

# Dimethylaminoethylated Hydroxypropyl-Chitosan: Preparation and Application as Polymeric Ligand to Form Rh<sub>6</sub> Cluster Complexes for the Reduction of Benzaldehyde and Nitrobenzene

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**ABSTRACT:** Hydroxypropyl chitosan and its dimethylaminoethylated derivative were prepared in different conditions. Experimental results indicated that the degree of substitution (DS) of hydroxypropyl chitosan was strongly related to the molar ratio of propylene oxide to the glucosamine unit of chitosan, the used solvent, the reaction temperature and the amount of sodium hydroxide. Moreover, the obtained hydroxypropyl chitosan could be effectively dimethylaminoethylated by the reaction with dimethylaminoethyl chloride in the presence of NaH under DMAC solution. By the combination of dimethylaminoethylated hydroxypropyl chitosan and Rh<sub>6</sub>(CO)<sub>16</sub>, benzaldehyde and nitrobenzene could be converted into correspondingly reductive products in high yields under the WGSR condition. © 2001 John Wiley & Sons, Inc. *J Appl Polym Sci* 80: 447–453, 2001

**Key words:** chitosan; hydroxypropyl chitosan; dimethylaminoethylation; Rh<sub>6</sub>(CO)<sub>16</sub>; reduction; WGSR

## INTRODUCTION

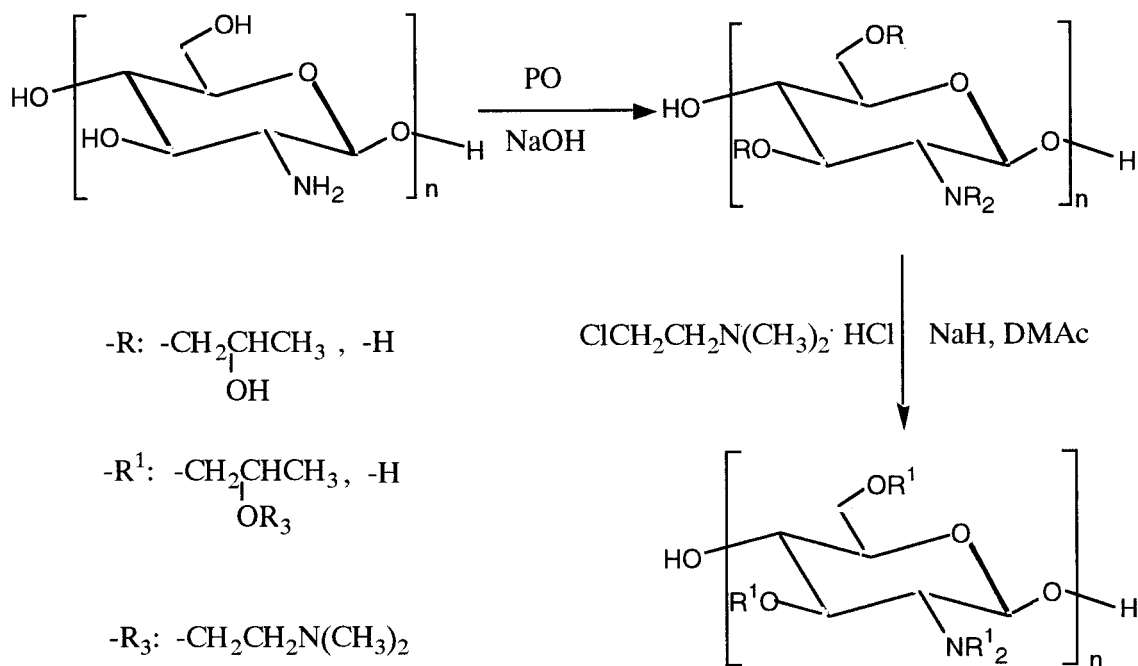
Chitosan and its derivatives have attracted much attention recently as polymeric supports in various fields such as enzyme immobilization, cell encapsulation, and controlled release pharmaceutical application.<sup>1–5</sup> Our interest in utilization of chitosan and its derivatives as polymeric supports prompts us to examine the possibility of the immobilization of Rh cluster complexes on chitosan-based derivatives to form polymeric catalysts for the reduction of carbonyl and nitro compounds.

During development of efficient metal catalysts for organic synthesis in aqueous system, it was

found that homogeneous Rh carbonyl clusters in the presence of CO and H<sub>2</sub>O effectively catalyzed deoxygenation of various N—O bonds, chemoselective reduction between carbonyl and olefinic functions, and hydrohydroxymethylation of olefins via hydroformylation.<sup>6–12</sup> Amines and pyridines were effective additive bases that accelerated the catalytic activities of the above reactions.<sup>7</sup> Homogeneous catalyst systems consisting of Rh<sub>6</sub>(CO)<sub>16</sub> and amines were found to have high activities for the water–gas shift reaction (WGSR), reduction of aldehydes, and deoxygenation of various N—O bonds under the WGSR conditions.<sup>9</sup> Furthermore, the Rh complex catalyst was reported to be heterogenized onto several kinds of synthetic polymers.<sup>13</sup> In the previous study, a multifunctionalized polystyrene having 2-(dimethylamino)ethoxy moieties was found to be effective to immobilize the catalyst system;<sup>14</sup>

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Scheme 1

similarly, chitosan-based derivatives having (dimethylamino)ethoxy moieties thus were expected to be an effective polymeric ligand for this purpose.

The main difficulty in preparing chitosan-based derivatives was the low modification efficiency due to low solubility of chitosan in organic solvents. To obtain chitosan derivatives having high DS of (dimethylamino)ethoxy group, one of the effective modification methods was to prepare a chitosan-based precursor, then further proceeding dimethylaminoethylation. Hydroxypropyl chitosan (HPCT) having a good solubility in organic solvents and a lot of hydroxide groups thus was chosen as such a precursor. In this presentation, hydroxypropyl chitosan was prepared by using either a flask or an autoclave as a reactor, then dimethylaminoethylated with (dimethylamino)ethyl chloride (DMAE-Cl). The aminated chitosan prepared was combined with  $\text{Rh}_6$  cluster complexes and applied to the reduction of benzaldehyde and nitrobenzene under the WGS condition.

## EXPERIMENTAL

### Materials

Chitosan was purchased from Wako Pure Chemical Co., Japan. Weight-average molecular weight

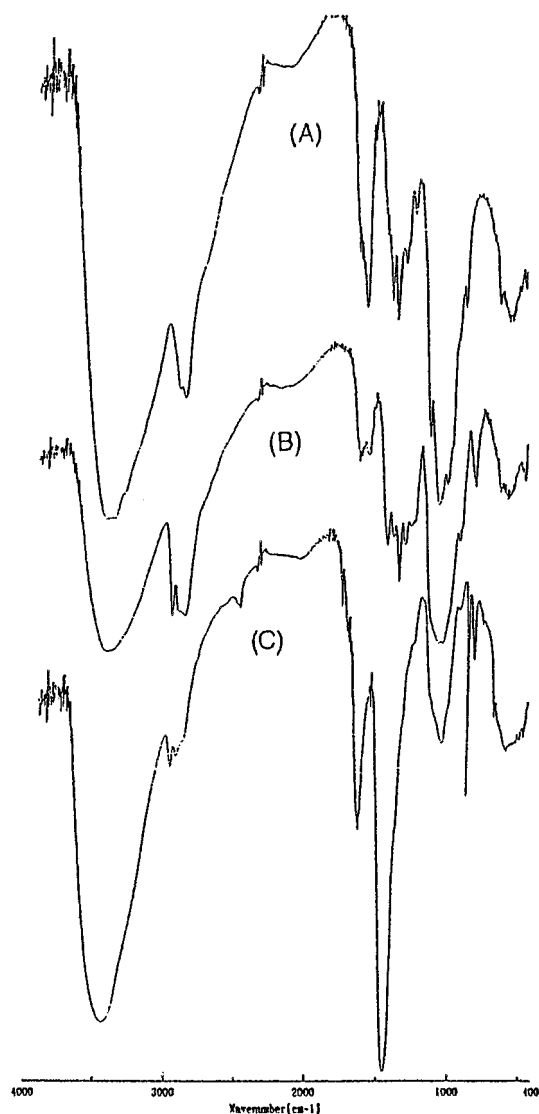
of chitosan was determined to be  $1.2 \times 10^6$  by GPC. Degree of deacetylation of chitosan was determined to be 2% by  $^1\text{H-NMR}$  spectra.  $\text{Rh}_6(\text{CO})_{16}$  was prepared according to the method by Chini.<sup>15</sup>

Benzaldehyde, nitrobenzene, toluene, 2-ethoxyethanol were dried and purified by the procedures reported in the literature<sup>16</sup> and stored under the nitrogen atmosphere.

*N,N*-Dimethylacetamide (DMAc), tetrahydrofuran (THF), and dimethyl sulfoxide (DMSO) were dried and purified by ordinary methods. Propylene oxide (PO), heptane, isopropyl alcohol (2-propanol), and *t*-butyl alcohol (*t*-butanol) were used without further purification.

### Typical Procedure of Preparing Hydroxypropyl Chitosan (HPCT)

Chitosan (0.99 g), NaOH (0.20 g),  $\text{H}_2\text{O}$  (1 mL), and mixing solvent (24 mL of heptane, 8 mL of *t*-butanol) were added to a flask and the mixture was stirred at room temperature under the nitrogen atmosphere for 2 h. Propylene oxide (5.50 g) then was added, the temperature was raised to  $80^\circ\text{C}$  and kept for 7 h. After the reaction, the organic phase was disposed and the slurry was diluted with hot water. White precipitate was collected by filtration and fully washed with water, then dried over vacuum at  $60^\circ\text{C}$ . Yield: 61%. DS: 3.35.



**Figure 1** IR spectra of chitosan and its derivatives: (A) chitosan; (B) hydroxypropyl chitosan (HPCT); (C) dimethylaminoethylated hydroxypropyl chitosan (HPCTDE).

#### Typical Procedure of Dimethylaminoethylation of HPCT

To a flask containing 40 mL of DMAc, 0.63 g of HPCT-2 was added. The mixture was heated at 75°C for 1.5 h with stirring. After the temperature was decreased to room temperature, 1.52 g of NaH (abt. 50% ) was added and the temperature was raised to 75°C and kept for 2 h with stirring; 0.54 g of DMAE-Cl · HCl was added, and the reaction was proceeded at 75°C for 3 h. The resulting mixture was poured into 150 mL of the mixing solvent (100 mL of ethanol, 50 mL of acetone), the precipitate was filtered and washed fully

with the mixing solvent of ethanol and acetone, and dried at 60°C over vacuum. Yield: 78%. DS: 2.19.

#### Reduction of Benzaldehyde and Nitrobenzene Catalyzed by the Complexes Formed by Dimethylaminoethylated HPCT and Rh Clusters in the Presence of CO and H<sub>2</sub>O

Typical procedure of reduction of benzaldehyde: To a 50-mL stainless autoclave, HPCTDE-1 (0.14 mmol), Rh<sub>6</sub>(CO)<sub>16</sub> (0.01 mmol), benzaldehyde (2.01 mmol), toluene (3 mL), and H<sub>2</sub>O (80 mmol) were added, respectively. After the autoclave was sealed, evacuated, and flushed three times with CO, the pressure was raised to 10 atm, and the reaction mixture was stirred at 80°C for 24 h. After the reaction, the organic phase of the filtrate was measured by gas chromatography. The yield of benzyl alcohol was about 25.1%.

The reduction of nitrobenzene was proceeded by the similar procedure to the reduction of benzaldehyde.

#### Characterization

GC analysis was performed by Shimadzu GC-8A with TCD detector and a 2-m column (KOCL-3000T). IR spectra of chitosan and its derivatives were recorded on JASCO FT/IR-410 Fourier Transform Infrared Spectrometers. Elemental analysis was performed on 2400 II CHNS Perkin-Elmer Instruments. <sup>1</sup>H-NMR spectra were obtained on JNM-AL400 spectrometers. About 20 mg of a sample dissolved in 1 mL of D<sub>2</sub>O/CF<sub>3</sub>COOH (95:5 V/V) in a 5-mm sample tube was measured at 80°C. The deuterium resonance was used as a field frequency lock, and the chemical shifts were referred to internal sodium 2,2-dimethyl-2-silapentane-5-sulfonate (DSS).

#### Determination of the Degree of (dimethylamino)ethylation<sup>17</sup>

To 50 mg of a sample were added 0.2 M hydrochloric acid (5 mL) and deionized water (50 mL), and the mixture was stirred to dissolve or swell the sample. The sample was then titrated with 0.1 M sodium hydroxide, and the average number of substituents per pyranose unit was calculated.

## RESULTS AND DISCUSSION

A schematic representation of the preparation of dimethylaminoethylated hydroxypropyl chitosan

**Table I** Preparation of HPCT<sup>a</sup>

No.	CT <sup>b</sup> (g)	PO <sup>c</sup> : CT (mol ratio)	NaOH (g)	Temp. (°C)	Time (h)	Yield (%)	DS <sup>d</sup>
HPCT-1	1.00	6.5 : 1	0.20	80	7	75	1.04
HPCT-2	0.99	15.4 : 1	0.20	80	7	61	3.35
HPCT-3	1.50	17.9 : 1	0.10	80	7	67	2.13
HPCT-4	2.99	15.0 : 1	0.31	80	8	30 <sup>e</sup>	2.58
HPCT-5	4.00	16.5 : 1	0.55	50	8	74	2.46
HPCT-6	4.00	16.5 : 1	0.55	50	16	64	3.20
HPCT-7	2.01	16.5 : 1	0.38	90	7	59 <sup>f</sup>	3.07

<sup>a</sup> Mixing solvents (heptane: *t*-butanol = 3 : 1 in volume) were used; <sup>b</sup> CT: Chitosan; <sup>c</sup> PO: Propylene Oxide; <sup>d</sup> DS: degree of substitution, calculated on the basis of *N* in the product; <sup>e</sup> 2-propanol as a solvent; <sup>f</sup> autoclave instead of flask as a reactor.

(HPCTDE) was shown in Scheme 1. Hydroxypropyl chitosan (HPCT) was prepared as an intermediate, and then further aminated with DMAE-Cl in the presence of NaH.

#### Preparation and Characterization of HPCT

HPCT could be prepared by the reaction of chitosan with propylene oxide in the presence of sodium hydroxide solution. As shown in Figure 1, compared with chitosan, the IR spectrum of HPCT exhibited absorption at 1375 cm<sup>-1</sup>, which was assigned to the CH<sub>3</sub> symmetrical deformation vibration. In addition, the peaks at 1100 cm<sup>-1</sup> assigned to C—O stretching vibration in the ether bond of HPCT and 2885 cm<sup>-1</sup>, 1469 cm<sup>-1</sup> contributed to the C—H bond became obviously stronger; in contrast, the absorption peaks at 1592 cm<sup>-1</sup> related to the N—H bond was greatly weaken. A multippeak at 1.15 ppm in <sup>1</sup>H-NMR spectra of HPCT, which was assigned to be the CH<sub>3</sub> group in the hydroxypropyl unit of HPCT, appeared. The above results demonstrated that the hydroxypropyl unit was introduced into the HPCT structure.

HPCT was prepared in different conditions, and the results were shown in Table I. It was found that when 2-propanol instead of the mixing solvent composing of *n*-heptane and *t*-butanol was used, the yield of HPCT was low, although the DS of HPCT did not change greatly (HPCT-4). This might be ascribed to the good solubility of HPCT in 2-propanol decreasing the yield. On the other hand, the DS of HPCT was found to be related to the molar ratio of propylene oxide and glucosamine unit of chitosan, the reaction temperature, and the amount of sodium hydroxide. In the case of a low molar ratio, such as 6.5 : 1 (HPCT-1),

the DS of HPCT was only 1.04, but the DS increased to 3.35 when the molar ratio reached 15.4 : 1. If the reaction was carried out under the low temperature such as 50°C, HPCT with high DS could be obtained by extending the reaction time (HPCT-5 and 6). Besides, the amount of sodium hydroxide about equal to the 10–20% wt of chitosan was required to produce a high DS of HPCT. In addition, using either an autoclave or a flask as a reactor (HPCT-7), a quite high DS of HPCT could be obtained.

#### Preparation and Characterization of Aminated HPCT

Also, as shown in Figure 1, after HPCT was dimethylaminoethylated with DMAE-Cl, the absorption peak at 1456 cm<sup>-1</sup> associated with —CH<sub>3</sub> obviously became stronger. In addition, the new peak at 880 cm<sup>-1</sup> assigned to C—N stretching vibration appeared, indicating the introduction of a dimethylaminoethylate group into HPCT. The appearance of the peak at 2.92 ppm assigned to the hydrogen in —N(CH<sub>3</sub>)<sub>2</sub> in <sup>1</sup>H-NMR spectra further proved the above conclusion.

Dimethylaminoethylated hydroxypropyl chitosans (HPCTDE) were prepared in different conditions, and the results were indicated in Table II. It was found that the DS of the aminated HPCT was affected greatly by the molar ratio of DMAE-Cl and the hydroxypropyl group of HPCT as well as the solvents. In the experimental conditions, about 2.0 of the molar ratio was suitable for preparing high DS of the products. In addition, among the three solvents, DMAC, DMSO, and THF, choosing DMAC as a solvent was more suitable for preparing HPCTDE with high DS.

**Table II** Preparation of HPCTDE<sup>a</sup>

No	Starting HPCT	HPCT (g)	DE/HPCT <sup>b</sup> (mol)	Solvent	Yield (%)	DS <sup>c</sup>
HPCTDE-1	HPCT-2	0.63	2.11	DMAc	78	2.19
HPCTDE-2	HPCT-2	0.34	7.08	DMSO	98	1.05
HPCTDE-3	HPCT-3	0.50	3.10	DMAC	94	1.14
HPCTDE-4	HPCT-3	0.44	2.42	DMSO	70	1.06
HPCTDE-5	HPCT-5	0.51	1.75	DMAC	53	1.94
HPCTDE-6	HPCT-5	0.51	0.83	DMAC	76	1.49
HPCTDE-7	HPCT-5	1.21	1.77	DMAC	81	1.92
HPCTDE-8	HPCT-5	0.51	2.31	THF	80	1.53

<sup>a</sup> Excess of NaH was used. HPCT was first activated with NaH at 75°C for 2 h, then reacted with DMAE-Cl at 75°C for additional 3 h.

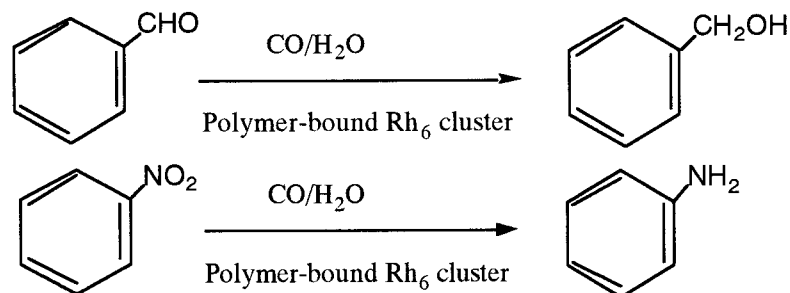
<sup>b</sup> DE/HPCT: molar ratio of DMAE-Cl and hydroxypropyl group in HPCT.

<sup>c</sup> DS: Degree of substitution, calculated on the basis of titration.

### Reduction of Benzaldehyde and Nitrobenzene in the Presence of HPCTDE and an Rh<sub>6</sub> Cluster under WGSR Conditions

The catalytic reduction of benzaldehyde and nitrobenzene could be achieved by a polymer-bound

Rh<sub>6</sub> cluster complex under the WGSR condition, as shown in eqs. (1) and (2). In this catalytic reaction, water, a safe and cheap resource, was used as a hydrogen source in place of molecular hydrogen.<sup>18</sup>



As shown in Table III, benzaldehyde and nitrobenzene could be effectively converted into corresponding reductive products, benzene alcohol and aniline, in the appropriate conditions. It was found that the yield was affected by the molar amount of functional group in used HPCTDE, reaction temperatures, and solvents. Increasing the amount of HPCTDE would improve the yield. Among the three reaction temperatures, 60, 80, and 120°, 80°C was more suitable to the catalytic reaction. It was also found that the effectiveness of HPCTDE was affected by the used solvents. The system exhibited higher catalytic activities using 2-ethoxyethanol as a solvent rather than toluene.

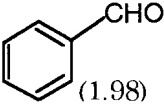
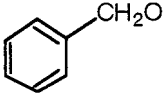
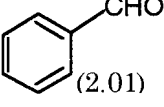
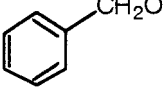
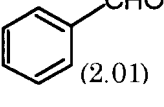
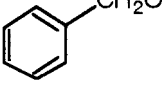
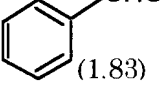
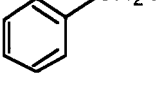
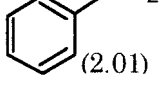
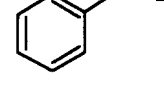
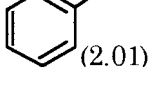
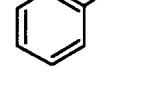
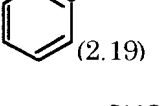
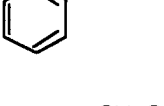
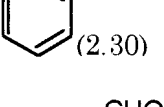
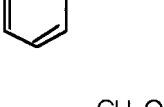
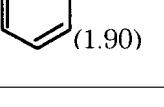
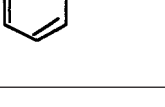
As for the catalytic system, (Rh<sub>6</sub>(CO)<sub>15</sub>H)<sup>-</sup> is proposed to be an active species. The hydride Rh cluster anion (Rh<sub>6</sub>(CO)<sub>15</sub>H)<sup>-</sup> was detected under

the WGSR conditions, the Rh cluster anion derived from nucleophilic attack of OH<sup>-</sup> on Rh<sub>6</sub>(CO)<sub>16</sub> is bound to the aminated polymer through ionic binding with an ammonium cation in the polymer.<sup>19</sup> The same Rh species could be also generated in the aminated polystyrene using CO and H<sub>2</sub>, which showed high selectivity for aldehyde reduction.<sup>20</sup>

### CONCLUSION

Chitosans with a high DS of the hydroxypropyl group were obtained by choosing the suitable solvent, the molar ratio of propylene oxide to the glucosamine unit of chitosan, the reaction temperature, and the amount of sodium hydroxide. The obtained HPCT could be directly dimethyl-

**Table III Reduction of Benzaldehyde and Nitrobenzene in the Presence of HPCTDE<sup>a</sup>**

No.	HPCTDE (mmol)	Substrate (mmol)	Product	Solvent	Temp. (°C)	Yield <sup>b</sup> (%)
1	HPCTDE-1 (0.14)	 (1.98)		Toluene	60	17.5
2	HPCTDE-1 (0.14)	 (2.01)		Toluene	80	25.1
3	HPCTDE-1 (0.14)	 (2.01)		Toluene	120	10.4
3	HPCTDE-1 (0.28)	 (1.83)		Toluene	80	62.0
5	HPCTDE-1 (0.14)	 (2.01)		Toluene	80	47.8
6	HPCTDE-1 (0.14)	 (2.01)		2-Ethoxy-ethanol	80	68.5
7	HPCTDE-7 (0.14)	 (2.19)		Toluene	80	24.1
8	HPCTDE-7 (0.14)	 (2.30)		2-Ethoxy-ethanol	80	49.4
9	HPCTDE-7 (0.28)	 (1.90)		2-Ethoxy-ethanol	80	96.6

<sup>a</sup> Reaction conditions: Rh<sub>6</sub>(CO)<sub>16</sub> 0.01 mmol; Solvent 3.0 mL; H<sub>2</sub>O 80 mmol; P<sub>CO<sub>2</sub></sub> = 10 atm; 24 h.

<sup>b</sup> Yields were determined by GC.

aminoethylated by the reaction with DMAE-Cl. By the combination of the aminated chitosan with Rh<sub>6</sub> clusters, polymer-bound Rh cluster complexes formed in the presence of CO and H<sub>2</sub>O

were found to show high catalytic activities for converting benzaldehyde and nitrobenzene into corresponding reductive products in high yields. As for the catalytic reaction, choosing suitable sol-

vent and reaction temperature was important. In the experimental conditions, hydrogenation effectively occurred at 80°C under 2-ethoxyethanol solution.

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