

Physico-chemical Behavior of Polymeric Hydrogels

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Abstract

New polymeric hydrogels based on vinyl ethers have been synthesized by the γ -initiated polymerization method. Their physical chemistry and physical mechanical properties have been studied. It has been shown that structure and swelling behavior of the hydrogels can be regulated by the changing of synthesis conditions nature of monomers. Novel stimuli-sensitive polymers have been synthesized by the varying of macrochains hydrophilic-hydrophobic balance. The some biomedical aspects of application of hydrogels in capacity of drain aging polymeric materials in ophthalmology surgery, implants in plastic surgery as well as drug delivery systems have been investigated.

keywords : polymeric hydrogel, γ -initiated polymerization, swelling behavior, plastic surgery

1. Introduction

Due to unique properties, polymeric hydrogels are widely used in various fields of medicine [1].

Vinyl ethers of glycols and aminoalcohols produced on Alash Co. Ltd., Kazakstan, are specific and perspective monomers to synthesize a various kinds of hydrogels with unique physico-chemical and physico-mechanical properties. It was found by our research team that the gamma-irradiation polymerization method is more effective to obtain both water-soluble and water-swelling co-polymers, the radical mechanism of reactions was found [2]. Molecular-weight and conformation characteristics were studied, and main constants were determined [3].

Presented work is continuation of the investigation on using γ -irradiation technologies for synthesis of bio-medical cross-linked polymers based on vinyl ethers of stimuli-sensitive polymers as well as pH-sensitive and thermo-sensitive polymers which can be used as controlled drug releasing and delivery systems, draining in ophthalmology surgery etc.

2. Gamma-irradiation synthesis

2.1. Polymerization of vinyl ethers of glycols

To optimize the synthesis of polymeric gels based on vinyl ethers, the influence of cross-linking agent (CA) structure and nature as well as conditions of cross-linking process on the equilibrium swelling state, elasticity module and the basic parameters of hydrogels was studied [4]. The hydrogels based on vinyl ether of ethyleneglycol (VEEG) and vinyl ether of diethyleneglycol (VEDEG) were synthesized in the presence of divinyl ether of diethyleneglycol (DVEDEG), N,N'-methylene-bis-acrylamide (BAA), N,N-bis(2-vinyloxyethyl)urea (BU), N,N-bis(2-vinyloxyethyl)ethylurethane (BEU) and allyloxyethylcellulose (AOEC), M_n 120000 as cross-linking agents. BAA is bifunctional acrylic cross agent, which is widely used at the synthesis of hydrogels. BU and BEU are analogue to DVEDEG and they are vinyl ethers. AOEC is high molecular weight cross agent.

At the using of the vinyl ethers with similar activities of double bonds as a cross-agent,

practically same result takes place. In all cases, the increasing of the CA concentration and absorbed irradiation dose D leads to the increasing of gel fraction yield and cross-linking degree. Exception is only BAA, which has high reactivity of its double bounds. As it is seen from Fig. 1, the swelling degree α and cross-linking degree (parameter n that is determined from Flory-Rener equation) pass through maximum and minimum respectively and gel fraction yield increases during the increasing of irradiation dose. It can be supposed that the reason of observed effects is the peculiarities of three dimensional radical co-polymerization in the system VEEG-BAA with significant difference in monomer and CA activities. BAA as a more reactive agent is consumed at initial conversion degrees. It depresses the effects concerned with increasing of network charge. So then, the significant difference between the monomer and CA activities is accompanied by more inhomogeneous network formation with low and high cross-linking density phases in comparison with systems in which co-monomer activities are similar.

The network formation process through the participation of pendant double bonds on the degree of conversion was detected by Raman spectroscopy. It is proved that the double bonds of more active cross-agent BAA are involved into the polymerization process completely. The swelling degree α of hydrogels decreases with the CA connection increasing except only AOEC. The equilibrium swelling degree value of VEEG polymer (PVEEG) hydrogels cross-linked by AOEC increases due to the polymer's chains. It makes it possible to obtain the high swelling hydrogels containing up to 100 g of water per 1 g of dried polymer. One can proposed that the application of CA having double bounds closed to monomers' double bonds on activity is more affective. Therefore, the DVEDEG, which is closed to vinyl ether of glycols (VEG) on

activity and structure, was used as a CA in further experiments.

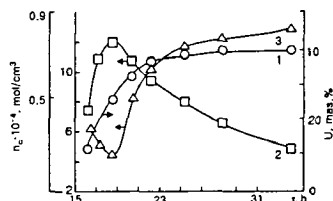


Fig. 1. The influence of irradiation period at dose rate 120 rad/sec on gel-fraction yield (1), swelling degree (2), and cross-linking degree (3) for PVEEG hydrogels with BAA as CA.

It was showed earlier that one of the effective way to regulate the co-polymerization process of VEG to carry out the reaction in aqueous solutions. In contrast to organic solutions, we observed the growth of reaction rate and molecular weight of linear polymers, the change of the composition and structure of the polymers in aqueous solutions.

In the present communication, this procedure was also used for the three dimensional γ -irradiation polymerization of VEEG and BEDEG in the presence of DVEDEG. A considerable influence of water molecules on the kinetics of polymerization, swelling and strength parameters of hydrogels was established. Consequently, the kinetic effect of enhancing during the three dimensional polymerization leads to the formation of more cross-linked network structure. It is possible to regulate the physico-chemical and physico-mechanical properties of hydrogels by variation of the structure and nature of both monomers and cross-agents, changing the concentration of cross-linkers, dose of irradiation and by addition of water molecules into the reaction mixture. The structure of networks can be calculated theoretically (M_c^{theor}), determined from the equilibrium swelling data (M_c^{mech}) and of M_c^{mech} , M_c^{es} and as well as theoretically

calculated M_c^{mech} are different. The increasing of the irradiation dose D leads to the decreasing of M_c^{mech} and M_c^{es} . M_c^{es} is always higher than M_c^{mech} . At the same time, the values of M_c^{mech} and M_c^{es} for VEEG hydrogels are high than that of VEDEG. It should be noted that $M_c^{mech}/M_e^{theor} < 1$ for both VEEG and VEDEG hydrogels independently on the reaction conditions exception for the VEEG at low D and concentration of CA. The difference between M_c^{mech} and M_c^{es} for networks is probably the result of heterogeneity of their structure and can be explained by the presence of regions with low (diluted phase) and high (concentrated phase) volume fraction of macromolecules. The low value of experimentally found M_c in comparison with calculated one is the evidence that the real VEEG and VEDEG networks are more cross-linked. The side substitutes of vinyl monomers (VEEG and VEDEG) also can additionally participate in the formation of three dimensional structures during the γ -irradiation (co)polymerization. However, the contribution of these reactions was not taken into consideration when M_e^{theor} was calculated. The increasing of the side substitute (for instance in the case of VEDEG) leads to increasing the probability of such reactions.

2.2. New pH-sensitive polymeric hydrogels

Novel pH-sensitive anionic polymers were synthesized by γ -initiated radical co-polymerization of AA vinyl ethers vinyl alkyl ethers (VBE and VIBE) of hydrophobic nature. The relative activity of vinyl ethers and AA has been determined via the binary co-polymerization investigation of at low conversion degree in aqueous solutions. It has been found that vinyl ethers are considerably less active in comparison with AA:

$$r_1(AA)=5.4 \quad r_2(VBE)=0.01$$

$$r_1(AA)=5.6 \quad r_2(VIBE)=0.01$$

The co-polymerization rate depends on active acrylic co-monomer concentration in the feed. With conversion and enriching of reaction mixture by low active acrylic monomer the co-polymerization rate is decreased, AA units content in polymer composition is decreased and composition inhomogeneity is appeared.

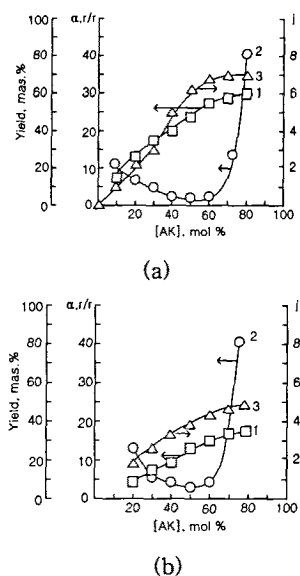


Fig. 2. The influence of the feed composition on gel-fraction degree (1), swelling degree a (2), and cross-linking index j (3) of copolymers VBE-AA (b).

$[CA]=4 \text{ mol.}\%$; $D=102,1 \text{ kGy}$; $\text{alcohol } 50 \text{ vol.}\%$

Similar regularities were observed for three dimensional co-polymerization of vinyl alkyl ethers (VAE) with AA in the presence of DVEDEG as c cross-agent. An increasing of acrylic co-monomer concentration in the feed increases the rate and yield of sol and gel fractions. As it is well known, for polyelectrolyte gels the high equilibrium swelling degrees polymeric network. But, the swelling degree of cross-linked copolymers VAE-AA does not increase and falls down with the increasing of AA concentration in the feed until definite value (Fig. 2). It can be supposed that the reason of

observed effects is the peculiarities of difference in monomer activities. AA as a more reactive co-monomer, is consumed at initial conversion degrees. It is accompanied by the formation of high density network (low α and high n_c). It depresses the effects concerned with increasing of network charge. These results are in accordance with data on VEEG three-dimensional polymerization with BAA as a cross agent. Moreover, copolymers are enriched with hydrophobic component. The significant difference between the monomers activities is accompanied by more inhomogeneous network formation with low and high cross-linking density passes in comparison with systems in which co-monomer activities are similar.

The comparative analysis of the data on the synthesis of copolymers of vinyl alkyl ethers with acrylic acid showed, that the values of gel fraction yield and cross linking density are higher and the equilibrium swelling degrees are lower for VBE-AA system than for VIBE-AA system. Thus, the equilibrium swelling of hydrogels in water can be regulated not only by an increase of hydrophilic fragments concentration in the network but, by changing of the structure of vinyl alkyl ether. namely, the transition from VBE to VIBE in the line of cases is accompanied by an increase of α in approximately two time at the same synthesis conditions.

3. Conclusion

It has been shown that the γ -irradiation (co)polymerization is one of the effective method for obtaining of various types of hydrogels on the basis of vinyl ethers of glycols and aminoalcohol. Physico-chemical and physico-mechanical properties of hydrogels can be regulated by variation of synthesis conditions. New types of hydrogels derived from hydrophilic and hydrophobic monomers are thermo- and pH-sensitive, and they can be used as controlled

drug releasing system. The phase and volume transitions of hydrogels can be regulated by varying of the hydrophobic/hydrophilic balance of network, by introduction of ionic groups into the neutral network and by addition of low-molecular-weight salts.

Composition of polymer hydrogel based on vinyl ether of ethyleneglycol has successfully passed the pre-clinical tests for application in plastic surgery in injection form.

Acknowledgements

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