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PROPERTIES OF AQEOUS SOLUTIONS OF O,N-CARBOXYMETHYL CHITOSAN WITH VARIOUS ADDITIVES

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Samples of carboxymethyl chitosan have been synthesized with different extents of substitution by changing the reaction conditions. Carboxymethyl chitosan completely dissolves in water when the extent of substitution exceeds 90%. The rheological properties were studied for 4% aqueous solutions of carboxymethyl chitosan with $CaCl_2$ and $Ca(OH)_2$ as additives as well as for a mixture of carboxymethyl chitosan and polyethylene oxide with added $CaCl_2$. The introduction of additives to aqueous solutions of carboxymethyl chitosan leads to enhanced viscosity and gel formation.

Natural polymers remain in demand and will continue to find common use because of a number of reasons such as their renewability in nature, capacity to undergo biodecomposition, and biocompatibility [1-3]. Chitin is the second-most common natural polymer after cellulose and its derivatives are finding increasing use in many areas [4-6]. Chitin dissolves in a limited number of solvents convenient for practical application, while chitosan (CTS) dissolves in acidified aqueous media. This polymer is finding increasing use in agriculture, the food industry, pharmaceuticals, biomedicine, and cosmetics. The insolubility of chitin and chitosan in water limits their use.

Chitin and CTS are chemically modified to impart water solubility. Water-soluble derivatives of CTS have been obtained containing hydroxypropyl, carboxymethyl, carboxyethyl, sulfate, and phosphate groups. Water-soluble copolymers of CTS have also been obtained [7]. The most convenient method for obtaining water-soluble CTS derivatives is the synthesis of carboxymethyl chitosan (CM-CTS). The conditions for the synthesis of CM-CTS are similar to the conditions for commonly used carboxymethyl cellulose. Carboxymethylated derivatives of chitin and CTS have also been obtained and studied [8, 9].

By adjusting the conditions for the synthesis of CM-CTS, we may obtain samples completely soluble in aqueous solutions at different pH and samples, which are insoluble in water in a certain pH range [10, 11]. Aqueous solutions of CM-CTS have found use in cosmetics and biomedicine [12-14]. Both scientific and practical interest is found for gel-like systems obtained from aqueous solutions of CM-CTS, which may be used for the preparation of creams and ointments.

In the present work, we obtained water-soluble CM-CTS and studied the rheological properties of aqueous solutions of this material with various additives. The starting material was chitosan isolated from the outer skeletons of crabs (obtained from Bioprogress, Russia) with deacetylation (DA) of 88% and molecular mass $1.15 \cdot 10^5$ as well as polyethylene oxide (PEO) with molecular mass $3.5 \cdot 10^4$ obtained from Sigma Aldrich, USA.

The sample of CM-CTS was synthesized by a procedure similar to the reaction conditions described by Chen and Park [10]. A weighed sample of 10 g chitosan was taken in all cases. The ratio of the reagents in the reaction medium [NaOH and monochloroacetic acid (MCAA)], the composition of the reaction mixture (water/isopropyl alcohol), temperature, and reaction duration were all varied. The extent of substitution (ES) and DA of the CM-CTS samples were determined conductometrically using reported methods [15, 16]. The characteristic viscosity of the chitosan and CM-CTS samples was determined according to the recommendations of Pogodina et al. [17].

The solubility of the samples was determined relative to the preparation of 1% solutions of the polymers. Weighed samples (1 g) were placed into 99 g distilled water. We also used 2% solutions of acetic acid (AA) and NaOH. The mixtures were stirred for 4 h. The solutions were then centrifuged for 0.5 h at 4500 rpm to separate the insoluble

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Table 1. Conditions for the Synthesis CM-CTS, Values of DA, ES and [η] of the Samples Obtained

Sample	*t*, °C	τ, h	Water/IPA, %	NaOH/MCAA, g/g*	DA, %	ES, %	[η], dl/g
Chitosan					0	83	4.99
CM-CTS-1	40	1	80/20	13.5/15.0	16	78	4.89
CM-CTS-2	40	2	80/20	13.5/15.0	25	70	4.57
CM-CTS-3	40	3	80/20	13.5/15.0	33	70	4.42
CM-CTS-4	40	4	80/20	13.5/15.0	34	70	3.79
CM-CTS-5	60	2	80/20	13.5/15.0	21	61	
CM-CTS-6	60	2	80/20	13.5/27.0	37	73	
CM-CTS-7	60	2	20/80	13.5/15.0	50	70	
CM-CTS-8	60	4	20/80	13.5/15.0	70	65	
CM-CTS-9	20	24	20/80	13.5/15.0	90	65	4.48

*The amount of reagents (in g) added to the reaction mixture for 10 g chitosan.

Table 2. Solubility of CM-CTS in Water and 2% Aqueous NaOH and AA

Sample	Solubility, %		
	water	2% aqueous NaOH	2% aqueous AA
Chitosan	IS	IS	S
CM-CTS-1	IS	IS	S
CM-CTS-2	IS	IS	S
CM-CTS-3	IS	IS	S
CM-CTS-4	IS	IS	S
CM-CTS-5	40	20	S
CM-CTS-6	10	50	S
CM-CTS-7	86	78	S*
CM-CTS-8	95	86	S*
CM-CTS-9	95	97	S*

Note: IS - insoluble, S - soluble, S* - soluble in 0.1 N hydrochloric acid.

part. The resultant precipitate was washed on the filter with ethanol, dried in vacuum at 50°C, and weighed. The solubility (in %) was calculated using the formula

$$S = \frac{M_1 - M_2}{M_1} \cdot 100$$

where M_1 is the mass of the weighed sample and M_2 is the mass of the insoluble part of the sample.

The study of the rheological properties of moderately concentrated (4%) aqueous solutions was carried out using a Rheotest-2.1 rheoviscosimeter in the shear stress range 3-600 Pa. Calculated amounts of concentrated aqueous solutions of $CaCl_2$ and $Ca(OH)_2$ were added to the 4% aqueous solutions. These solutions were mechanically stirred for 1 h prior to studying the rheological properties of the prepared mixtures.

Table 1 shows the conditions for the synthesis of CM-CTS and the values of their DA, ES, and [η], while Table 2 gives the values for solubility of the samples obtained in water and 2% aqueous AA and NaOH. CTS-CM with high ES could not be obtained using a reaction mixture with an excess of water (80/20 water/IPA) (Table 1, samples CM-CTS-1–CM-CTS-6). These results are in good accord with the data of other workers [10, 11]. Increasing the reaction time (τ) from 1 to 4 h at 40°C leads to an increase in ES to 34%. In this case, a decrease in the DA of the samples from 83 to 70% is observed, indicating that the carboxymethylation reaction proceeds mainly at the polysaccharide hydroxyl groups. However, there is also partial addition of carboxymethyl groups at the amino groups. Since the reaction is carried out in an aqueous alkaline medium, there is oxidative destruction of the chitosan molecules, as indicated by the decrease in the values of [η] for the CM-CTS samples. Increasing the reaction temperature (*t*) and the amount of MCAA in the reaction medium did not lead to a significant increase in ES when using 80/20 water/isopropyl alcohol (IPA) (samples CM-CTS-5 and CM-CTS-6).

CM-CTS samples with high ES (see CM-CTS-7–CM-CTS-9) were obtained only using a reaction mixture with excess isopropyl alcohol (20/80 water/IPA), which is also in good accord with the results of other workers [10, 11]. The

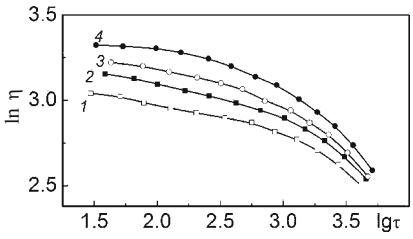

Fig. 1.

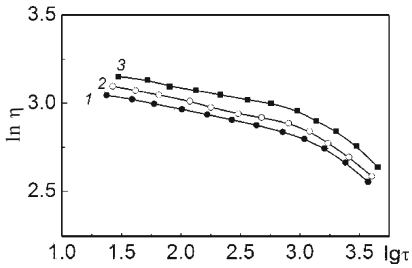

Fig. 2.

Fig. 1. Flow curves of 4% aqueous solutions of CM-CTS (*1*) and CM-CTS with added 0.063 (*2*), 0.125 (*3*), and 0.188 mole $CaCl_2$/mole CM-CTS (*4*).

Fig. 2. Flow curves of 4% aqueous solutions of CM-CTS (*1*) and CM-CTS with added 0.07 (*2*) and 0.35 mole $Ca(OH)_2$/mole CM-CTS (*3*).

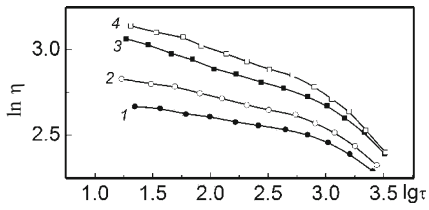

Fig. 3.

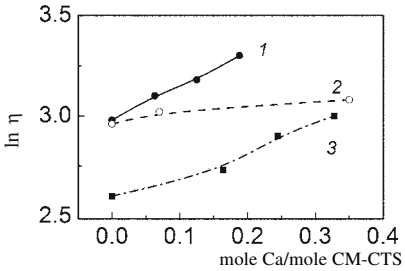

Fig. 4.

Fig. 3. Flow curves of 4% aqueous solutions of CM-CTS + PEO (*1*) and CM-CTS + PEO with added 0.164 (*2*), 0.245 (*3*), and 0.328 mole $CaCl_2$/mole CM-CTS (*4*).

Fig. 4. Dependence of the viscosity of 4% aqueous solutions of CM-CTS on the amount of added $CaCl_2$ (*1*), $Ca(OH)_2$ (*2*), and CM-CTS + PEO with $CaCl_2$ (*3*) (viscosity at log τ 2.0).

greatest ES value was obtained carrying out the reaction at room temperature (CM-CTS-9) but with a very long reaction time, which is inconvenient for the industrial production of chitosan ether.

The data given in Table 2 show good solubility in water for CM-CTS with ES > 70%. Since CM-CTS is a polyampholite containing amino and carboxyl groups, we should expect its solubility in both acidic and alkaline media. CM-CTS samples with low ES (up to 50%) are insoluble or only partially soluble in aqueous NaOH but, similar to chitosan, highly soluble in acidic aqueous solutions. Good solubility of CM-CTS in aqueous NaOH is observed only for ES > 70%. Complete solubility of CM-CTS in alkaline media occurs when ES = 90%.

In order to raise the viscosity of aqueous solutions of CM-CTS or obtain gel-like systems, we use additives of the salts of polyvalent metals, synthesize copolymers with CM-CTS as a component [7, 18-21], or mix with other polymers [22-24]. In order to investigate the intermolecular interactions in concentrated solutions, we studied the rheological properties of 4% aqueous solutions of CM-CTS with ES = 70% with added $CaCl_2$ and $Ca(OH)_2$. Chitosan is partially compatible with polyethylene oxide [25]. Thus, we studied the rheological properties of 4% aqueous solutions of 85/15 CM-CTS/PEO with added $CaCl_2$.

The flow curves of all the systems studied represent incomplete flow curves of non-Newtonian liquids (Figs. 1-3). The structural viscosity branch appears at log τ > 2.5. For convenience of comparison, the curves for the dependence of the viscosity of the mixtures studied on the amount of additive are shown in Fig. 4. The introduction of $CaCl_2$ into a solution of CM-CTS leads to a greater increase in viscosity than upon the introduction of $Ca(OH)_2$ (Fig. 4, curves *1* and *2*). Mixing a solution of CM-CTS with a solutions of PEO (curve *3*) reduces the viscosity due to the lower viscosity of the PEO solution. (PEO with a low molecular mass). However, the trend for increasing viscosity of CM-CTS/PEO with added $CaCl_2$ remains similar: as in the case of the solution of CM-CTS with added $CaCl_2$, the viscosity is considerably enhanced. Thus, the viscosity of aqueous solutions of CM-CTS may be varied in a rather broad range up to the formation of gels by introducing Ca^{2+} ions as aqueous solutions of $CaCl_2$ or $Ca(OH)_2$ into solutions of chitosan ether.

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