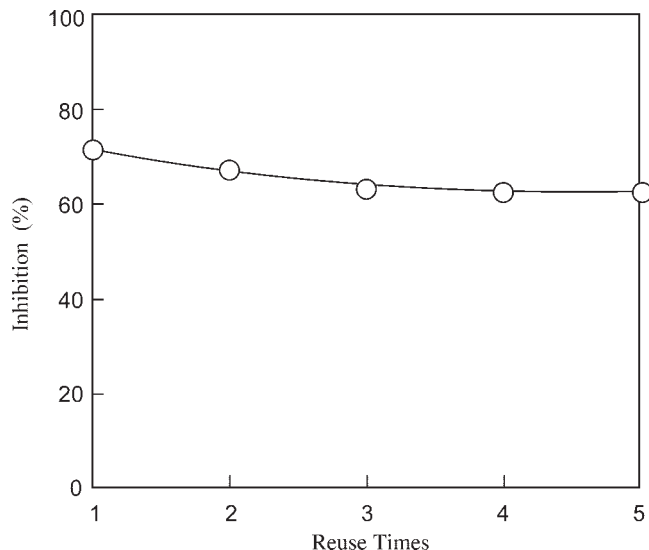
Figure 10 Reuse of the resin for inhibition of peroxide generation. Resin : RAS-4G-3,5-DHBA 0.1g. Time : 6h.

hydroperoxide (AOOH) must be generated continuously in the absence of resins having phenolic derivatives. On the other hand, in the presence of resins having phenolic derivatives (R-Ph-OH), the inhibition mechanism of the resins having phenolic derivatives is assumed to perform as shown in Figure 9, that is, R-Ph-OH reacts with A radical and gives metastable R-Ph-O·(reaction IV). The generation of hydroperoxides is mainly inhibited by this reaction IV. However, AOO radical must also be generated by reaction II. The generated AOO radical also reacts with R-Ph-OH to give the R-Ph-O radical. Thus, the generation of hydroperoxides is suppressed with the resins having phenolic derivatives (R-Ph-OH). R-Ph-OH is reformed by coupling of R-Ph-O with H radical. We mentioned before that only the RAS-4G had decomposition ability against 1,4-dioxane hydroperoxide. However, we found that the RAS-4G-DHBA and RAS-4G-3,4,5-THBA had higher inhibition ability against the generation of 1,4-dioxane hydroperoxide than the RAS-4G, although the radical scavenging ability of the RAS-4G was higher than RAS-4G-DHBA. This indicates that the decrease in the concentration of 1,4-dioxane hydroperoxide, in the presence of the RAS-4G, must not be brought about by the decomposition of its hydroperoxide with the resin. The reason for the difference of the inhibition ability, against the RAS-4G and the RAS-4G-DHBA, will be clarified by further investigation. This is due to the difference of the structure between radicals formed in autoxidation of 1,4-dioxane and DPPH.

Reuse of the RAS-4G-3,5-DHBA for the inhibition of the generation of 1,4-dioxane hydroperoxide

The RAS-4G-3,5-DHBA was reused five times for the inhibition of the generation of 1,4-dioxane hydroper-

oxide. The results are shown in Figure 10. The inhibition ability hardly decreased with increasing use five times. This result indicates that the R-Ph-OH is easily reformed by a coupling reaction of the R-Ph-O radical with the H radical.

CONCLUSIONS

1. Resins having phenolic derivatives could be prepared by amination of macroreticular CMS-4G copolymer beads with potassium phthalimide, followed by reaction of the aminated resins (RAS-4G) with various benzoic acid derivatives having phenolic hydroxyl groups.
2. The resins having phenolic derivatives obtained had inhibition ability against the generation of 1,4-dioxane hydroperoxide. The RAS-4G also had inhibition ability against the generation of 1,4-hydroperoxide. The RAS-4G-DHBA and RAS-4G-3,4,5-THBA exhibited higher inhibition ability than the RAS-4G. In particular, the RAS-4G-3,4-DHBA exhibited the highest inhibition ability against the generation of 1,4-dioxane hydroperoxide.
3. The inhibition ability of resins having phenolic derivatives hardly decreased, even after the resins were reused five times.

References

1. Weisburger, J. H.; Veliath, E.; Larios, E.; Pittman, B. Mutat Res 2002, 516, 19.
2. Boots, A. W.; Haenen, G. R. M. M.; den Tartog, G. J. M.; Bast, A. Biochim Biophys Acta 2002, 1583, 279.
3. Hagerman, A. E.; Dean, R. T.; Davies, M. J. Arch Biochem Biophys 2003, 414, 115.
4. Ogata, M.; Hoshi, M.; Shimotohno, K.; Urano, S.; Endo, T. JAOCS 1997, 74, 557.
5. Nonaka, T.; Nishida, H.; Tagawa, R.; Egawa, H. Chem Lett 1982, 1385.
6. Nonaka, T.; Nishida, H.; Tagawa, R.; Egawa, H. J Polym Sci Chem Ed 1984, 22, 3815.
7. Kaneda, T.; Ueta, N., Eds. Kasanka Shishitsu Jikkenhou; Ishiyaku shuppan: Tokyo, 1993; p 15.
8. Tanaka, K.; Sakai, S.; Tomiyama, S.; Yamada, F. Bull Chem Soc Jpn 1991, 64, 2677.
9. Tomiyama, S.; Sakai, S.; Nishiyama, T.; Yamada, F. Bull Chem Soc Jpn 1993, 69, 299.
10. Yamaguchi, K.; Ohkatsu, Y. Sekiyu Gakkaishi 1996, 39, 273.
11. Yamaguchi, K.; Hayashi, E.; Ohkatsu, Y. Sekiyu Gakkaishi 1996, 39, 279.
12. Nishiyama, T.; Sakita, K.; Fuchigami, T.; Fukui, T. Polym Degrad Stab 1998, 62, 529.
13. Nonaka, T.; Uemura, Y.; Ohse, K.; Jyono, K.; Kurihara, S. J Appl Polym Sci 1977, 66, 1621.
14. Research Groups of Microanalysis, Ed. Yuki Biryo Teiryo Bunseki; Nankodo: Tokyo, 1969; p. 383.
15. Rieche, A.; Meister, R. Angew Chem 1936, 49, 101.
16. Uri, N. Autooxidation and Antioxidant; Lundberg, W. O., Ed.; Wiley: New York, 1961; Vol. I, Chapter 4.
17. Scott, G. Atmospheric Oxidation and Antioxidant; Elsevier: Amsterdam, 1965; Chapter 4.
18. Research Groups of Microanalysis, Ed. Yuki Biryo Teiryo Bunseki; Nankodo: Tokyo, 1969; p 468.