Tr. J. of Chemistry
21 (1997) , 151 – 161.

Influence of Some Crosslinkers on the Swelling of Acrylamide-Crotonic Acid Hydrogels

Erdener KARADAĞ*, Dursun SARAYDIN
Cumhuriyet University, Chemistry Department,
58140 Sivas-TURKEY
Olgun GÜVEN
Hacettepe University, Chemistry, Department,
06532 Beytepe, Ankara-TURKEY

Received 10.1.1996

Acrylamide-crotonic acid hydrogels in the form of rods are prepared by γ-irradiation of quaternary mixtures of acrylamide-crotonic acid-crosslinker-water with 2.6 and 5.2 kGy γ-rays. The influence of the applied dose, the relative content of crotonic acid and crosslinkers such as ethylene glycol dimethacrylate, 1.4 butanediol dimethacrylate and N,N′ methylenebisacrylamide on the swelling properties of the gel, the diffusional behaviour of water, the diffusion coefficient, and the network parameters of hydrogel systems are examined. Acrylamide-crotonic acid hydrogels containing various crosslinkers had a maximum swelling in the range 240-850 %. Water diffusion to hydrogels was non-Fickian. The diffusion coefficients varied between 4.6×10^{-7} and 9.1×10^{-7} cm^2 s^{-1}.

Introduction

A gel is a form of matter intermediate between a solid and a liquid. It consists of polymers, or long-chain molecules, crosslinked to create a tangled network and immersed in a liquid medium. The properties of the gel depend strongly on the interaction of these two components. The liquid prevents the polymer network from collapsing into a compact mass; the network prevents the liquid from flowing away[1]. The physicochemical nature of gels plays an important role in biological processes. The structural similarity of living tissue to gels led to the development of the first biomaterials 30 years ago[1]. These new materials have hydrophilic groups and a three-dimensional structure. Hydrogels are water-swollen polymer networks. They are of great interest both medically and commercially. Their three-dimensional structure provides important mechanical stability and their elastic response to abrupt or continuous changes is desirable in soft tissue replacements. Hydrogels have received renewed attention in recent as materials for biomedical, biological and pharmaceutical applications[2–4].

Hydrogels have widespread applications in biomedical, bioengineering, pharmaceutical, veterinary, food industry, agricultural and related fields. It is used as a controlled release system for drugs and some

*Present address: Adnan Menderes University, Chemistry Department 09100 Aydın-TURKEY physiological body fluids, the production of artificial organs and contact lenses in biomedicine, and as absorbent in the removal of some unwanted agents such as waste water in sanitary, agricultural, industrial and environmental applications[2-4].

In our previous study, the swelling behaviour of acrylamide-crotonic acid hydrogels prepared by γ-radiation without crosslinkers was reported[5]. In other studies of ours, the adsorptions of some cationic dyes by acrylamide-itaconic acid and acrylamide-maleic acid hydrogels[6-8], the adsorptions of uranyl ions and some heavy metal ions by acrylamide-itaconic acid and acrylamide-maleic acid hydrogels[9,10], the biocompatibility of blood by acrylamide-crotonic acid and acrylamide-itaconic acid hydrogels[11], and the prepartion and characterization of acrylamide-maleic acid hydrogels[12] were investigated.

In this study, highly swollen crosslinked acrylamide-crotonic acid hydrogels in rod form were prepared by copolymerization of acrylamide (monomer), crotonic acid (comonomer) and some tetrafunctional crosslinkers such as ethylene glycol dimethacrylate, 1,4 butanediol dimethacrylate and N,N′ methylenebisacrylamide by γ-radiation. The influence of γ-ray dose, crotonic acid and crosslinkers on the swelling properties, diffusional behaviour of water, and network properties of hydrogel systems were examined at the end of the swelling tests.

Experimental

For the preparation of hydrogel systems, acrylamide, AAm (B. D. H., Poole-UK) weighing 1 g and 0,20 and 40 mg crotonic acid; CA (B. D. H., Poole-UK) were dissolved in 1 ml aqueous crosslinker solution (Table 1). Crosslinker solutions were prepared by the dissolving of a crosslinker, such as ethylene glycol dimethacrylate [EGDMA], 1,4 butanediol dimethacrylate [BDMA] and N,N′ methylenebisacrylamide [NMBA] for three different concentrations (5,10 and 30 mg mL^{-1}). These quaternary solutions were placed in PVC straws 3mm in diameter and irradiated at 2.60 and 5.20 kGy in air at ambient temperature in a ^{60}Co Gammacell 200 type γ irradiator at a fixed dose rate of 0.91 kGy hr^{-1}, the dose rate being determined by the conventional Fricke dosimeter. The hydrogels were obtained in the form of cylinders, and fresh hydrogels obtained in long cylindrical shapes were cut into pieces 3-4 mm in length. They were dried in air and in a vacuum, and stored for swelling studies. Dried hydrogels were left to swell in distilled water at 25 $\pm$ 0.1°C to determine the parameters of swelling, diffusion and network. Swollen gels removed from the water bath at regular intervals were dried superficially with filter paper, weighed and placed in the same bath.

Table 1. Monomers and crosslinkers used in the preparation of hydrogel systems.

Name	Formula	Molar Mass (g $mole^{-1}$)
Acrylamide	$H_2C{=}CHCOHN_2$	71.08
Crotonic acid	$CH_3CH{=}CHCOOH$	86.09
Ethylene glycol dimethacrylate	$[H_2C{=}CCH_3COOCH_2]_2$	198.22
1,4 Butandiol dimethacrylate	$[H_2C{=}CCH_3COOCH_2CH_2]_2$	226.28
N,N′-methylenebisacrylamide	$(H_2C{=}CHCONH)_2CH_2$	154.17

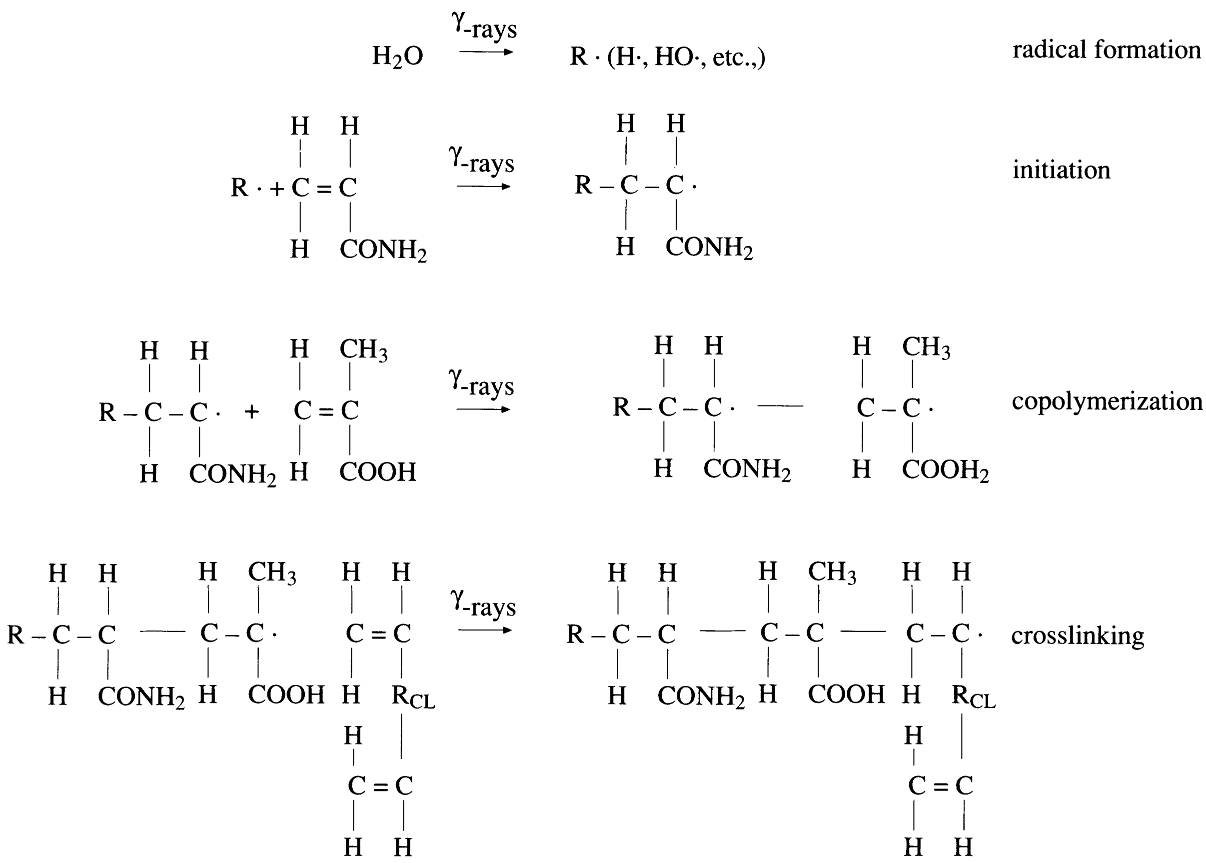
Results and Discussion

A radiation techniques seems to be promising for preparation of hydrogels because a polymer in aqueous solution or water-swollen state readily undergoes crosslinking on irradiation to yield a gel-like material.

Since this hydrogel is not contaminated with foreign additives and crosslinks must be composed of stable C-C bonds, it is of interest to study the preparation of hydrogels by irradiation[6-14].

Preparation

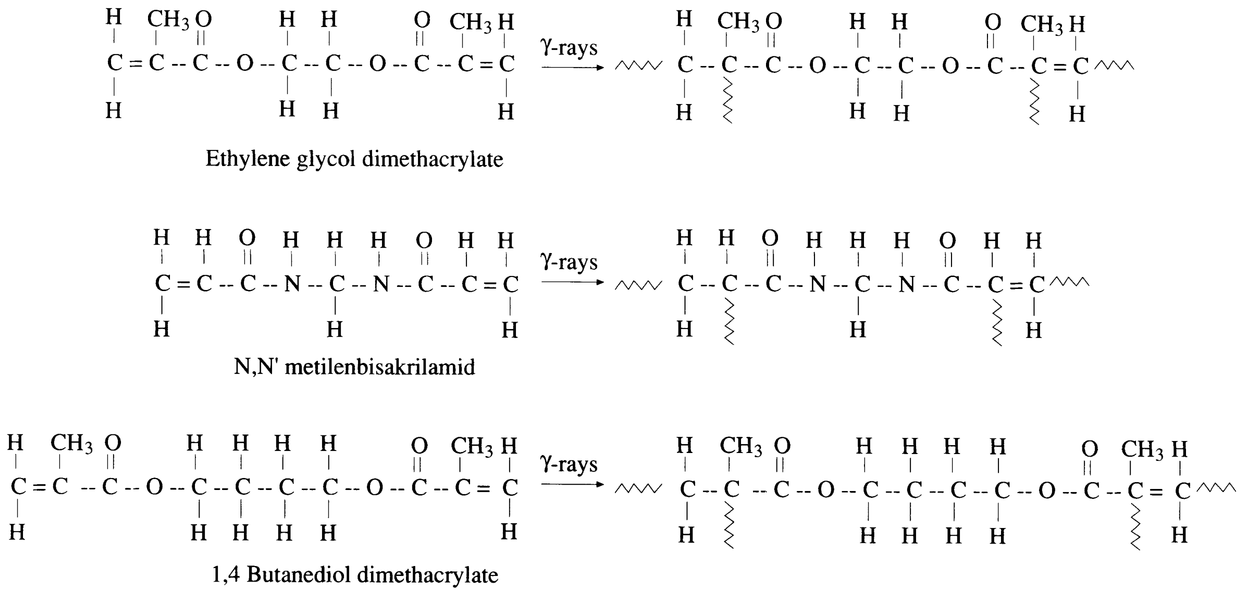
For the preparation of acrylamide (AAm) and acrylamide/crotonic acid (AAm/CA) copolymers containing crosslinkers, ionizing radiation processing was used. When monomers of acrylamide, crotonic acid and crosslinkers are irradiated with ionization rays such as γ-rays, one of the double bonds of $-C{=}C-$ on monomers breaks with the effect of ionization irradiation, and free radical occur. These free radicals react with each other, and a copolymer of acrylamide/crotonic acid occurs. The possible free radical polymerization reaction of poly (acrylamide/crotonic acid) by γ-rays irradiation is shown in Scheme 1[5].



Scheme 1. Possible copolymerization and crosslinking reaction mechanism between acrylamide and crotonic acid monomers with a crosslinker. R_{CL} show crosslinkers such as EGDMA, BDMA, and NMBA.

When the irradiation dosage increases during ionizing radiation of acrylamide, crotonic acid and water solutions the polymer chains crosslink, forming a gel structure. It is reported that gelation of polyacrylamide hydrogels is 2.0 kGy of the γ rays, irradiation doses at an ambient temperature[5,15]; therefore, 2.6 kGy of γ rays doses are based for preparation of AAm and AAm/CA hydrogels. In order to investigate the infuence of dosage on gelation, 5.2 kGy of γ ray irradiation was based for preparation of hydrogel systems[5].

The aim of this study is the investigation of the influence of some crosslinkers on the swelling of AAm/CA hydrogels. The molecular structure of used crosslinkers and their linking sites are shown in Scheme 2. These are tetrafunctional crosslinkers. If the double bonds at the end of the crosslinker molecules are acted on by γ ray irradiation, the monomer and comonomer molecules are bonded to each other.



Scheme 2. Linking sites of the crosslinkers.

Swelling Behaviour

Upon swelling, the hydrogels retained their shapes. Dried gels are glassy in form and quite hard, but swollen gels are very soft. The mass swelling [%S(m)] of the hydrogels was calculated from the following relation[5,12]:

$$\%S(m) = \frac{(m_t - m_o)}{m_o} \times 100 \tag{1}$$

where, m_t is the mass of the swollen gel at time t and m_o is the mass of the dry gel at time 0.

The water intake of initially dry hydrogels was observed over a long period. Swelling curves of AAm/CA containing crosslinker hydrogels are plotted and representative swelling curves are shown in Figures 1-2.

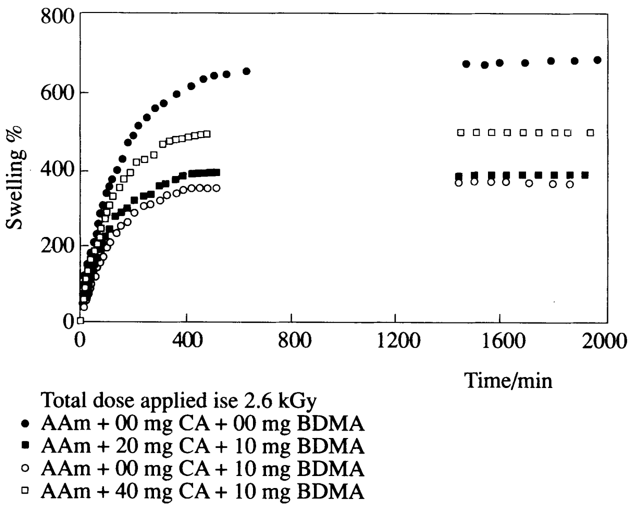


Figure 1. Swelling curves of AAm/CA hydrogels containing BDMA.

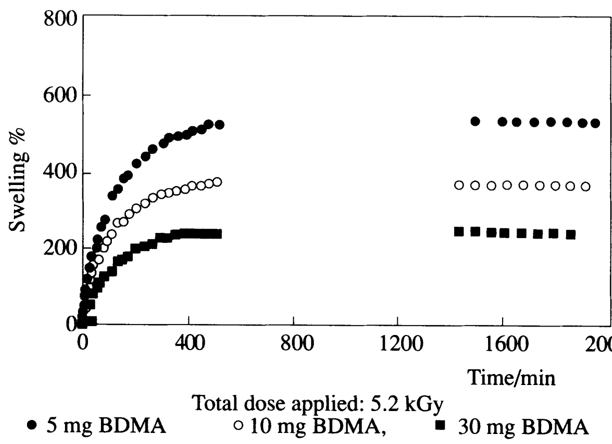


Figure 2. Effect of crosslinker on swelling of AAm/CA hydrogels containing BDMA

If Fig. 1-2 are studied together, it is seen that percentage swelling increases with time but reaches a constant value after a certain point. This value of swelling may be called equilibrium mass swelling. The values of equilibrium mass swelling of AAm/CA hydrogels containing crosslinkers are used for the calculation of some network characterization parameters. The values of equilibrium mass swelling of AAm/CA hydrogels are given Table 2.

Table 2. The values of equilibrium mass swelling % [%S(m)] and equilibrium volume swelling %[%S(v)] of AAm and AAm/CA hydrogels containing crosslinkers.

	5 mg CL				10 mg CL				30 mg CL			
Dose	2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy	
	%S(m)	%S(v)	%S(m)	%S(v)	%S(m)	%S(v)	%S(m)	%S(v)	%S(m)	%S(v)	%S(m)	%S(v)
EGDMA												
0 mg CA	631	824	536	700	492	643	474	619	450	588	333	435
20 mg CA	846	1105	696	909	627	816	606	791	552	721	400	522
40 mg CA	864	1128	791	1033	650	849	621	811	595	778	481	628
BDMA												
0 mg CA	494	645	388	507	369	481	337	440	283	369	261	341
20 mg CA	560	731	548	713	388	507	379	494	284	371	257	336
40 mg CA	595	777	524	684	500	683	442	578	280	366	281	368
NMBA												
0 mg CA	396	517	383	501	338	441	346	452	271	354	245	321
20 mg CA	444	580	425	555	369	482	336	439	281	368	268	351
40 mg CA	433	566	452	591	362	473	352	460	319	417	294	384

To determine the equilibrium volume swelling, it is necessary to place a sample of known density into a chosen solvent until mass measurements indicate the cessation of the uptake of liquid by the polymer. If no extractable is present, and all the imbibed solvent causes swelling, the volume swelling, % S(v), is given by

$$\%S(v) = \frac{(m_t - m_o)/d_s}{m_o/d_p} \times 100 \tag{2}$$

where m_o and m_t are the same parameters defined earlier, and d_s and d_p are the water density and polymer density, respectively[17]. The values of equilibrium volume swelling of AAm/CA hydrogels containing crosslinker are given Table 2.

Table 2 shows that the values of equilibrium mass swelling of AAm hydrogels range from 240% - 850%, but the values of equilibrium swelling of acrylamide-crotonic acid hydrogels are range from 900% - 2400%, while acrylamide hydrogel swells to about 660-690%[5]. The values of volume swelling varied similarly to the results of mass swelling. The hydrophilic group numbers of AAm/CA polymers are greater than those of acrylamide, so the swelling capacities of AAm/CA copolymers are greater than those of acrylamide polymers. Furthermore, if the irradiation dose increases, the equilibrium mass swelling degree of AAm/CA copolymers decreases. If the content of CA in AAm/CA copolymers increases, the equilibrium percentage swelling of AAm/CA copolymers increases. Furthermore, as mentioned before, the equilibrium swelling of AAm is lower than that of AAm/CA copolymers. The reason for this is the presence of hydrophilic groups in crotonic acid molecules. The more hydrophilic groups there are in crotonic acid, the higher the swelling capacity is in AAm/CA copolymers.

If the irradiation dose has increased, the number of the chains formed increases at unit copolymerization time and the crosslink density of the AAm/CA copolymeric system is higher than the lower irradiation doses and, at the same time, the number-average molar mass between the crosslinks, becomes smaller than the lower γ ray doses.

Swelling ratios of AAm/CA hydrogels containing crosslinkers are changed by the structure of the crosslinker. Generally, however, when crosslinkers are added to an AAm/CA hydrogel, it is known that there is a decrease in the swelling ratio because the molecules of the crosslinkers are placed between the chains of AAm and CA. Then the hydrophilic group number and the the swelling ratio decrease. The more crosslinker molecules there are in the hydrogel, the lower the swelling ratio is in AAm/CA hydrogel systems (Fig. 3).

As seen in Table 1 and Scheme 2, the crosslinker chains do not include a great number of hydrophilic groups. Furthermore, the swelling ratios of AAm/CA containing NMBA are generally lower than those of AAm/CA containing BDMA and EGDMA. The reason for this may be the (CO-OR) groups of BDMA and EGDMA. The (CO-NH-R) groups of NMBA may indirectly effect the swelling of the AAm/CA hydrogel as well as the swelling behaviour of the AAm hydrogel[5] (Fig 4).

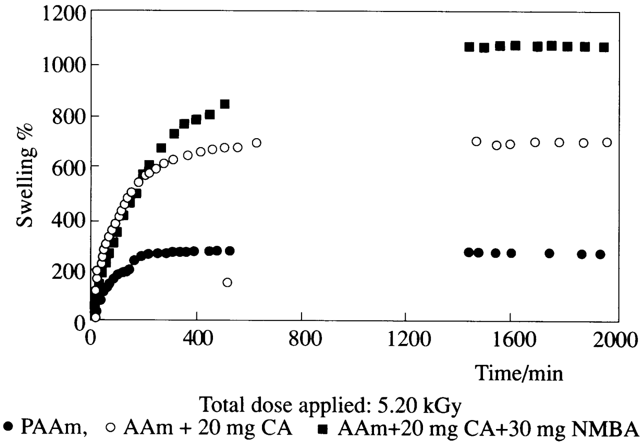


Figure 3. Swelling curves of AAm, AAm/CA and AAm/CA hydrogels containing NMBA.

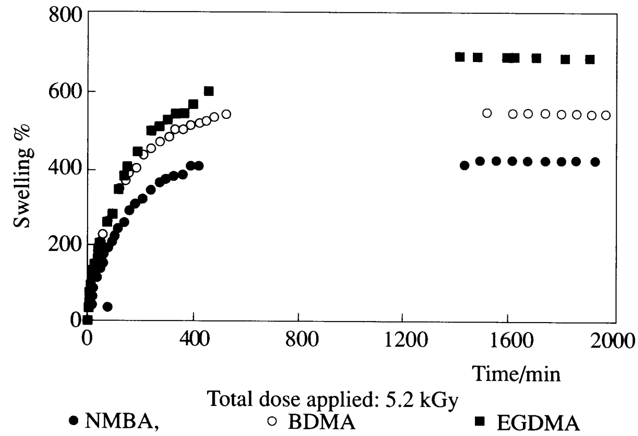


Figure 4. Effect of crosslinker on swelling of AAm/CA hydrogels containing 20 mg CA.

Diffusion of Water

The following equation was used to determine the nature of diffusion of water into hydrogels:

$$F = \frac{M_t}{M_\infty} = kt^n \tag{3}$$

where M_t and M_∞ denote the amount of solvent diffused into the gel at time t and infinite time (at equilibrium), respectively, k is a constant related to the structure of the network, and the exponent n is a number used to determine the type of diffusion. For cylindrical shapes, if n is the range of 0.45-0.50, diffusion is Fickian, whereas $0.50 < n < 1.0$ indicates that diffusion is of a non-Fickian type. This equation is applied to the initial stages of swelling, and plots of ln F versus ln t yield straight lines up to nearly a 60 % increase in the mass of the hydrogel[5,18].

For the hydrogels, ln F versus ln t plots were drawn using the kinetics of swelling (Fig. 5). Then n and k values were calculated from the slopes and intercepts of the lines, respectively. The values of diffusion constants and diffusional exponents of AAm/CA hydrogels containing crosslinkers are listed in Table 3.

In Table 3, it is shown that the values of diffusional exponent range between 0.50 and 0.80. Hence the diffusion of water into AAm/CA containing crosslinker hydrogels was taken to be a *non-Fickian* characteristic[16]. This is generally explained as a consequence of slow relaxation of the polymer matrix.

The swelling parameters are used to calculate the diffusion coefficient. The study of diffusion phenomena in hydrogels and water is of value in that it clarifies polymer behaviour[17]. For hydrogel characterization, the diffusion coefficient can be calculated by various methods[17–21]. The short time approximation method is used for the calculation of diffusion coefficients of AAm/CA hydrogels. The short time approximation is valid for the first 60% of the swelling[5,18].

Table 3. The values of n and k of AAm and AAm/CA hydrogels containing crosslinkers.

	5 mg CL				10 mg CL				30 mg CL			
Dose	2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy	
	k $\times 10^2$	n	k $\times 10^2$	n	k $\times 10^2$	n	k $\times 10^2$	n	k $\times 10^2$	n	k $\times 10^2$	n
EGDMA												
0 mg CA	3.82	0.62	5.35	0.54	1.56	0.82	4.77	0.52	2.10	0.74	6.10	0.54
20 mg CA	3.14	0.59	3.66	0.53	3.88	0.53	2.78	0.62	2.98	0.65	4.48	0.55
20 mg CA	4.60	0.53	4.69	0.53	2.36	0.69	2.61	0.63	3.14	0.59	5.96	0.51
BDMA												
0 mg CA	5.81	0.50	4.39	0.57	3.45	0.59	4.36	0.59	2.87	0.67	3.69	0.64
20 mg CA	3.52	0.57	4.50	0.55	5.44	0.53	5.74	0.52	3.13	0.62	3.39	0.68
40 mg CA	5.26	0.53	5.93	0.51	5.74	0.51	6.50	0.50	3.79	0.64	2.81	0.67
NMBA												
0 mg CA	1.58	0.75	2.72	0.69	2.18	0.75	2.81	0.66	3.35	0.70	5.22	0.54
20 mg CA	2.88	0.66	3.27	0.61	4.62	0.58	4.76	0.55	2.05	0.77	3.56	0.68
40 mg CA	3.13	0.63	3.70	0.59	3.52	0.62	4.27	0.60	7.90	0.45	5.38	0.55

The diffusion coefficients of cylindrical AAm/CA hydrogels are calculated from the following relations:

$$F = \frac{M_t}{M_\infty} = 4\frac{\left[Dt\right]^{1/2}}{\left[\pi r^2\right]} - \pi\frac{\left[Dt\right]}{\left[\pi r^2\right]} - \frac{\pi}{2}\frac{\left[Dt\right]^{3/2}}{\left[\pi r^2\right]} + \cdots \qquad (4)$$

where D is in $cm^2\ s^{-1}$, t is in sec and r is the radius of the cylindrical polymer sample in cm. A graphical comparison of equations (3) and (4) shows the semi-empirical equation (3) with n = 0.5 and $k = 4(D/\pi r^2)^{1/2}$.

For the hydrogels, F versus $t^{1/2}$ is plotted and some representative results are shown in Fig. 6. The diffusion coefficients were calculated from the slope of the lines. The values of the diffusion coefficient determined for the hydrogels are listed in Table 4.

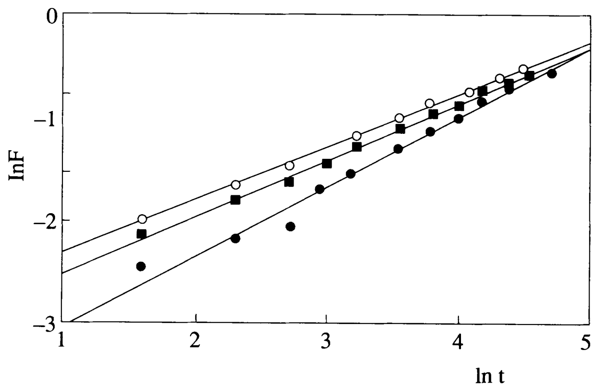


Figure 5. Swelling kinetic curves of AAm/CA hydrogels containing BDMA and 20 mg CA.

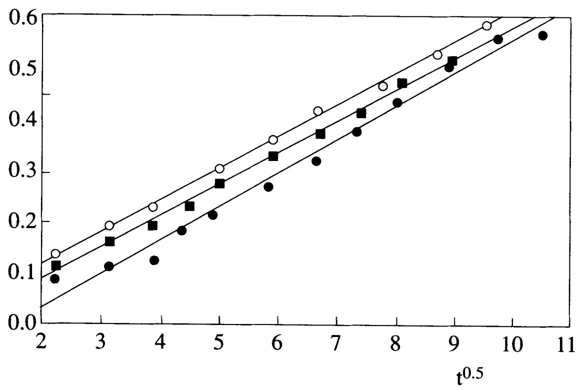


Figure 6. Plot of F versus $t^{0.5}$ of AAm/CA hydrogels containing BDMA and 20 mg CA.

Table 4. Diffusion coefficients (D $\times 10^{-7}$ cm^2 s^{-1}) of AAm and AAm/CA hydrogels containing crosslinkers.

	5 mg CL		10 mg CL		30 mg CL	
Dose	2.6 kGy	5.2 kGy	2.6 kGy	5.2 kGy	2.6 kGy	5.2 kGy
EGDMA						
0 mg CA	8.13	9.03	6.46	7.09	7.39	7.78
20 mg CA	7.31	5.92	7.30	6.84	6.87	6.06
40 mg CA	6.21	5.36	7.10	5.84	6.97	8.32
BDMA						
0 mg CA	7.28	5.21	6.22	6.80	5.31	7.12
10 mg CA	5.34	6.50	7.02	7.46	6.08	5.11
40 mg CA	8.60	8.61	7.28	5.89	5.57	7.93
NMBA						
0 mg CA	5.80	7.10	8.21	6.24	7.76	4.70
20 mg CA	7.31	5.92	7.30	6.83	6.88	6.06
40 mg CA	6.27	7.18	7.06	9.09	5.29	5.85

If Table 4 is examined, it will be seen that the values of the diffusion coefficient of the hydrogels varied from 4.6×10^{-7} cm^2 s^{-1} to 9.1×10^{-7} cm^2 s^{-1}.

Network Studies

One important structural parameter characterizing crosslinked polymers is M_c, the average molar mass between crosslinks, which is directly related to the crosslink density. According to Flory and Rehner's theory, for a network

$$M_c = -V_1 d_p \frac{(v_s^{1/3} - v_s/2)}{\ln(1 - v_s) + v_s + \chi v_s^2} \tag{5}$$

where M_c is the number-average molarmass of the chain between crosslinks, V_1 is the molar volume (mL mole^{-1}), d_p is the polymer density (g mL^{-1}), v_s is the volume fraction of the polymer in the swollen gel, and χ is the Flory-Huggins interaction parameter between the solvent and the polymer[22].

The swelling ratio(Q) is equal to $1/v_s$. Here, the crosslink density, q, is defined as the mole fraction of crosslinked units[22]

$$q = \frac{M_o}{M_c} \tag{6}$$

where M_o is the molar mass of the repeating unit. The other important parameter of crosslink density, v_e, as the number of elastically effective chains totally included in a network per unit volume. v_e is simply related to q. Since

$$v_e = \frac{d_p N_A}{M_c} \tag{7}$$

where N_A is the Avogadro number, then

$$v_e = \frac{d_p N_A q}{M_o} \tag{8}$$

Since the hydrogel is a copolymeric structure and contains a crosslinker (CL), the molar mass of the polymer repeat unit, M_o, can be calculated with the following equation:

$$M_o = \frac{m_{AAm} \times M_{AAm} + m_{CA} \times M_{CA} + m_{CL} \times M_{CL}}{m_{AAm} + m_{CA} + m_{CL}} \quad (9)$$

where m_{AAm}, m_{CA} and m_{CL} are the mass in g of acrylamide, crotonic acid and the crosslinker, and M_{AAm}, M_{CA} and M_{CL} are the molar mass in g mole^{-1} of acrylamide, crotonic acid and the crosslinker, respectively.

The values of V_1, d_p and χ were taken from the literature[13,23,24] and by using these values, the number-average molar mass between crosslinks, the crosslink density and the number of elastically effective chains of AAm and AAm/CA hydrogels are calculated and listed in Table 5 and 6.

Table 5. Number-average molar mass between crosslinks (M_c) of AAm and AAm/CA hydrogels containing crosslinkers.

	5 mg CL			10 mg CL			30 mg CL		
Dose		2.6 kGy	5.2 kGy		2.6 kGy	5.2 kGy		2.6 kGy	5.2 kGy
CA	M_o	M_c	M_c	M_o	M_c	M_c	M_o	M_c	M_c
EGDMA									
0 mg CA	71.45	14.400	9 020	72.40	7 100	6 380	74.97	5 490	2 280
20 mg CA	72.02	31 780	18 470	72.67	13 970	12 720	75.18	9 830	3 910
40 mg CA	72.29	33 550	26 450	72.92	15 460	13 630	75.38	12 120	6 650
BDMA									
0 mg CA	71.87	7 170	3 580	72.65	3 080	2 360	75.70	1 390	1 090
20 mg CA	72.15	10 220	9 620	72.91	3 580	3 330	75.90	1 410	1 040
40 mg CA	72.41	12 100	8 450	73.16	7 420	5 230	76.09	1 350	1 370
NMBA									
0 mg CA	71.49	3 680	3 450	71.90	2 370	2 550	73.50	1 230	895
20 mg CA	71.78	5 300	4 660	72.18	3 090	2 350	73.74	1 370	1 190
40 mg CA	72.05	4 770	5 570	72.44	2 930	2 690	73.97	2 000	1 570

In Table 5, it is shown that the number-average molar mass between crosslinks of the hydrogels increased with the increase of the CA contents of AAm/CA hydrogels, while decreasing with the increase of the irradiation dose, because CA in hydrogels includes many hydrophilic groups, so AAm/CA hydrogels swelled greatly. The values of the crosslink density and the number of elastically effective chains are inverse due to the value of the number-average molar mass between crosslinks (Table 6). The effects of the crosslinkers on the network parameters of AAm/CA hydrogels containing crosslinkers are similar to the swelling results of AAm/CA hydrogels[5].

Conclusion

In this study, acrylamide-crotonic acid hydrogels were prepared by copolymerization of acrylamide and crotonic acid with crosslinkers, such as ethylene glycol dimethacrylate, 1,4 butanediol dimethacrylate and N,N′ methylenebisacrylamide, with γ-irradiation. After swelling tests were performed, the influence of the applied γ-ray dose, the amount of crotonic acid and the type and amount of crosslinking agents on the swelling properties of the gel, the diffusional behaviour of water, and the diffusion coefficients and network properties of the hydrogel systems were examined. AAm/CA copolymers swelled from 900-2400%, while polyacrylamide swelled from 660-690%. If a crosslinking agent such as ethylene glycol dimethacrylate, 1,4 butanediol dimethacrylate and N,N′ methylenebisacrylamide is used in copolymerization, the swelling ranges from 300-850% in water. Water diffusion in the hydrogels was non-Fickian.

Table 6. The corsslink density ($q \times 10^2$) and the number of elastically effective chains ($v_e \times^{20}$) of AAm and AAm/CA hydrogels containing crosslinkers.

	5 mg CL				10 mg CL				30 mg CL			
Dose	2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy		2.6 kGy		5.2 kGy	
	q	v_e	q	v_e	q	v_e	q	v_e	q	v_e	q	v_e
EGDMA												
0 mg CA	0.49	0.54	0.79	0.87	1.02	1.10	1.13	1.23	1.36	1.42	3.28	3.43
20 mg CA	0.22	0.24	0.27	0.29	0.52	0.56	0.57	0.62	0.77	0.80	1.92	2.00
40 mg CA	0.22	0.23	0.38	0.42	0.47	0.51	0.54	0.58	0.62	0.65	1.13	1.18
EGDMA												
0 mg CA	1.00	1.09	2.00	2.19	2.36	2.55	3.08	3.33	5.46	5.66	6.97	7.23
20 mg CA	0.71	0.77	0.75	0.82	2.04	2.19	2.19	2.36	5.38	5.56	7.33	7.58
40 mg CA	0.59	0.65	0.86	0.93	0.98	1.06	1.39	1.50	5.65	5.82	5.56	5.72
EGDMA												
0 mg CA	1.94	2.13	2.07	2.27	3.04	3.31	2.82	3.08	6.00	6.40	8.21	8.76
20 mg CA	1.35	1.48	1.54	1.68	2.34	2.54	3.07	3.34	5.38	5.73	6.23	6.63
40 mg CA	1.51	1.64	1.29	1.41	2.47	2.68	2.70	2.92	3.69	3.92	4.72	5.01

It is concluded that AAm/CA hydrogels containing crosslinkers can be used a water retainer for carrying some substances in aquatic fields in pharmacy, agriculture, environmental and biomedical applications.

Acknowledgement

The authors gratefully acknowledge the support of the members of the Polymer Group in the Department of Chemistry, Hacettepe University.

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