

SYNTHESIS AND STUDY OF PHYSICO-CHEMICAL CHARACTERISTICS OF NOVEL CATIONIC (CO)POLYMERS BASED ON N-ISOPROPYLACRYLAMIDE AND N-(2-VINYLOXYETHYL)-N-(2-CYANOETHYL) AMINE

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Received 22 February 2018

Accepted 20 December 2018

ABSTRACT

This work deals with the development of a procedure for the isolation of a complex of biologically active substances from the aerial parts of some plants of Polygonum L. grown up in Kazakhstan and the determination of a possibility of their application to officinal medicine. The effect of various factors (the temperature, the extraction time, the raw material: solvent ratio) on the chemical composition of the extracts of a high yield of biologically active substances from Polygonum minus, P. aviculare, P. hydropiper is studied.

Keywords: Polygonum, antimicrobial activity, complex of BAS, flavonoids.

INTRODUCTION

The polymers which can rapidly change their properties with a slight change in the environmental parameters are called “smart” or susceptible polymers [1]. The increased interest to them is due to the combination of their unique properties that provide an wide application both in basic research and for practical purposes. Receptive polymer systems, water-soluble and water-swelling polyelectrolytes of a cationic type are now widely used in various industries, biotechnology and medicine because of their unique set of physico-chemical properties. They are used for the capillary electrophoresis of deoxyribonucleic acid, for the separation of proteins and antigens and targeted drug delivery, in chromatography, as a part of microfluidic devices, as catalysts, cell substrate and sensory materials [2 - 12]. At the same time, according to the specialists, the polycations containing

mainly side or primary-chains, secondary and tertiary amine or quaternary ammonium groups included in the basic chain have the greatest practical value. The possibility of modification and the production of new cationic polymers based on them with a variation of the substituents structure at the nitrogen atom, or through a distribution of groups along the macromolecule chain, and the like, opens wide prospects for their practical application [13 - 14]. The cationic polyelectrolytes are the objects of detailed research, due to the uniqueness of their physicochemical properties and the perspectives of application.

The acrylate derivatives containing nitrogen atoms in the backbone or in the side groups are the most widely used among the cationic monomers and polymers.

One of the most common methods of synthesizing polymers of a given set of physico-chemical properties is copolymerization. Factors that can affect the copoly-

merization rate of the ionic monomers include the nature of the (co)monomers, the pH, the ionic strength of the solution, the concentration of the low-molecular-weight salt or the neutralizing agent [15].

In this work cationic type (co)polymers based on N-isopropylacrylamide (NIPAAm) and N-(2-vinylloxyethyl)-N-(2-cyanoethyl) amine (VOECEA) are prepared by the radical polymerization method.

EXPERIMENTAL

Materials

The following materials were used as reagents in the synthesis of (co)polymers based on NIPAAm-VOECEA:

1. N-isopropylacrylamide purchased from Sigma-Aldrich (USA) with 97 % basic product content was used without further purification.

2. N-(2-vinylloxyethyl)-N-(2-cyanoethyl) amine was synthesized at the Bekturov Institute of Chemical Sciences through the reaction of the vinyl ester of monoethanolamine with acrylonitrile. The reaction proceeding within 6 h at a room temperature provided 98 % basic product content. The substance was used without further purification.

3. Dinitrile azoisobutyric acid was purchased from Sigma-Aldrich (USA) with a main product content of 98 %. It was used without further purification.

Analysis of (co)polymers

Solid state nuclear magnetic resonance (NMR)

The composition of the (co)polymers was determined by ^1H and ^{13}C NMR spectroscopy in deuterated dimethylsulfoxide (DMSO-d_6) using a NMR spectrometer JNM-ECO 400 from Jeol (Japan) at an operating frequency of 400 MHz.

Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectra of the (co) polymer samples were recorded using an ATR/FTIR spectrometer with a Fourier transducer "Spectrum Two IR Spectrometers" (USA) in the 4000 cm^{-1} - 400 cm^{-1} region at a room temperature.

Viscosity

The characteristic viscosity of the (co)polymers solutions was determined by measuring the time of flow of polymer solutions of different concentrations obtained using a 1 % solution of a common salt in Ubbelohde

viscometer at 20°C . The characteristic viscosity $[\eta]$ is evaluate in $[\text{mL g}^{-1}]$.

Thermal analysis

The thermal analysis of the (co)polymers was carried out using "Perkin Elmer Pyris 1 TGA" thermogravimetric analyzer from "Perkin Elmer Instruments" (UK) at a heating rate of $10^\circ\text{C min}^{-1}$ under a dry nitrogen atmosphere (99.99 %, flow rate 20 mL min^{-1}). The mass of the polymer samples was ca 10 mg - 12 mg.

Differential scanning calorimetry

The differential scanning calorimetry experiments of the samples were carried out on "Perkin Elmer Diamond DSC" device from "Perkin Elmer Instruments" (UK) at a scanning rate of $10^\circ\text{C min}^{-1}$ in an atmosphere of dry nitrogen. Since the thermoanalysis parameters, mainly the glass transition temperature were sufficiently sensitive to the experimental conditions and the presence of moisture inside the polymers, the system together with the samples was preheated to 210°C at a rate of $10^\circ\text{C min}^{-1}$, then cooled at a rate of $10^\circ\text{C min}^{-1}$. The second scan provided the experimental data required.

Copolymerization

The novel cationic (co)polymers of NIPAAm-VOECEA were synthesized under real initiation conditions in sealed ampoules of molybdenum glass in an alcohol solution (70:30 vol.%). The contents of the ampoules were previously purged with an inert gas for 15 min - 20 min. Then the ampoules were sealed.

Dinitrile azoisobutyric acid was used as an initiator. The radical polymerization was carried out at 60°C for 1 h up to 2.5 h. (Co)polymers [NIPAAm-VOECEA] = 90:10 mol. %; 70:30 mol. % and 50:50 mol. % were obtained by varying the ratios of the initial monomer mixture (IMM). The obtained copolymers of NIPAAm-VOECEA were isolated twice by precipitation in boiling water, then they were dried in a vacuum drying oven until a constant weight was obtained. The synthesized copolymers of NIPAAm-VOECEA were white solids with a yellowish shade. They formed white translucent crystals of a different size when triturated.

RESULTS AND DISCUSSION

NMR (^1H and ^{13}C) spectroscopy is used to determine the chemical composition of the (co)polymers obtained.

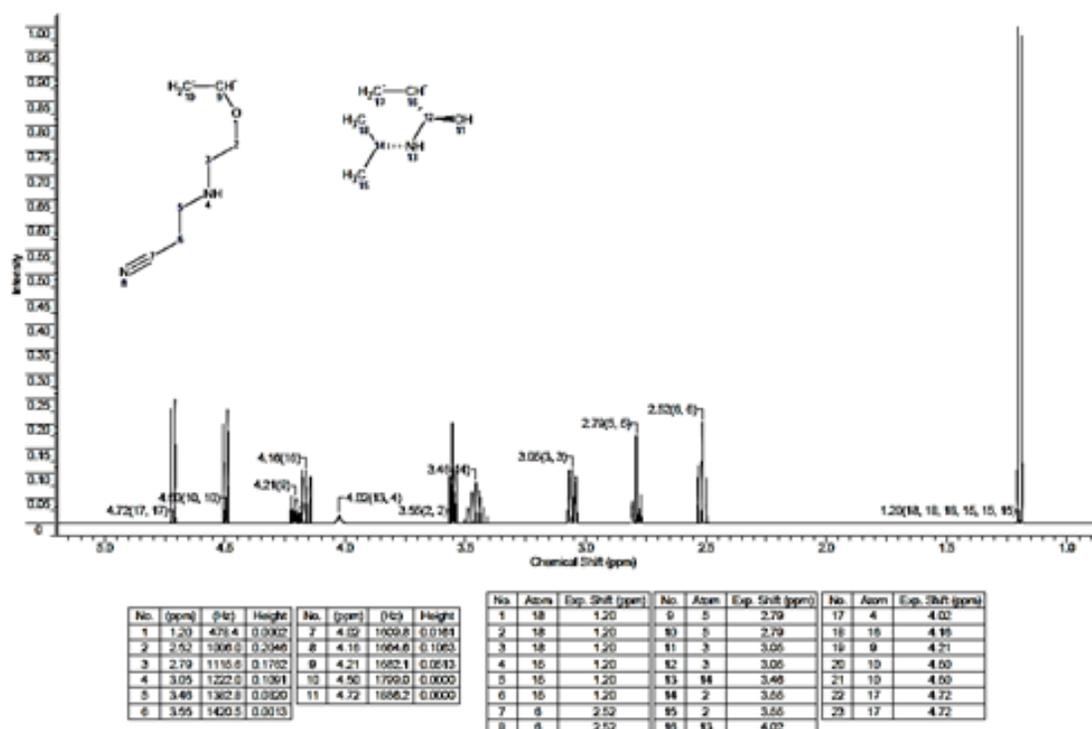


Fig. 1. ¹H NMR spectra of NIPAAm-VOECEA (co)copolymers.

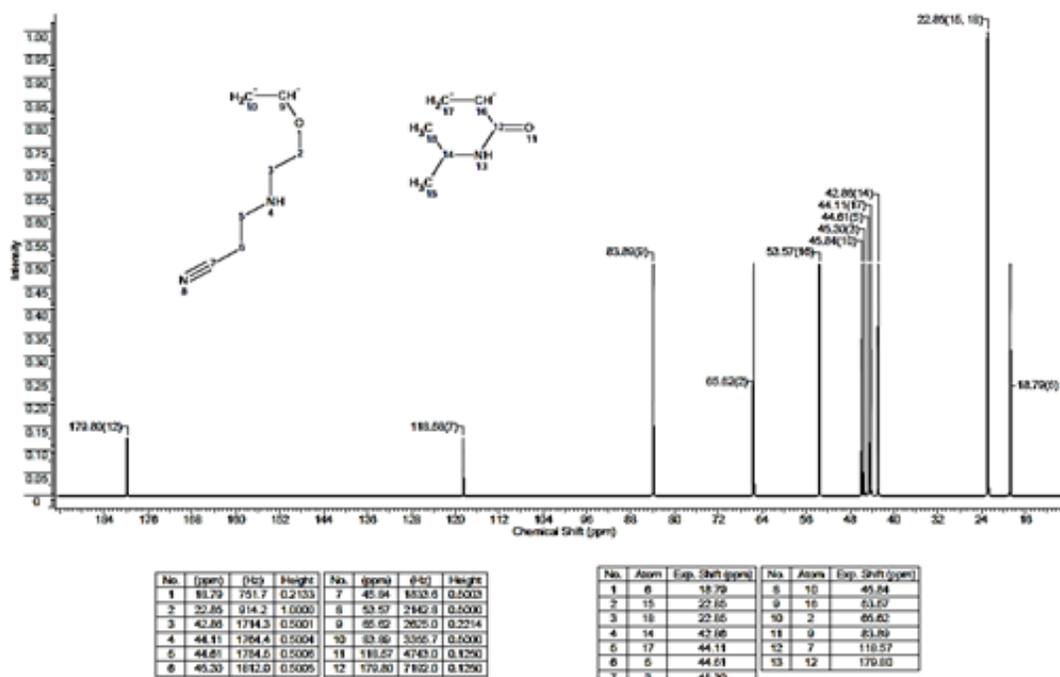


Fig. 2. ¹³C NMR spectra of NIPAAm-VOECEA (co)copolymers.

DMSO-d₆ is used as a solvent. Figs. 1 and 2 show the ¹H and ¹³C NMR spectra of NIPAAm-VOECEA copolymers samples, respectively. Signals of methyl (1.00 ppm) and methylene groups (1.13 - 2.30 ppm) are observed in the strong field of the proton spectrum of the investigated

compound. The protons of -CH₂-O- fragment resonate at a frequency of 3.66 ppm. Proton signals appear at the sp²-hybridized carbon atom at ca 3.86 ppm. The protons of the amino groups are characterized by signals with a chemical shift of 4.16 ppm.

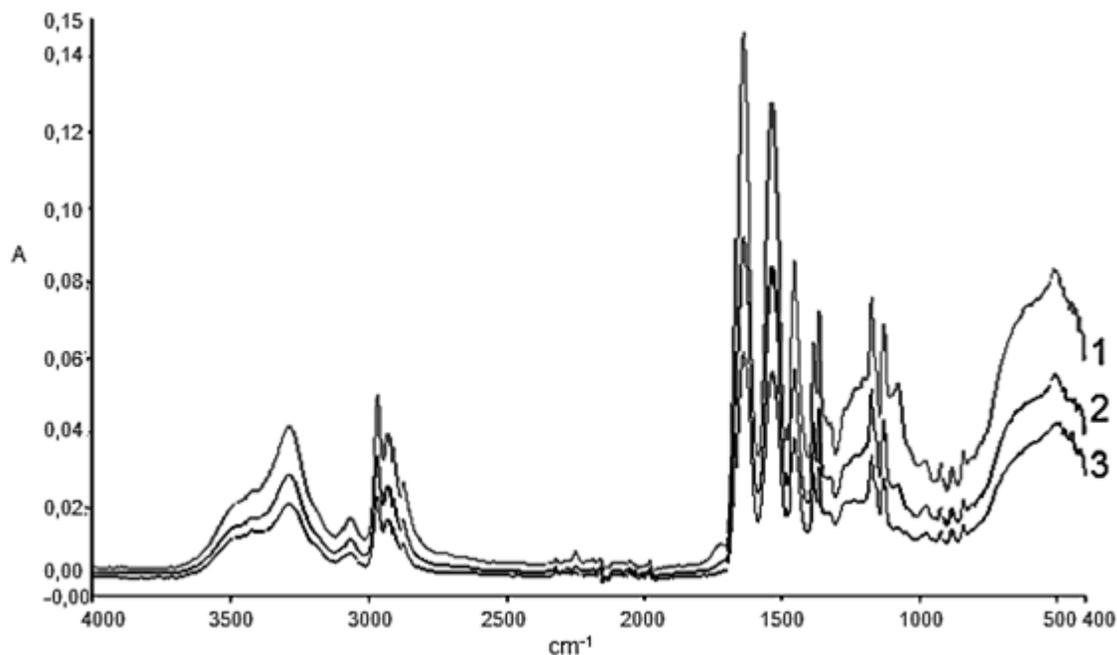


Fig. 3. IR spectra of NIPAAm-VOECEA (co)copolymers with IMM 50:50 (1); 70:30 (2); 90:10 (3) mol %.

The signals of the methyl and the methylene carbon atoms are manifested at 22.79 ppm (CH_3); 18.37 ppm and 47.84 ppm (CH_2); 68.14 ppm and 87.40 ppm ($\text{CH}_2\text{-O}$) in the carbon spectrum. The resonance of sp^2 -hybridized carbon atoms is noted in the region of 40.86 ppm. The highest-frequency signals (120.58 ppm - 170.00 ppm) belong to the carbon atoms of the nitrile and the carbonyl groups.

IR spectra of (co)polymers based on NIPAAm and VOECEA are recorded. Fig. 3 shows the IR spectra of NIPAAm-VOECEA (co)polymers of a various composition. It is found that in all spectra the peaks of 2970 cm^{-1} and 2930 cm^{-1} correspond to the isopropyl methyl group and the asymmetric valence vibration of the methylene group in the polymer chain of NIPAAm-VOECEA (co) polymer, respectively. The number of waves at 1535 cm^{-1} and 1640 cm^{-1} characterize the amide and hydrogen bonds, respectively. The wave of ether groups C-O-C is

noticeable at 1080 cm^{-1} .

The characteristic viscosity of the (co)polymers solutions is determined by measuring the time of flow of solutions of different concentrations obtained using a 1N solution of a common salt in Ubbelohde viscometer at 20°C . The characteristic viscosity $[\eta]$ is evaluated in $[\text{mL g}^{-1}]$. The values obtained are listed in Table 1.

Fig. 4 shows the data of the thermogravimetric analysis (TGA) of the samples of NIPAAm-VOECEA copolymers of a various composition. The destruction of the copolymers proceeds in two stages. The initial weight loss by about 8 % - 10 % is observed around 100°C - 110°C . It is caused by the release of the moisture absorbed from the air.

The final and complete loss of the copolymer mass to 90 % begins at ca 370°C and reaches a maximum at 450°C leading to complete degradation of the copolymers. As can be seen from Fig. 4, the thermal degradation

Table 1. The characteristics of obtained (co)polymers.

No	Composition of initial monomer mixture, mol.%		Product yield, %	$[\eta]$ in 0,1 N NaCl, mL/g	Solubility in water
	NIPAAm	VOECEA			
1	50,0	50,0	65,5	3,65	Good
2	70,0	30,0	68	3,5	Good
3	90,0	10,0	70,2	3,1	Good

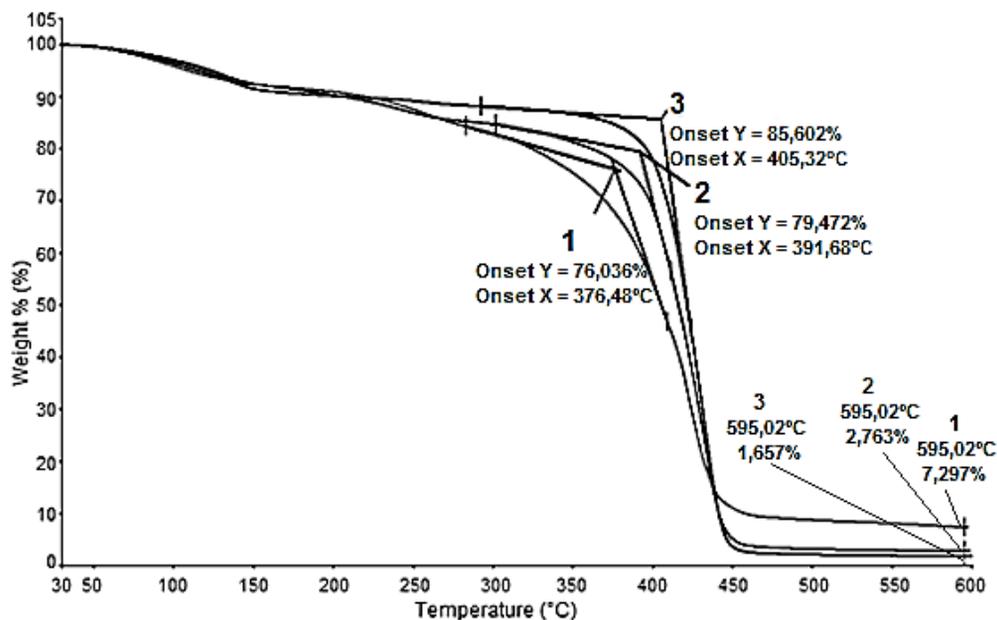


Fig. 4. TGA Curves of (co)polymers of NIPAAm-VOECEA with IMM 50:50 (1); 70:30 (2); 90:10 (3) mol %.

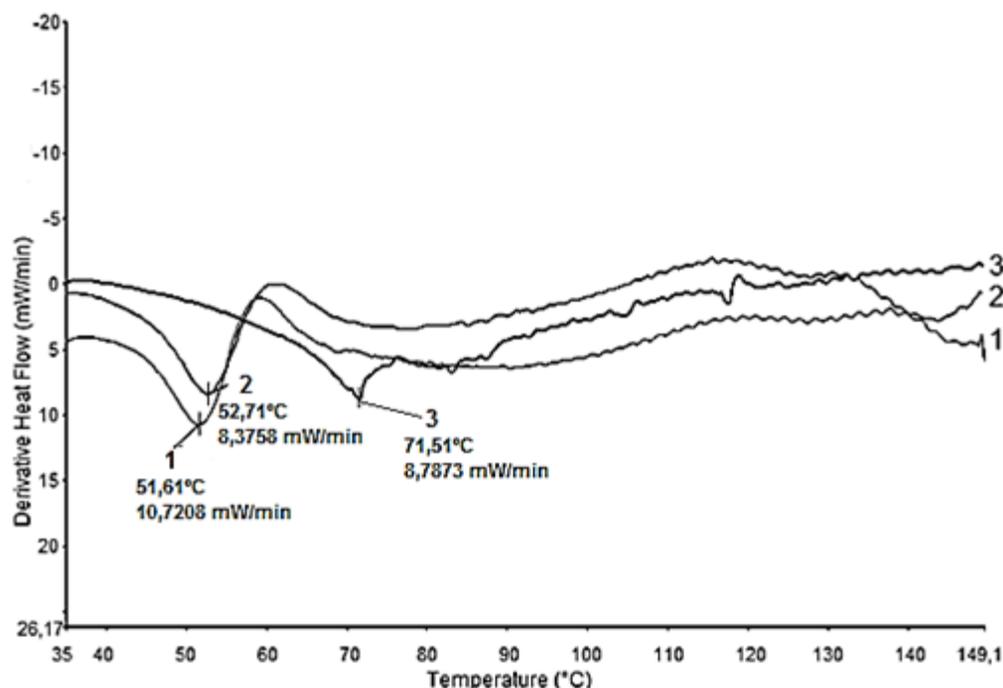


Fig. 5. DSC thermogram curves for NIPAAm-VOECEA (co)polymers with IMM 50:50 (1); 70:30 (2); 90:10 (3) mol %.

begins at low temperatures with the decrease of NIPAAm links in the composition of the (co)polymers. This is due to the presence of oxygen in the links of VOECEA, i.e. the presence of oxygen promotes the destruction of the (co)polymers at low temperatures. In general, the absence of obvious kinks indicates that the samples do

not contain low-molecular-weight impurities including a solvent and an oligomer.

The glass transition temperature is one of the most important characteristics of the polymers, which determines the temperature range of their application. Typically the (co)polymers have an identical value of

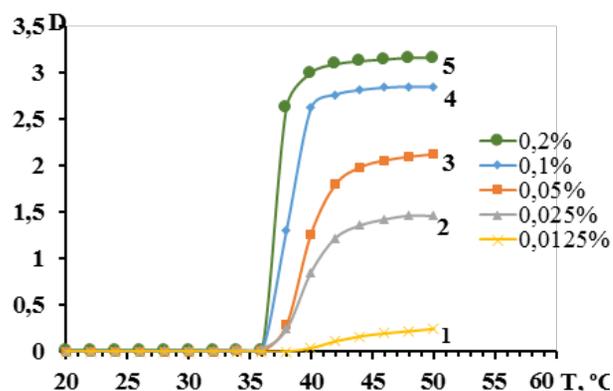
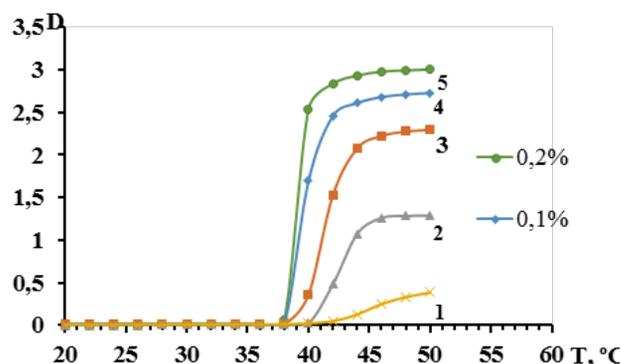


Fig. 6. Dependence of the optical density of NIPAAm-VOECEA (co)polymers with IMM 50:50 (a); 70:30 (b) Mol.% from the temperature: [NIPAAm-VOECEA] = 0.0125 (1); 0.025 (2); 0.05 (3); 0.1 (4); 0.2 (5) g/dl.

the glass transition temperature (T_g). The (co)polymers with a noticeable predominance of the links of one of the monomers are similar in properties to the polymer of the latter. Herewith, the comonomer present in a smaller amount plays a modifier role.

The glass transition temperature of the (co)polymers is determined using a differential scanning calorimetry (DSC) instrument. Fig. 5 presents the results of DSC analysis of NIPAAm-VOECEA (co)polymers. It is determined that T_g shifts to the region of higher values with increase of NIPAAm content of the (co)polymer composition.

According to ref. [16], the glass transition temperature (T_g) of NIPAAm homopolymer is about 85°C - 130°C. It is seen that T_g of the (co)polymers with IMM of 90% NIPAAm is 72°C (Fig. 5). And for (co)polymers with IMM 50:50 mol. % and 70:30 mol. % T_g decreases to 51°C - 53°C. This is due to the clotting of the polymer chain and the rigidity of NIPAAm links.

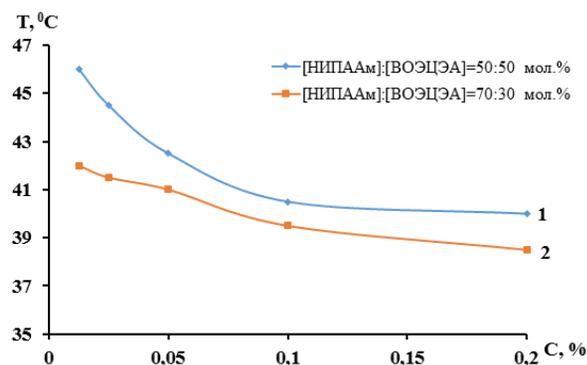


Fig. 7. Phase transition diagram of NIPAAm-VOECEA (co)polymers with IMM 50:50 (1); 70:30 (2) mol %.

Investigation of the thermosensitive properties of (co)polymers

The phase transitions of the aqueous solutions of NIPAAm-VOECEA (co)polymers (IMM [NIPAAm]:[VOECEA] = 50:50 mol. % and 70:30 mol. % are studied by the turbidimetric method. According to Figs. 6 a, b the degree of turbidity of the solution is increased with temperature increase. Consequently, the temperature change is a cause of the stratification into two phases of the initial homogeneous mixture. This is due to the rupture of the hydrogen bonds and the enhancement of the hydrophobic interactions. The latter are sufficiently strong at low temperatures, i.e. they allow macromolecules to be in an unassociated form in aqueous solutions. It is found that the temperature of the phase transition of the solution increases with increase of the cationic monomer units in the composition of the (co)polymers based on NIPAAm.

Based on the turbidimetry data obtained, diagrams of the phase transitions of the water-soluble cationic NIPAAm-VOECEA (co)polymers are constructed (Fig. 7). It is found that the (co)polymers obtained have a lower critical solution temperature (LCST). Moreover, the dependence of the phase transition temperature on the composition of (co)polymer is identified, i.e. LCST is shifted to higher temperatures with increase of VOECEA links. Fig. 8 illustrates the effect of the ionic strength of the medium on the phase transition temperature. The increase the ionic strength of the solution leads to a decrease of LCST. It is proved that the presence of low molecular weight salts is a factor contributing to the phase transition. This is due to a decrease in the thermodynamic quality of the solvent. Figs. 9 a, b illustrate the effect of pH on the thermal sensitivity of the copolymers solutions.

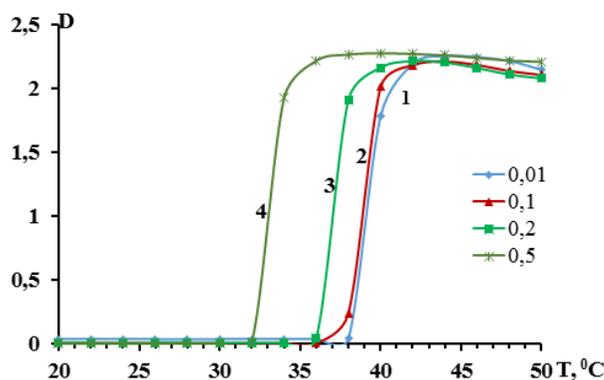


Fig. 8. Dependence of optical density of NIPAAm-VOECEA (co)polymers with IMM 50:50 mol % from the temperature: [NIPAAm-VOECEA] = 0.1 g/dl; [NaCl] = 0.01 (1); 0.1 (2); 0.2 (3); 0.5 (4) mol/l.

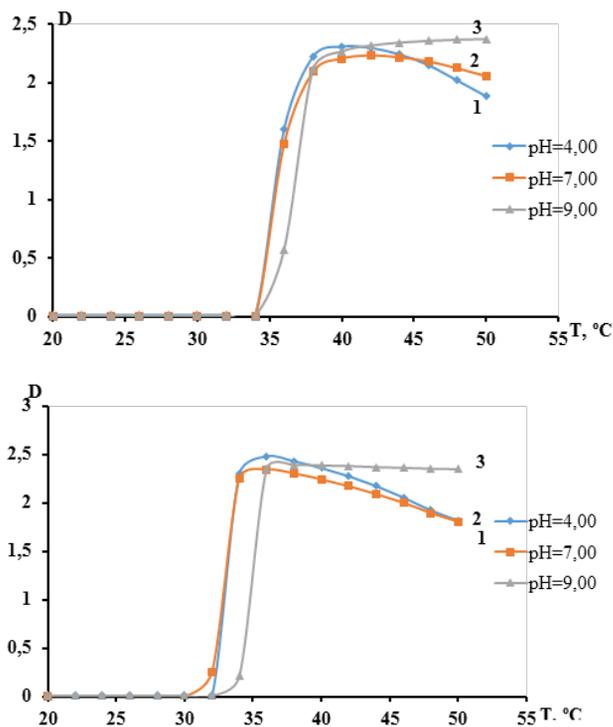


Fig. 9. Dependence of the optical density of NIPAAm-VOECEA (co)polymers with IMM 50:50 (a); 70:30 (b) mol % from the temperature at different pH values: [NIPAAm-VOECEA] = 0.1 g/dl; PH = 4.00 (1); 7.00 (2); 9.00 (3).

CONCLUSIONS

Novel water-soluble cationic (co)polymers based on N-isopropylacrylamide and N-(2-vinyloxyethyl)-N-(2-cyanoethyl) amine are obtained by radical copolymeri-

zation. They are characterized by a high characteristic viscosity attributed to their high molecular mass.

The studies of the IR and NMR spectra of the synthesized new cationic (co)polymers indicate the occurrence of radical copolymerization. According to the results of the thermogravimetric and the differential calorimetric analysis, an increase of N-isopropylacrylamide units in the composition of the (co)polymer shifts the glass transition temperature and the destruction temperature to higher values.

The synthesized (co)polymers have a positive charge and thermosensitive properties, which makes them perspective for application in medicine, biotechnology and electronics.

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