

Swelling characterization of gamma-radiation induced crosslinked acrylamide/maleic acid hydrogels in urea solutions

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Abstract

Swelling behaviors of crosslinked acrylamide/maleic acid (CAMA) hydrogels synthesized by gamma-radiation crosslinking of acrylamide and maleic acid in aqueous urea solutions were investigated. CAMA hydrogels containing different amounts of maleic acid were obtained in the form of rods via a radiation technique. Swelling experiments were performed in two different urea concentrations at 25 °C, gravimetrically. The hydrogels showed enormous swelling in aqueous medium and displayed swelling characteristics that were highly dependent on the chemical composition of the hydrogels and irradiation dose. Diffusion behavior and some swelling kinetics parameters were investigated. The values of the swelling percent of CAMA hydrogels were between 935% and 5212%, while the values of the swelling percent of acrylamide hydrogels were between 669% and 923%. The difference of the concentrations of urea solutions was not affected by the swelling properties of the hydrogel systems. Urea/water diffusion into hydrogels was found to be non-Fickian in character. Equilibrium urea/water contents of the hydrogel systems were changed between 0.8699 and 0.9812.

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1. Introduction

Ionizing radiation has been found to be widely applicable in modifying the structure and properties of polymers, and can be used to tailor the performance of either bulk materials or surfaces. A lot of research in polymer radiation chemistry has led to numerous applications of commercial and economic importance, and work remains active in the application of radiation to practical uses involving polymeric materials [1–9].

Research on the use of radiation in the production of hydrogels has become intense during more than a dec-

ade; interest has grown continuously and a large number of papers have been published in the last years. Numerous applications have been found or envisioned for these materials, particularly in the biomedical area. Some special areas where hydrogels are used are wound dressing, soft contact lenses, controlled-released drug delivery systems, artificial skin, water absorbents, and adsorbents for metal ions or enzymes for purification or catalysis applications [1–9].

Hydrogels consist of a three-dimensional network of hydrophilic polymer chains (polyvinylpyrrolidone, polyacrylamide, polyvinylalcohol, etc.) that can be swollen with water. The materials usually contain a much higher amount of water than of polymer. Some gels can reach extremely high proportions of water, and are referred to as “superabsorbent” materials.

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Specially modified hydrogels are being studied for wastewater purification. Gels containing acid groups have been made to bind ions, including some heavy metals, for use in removal of metals and dyes from aqueous media [10–14]. Adsorption of some species, such as enzyme, amino acids or other biochemical/physiological species in aqueous media has been studied for use in industrial and/or biotechnological processes [15–17]. Hydrogels can be used as a composite membrane for various enzymes. For example, for immobilization of urease enzyme, various composite hydrogel membranes can be used [15]. Urease is a highly specific enzyme. It catalyzes the hydrolysis of urea to ammonium and carbon dioxide. It has been immobilized for analytical and biomedical purposes. One of the major applications of immobilized urease is the direct removal from blood for detoxification, or in the dialysis regeneration systems of artificial kidney machines. Other applications of immobilized urease will be in a bioreactor for the conversion of urea present in fertilizer wastewater effluents to ammonia and carbon dioxide or in the food industry for the removal of urea from beverages and foods [15].

Urea is one of the main toxic wastes in the dialysate solution from hemodialysis. The most effective way of removing urea from aqueous solutions is the utilization of immobilized urease as no efficient adsorbent is available for urea. On the other hand, urea has a great importance in biological systems.

It was of interest to swelling properties of acrylamide and crosslinked acrylamide/maleic acid (CAMA) hydrogels in urea solutions for new hydrogels synthesis for urea treatment as new membranes or crosslinked polymeric carriers, or adsorption. The present paper reports a swelling study in urea solutions of a novel type of hydrogel prepared acrylamide and maleic acid by gamma-radiation technique.

2. Materials and methods

2.1. Experimental materials and preparation

The sources of water, the monomers; acrylamide and maleic acid (MA), gamma-irradiation doses were given before [18]. The method of preparation of the gamma-radiation induced CAMA hydrogel systems was the same as described in our earlier communication [18]. Urea was provided from MERCK (Darmsdat, Germany).

2.2. Swelling measurements in urea solutions

A fundamental relationship exists between the swelling of a polymer in a solvent and the nature of the polymer and the solvent. Aqueous urea solutions have been

prepared as 0.01 and 0.03 M. The swelling percent, $S\%$, of the hydrogels in the aqueous urea solutions, was calculated from the following relation:

$$S\% = \frac{w_t - w_0}{w_0} \times 100, \quad (1)$$

where w_t is the mass of the swollen gel at time t and w_0 is the mass of the dry gel at time 0.

3. Results and discussion

A network is obtained by permanently linking polymeric chains together in the form of a three-dimensional structure by high energy radiation (e, γ , UV), peroxide cures and sulfur cures. The processes are known as crosslinking, curing and vulcanization, respectively. Crosslinking can be brought about by either chemical reactions that form covalent bonds between chains or by physical aggregation of units from two or more chains. To crosslink a polymeric system, high-energy radiation (or ionizing radiation), such as electrons (e), gamma rays (γ) and ultraviolet (UV) light, can also be used.

The radiation technique seems promising for the preparation of hydrogels because polymers in aqueous solution or a monomer dissolved in water undergo crosslinking on irradiation to yield a gel-like material.

3.1. Equilibrium swelling studies

The urea/water intake of initially dry hydrogels was followed for a period of time, gravimetrically. Swelling isotherms of the hydrogels were constructed and representative swelling curves are shown in Fig. 1.

Fig. 1 shows that swelling increases with time up to a certain level, then levels off. This value of swelling may be called the equilibrium swelling percent ($S_{eq}\%$). $S_{eq}\%$ of CAMA hydrogels are used for the calculation of swelling characterization parameters. $S_{eq}\%$ of CAMA hydrogels are given in Table 1.

Table 1 shows that $S_{eq}\%$ of acrylamide are 670–923%, but $S_{eq}\%$ of CAMA hydrogels are 935–5212% with the incorporation of MA groups into acrylamide hydrogels. Hydrophilicity of CAMA copolymers becomes greater than that of acrylamide, so, the swelling of CAMA copolymers is greater than the swelling of acrylamide hydrogels.

In Table 1, $S_{eq}\%$ of the hydrogels decreased with the increase in the irradiation dose and increased with the MA content in the copolymers. $S_{eq}\%$ of CAMA hydrogels is higher than $S_{eq}\%$ of acrylamide hydrogels. The reason for this is the hydrophilic groups on the MA. The chemical structure of CAMA hydrogel systems was demonstrated simply on Scheme 1. Here

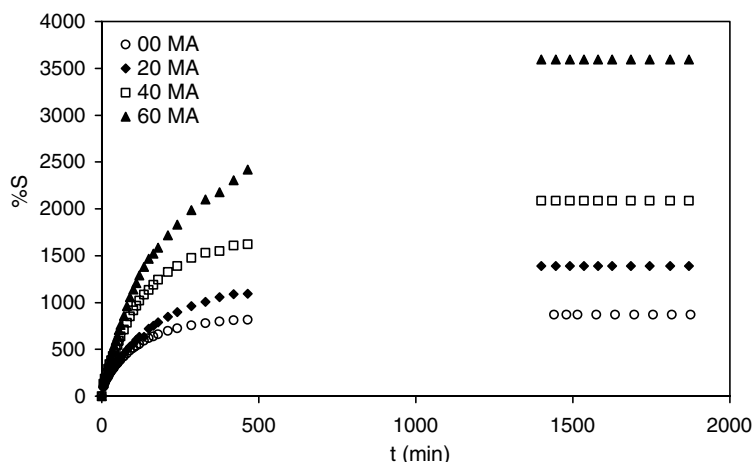
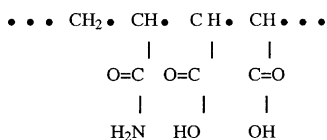
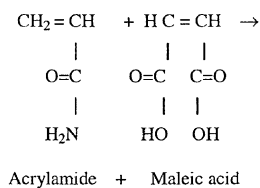


Fig. 1. Swelling isotherms of CAMA hydrogels in 0.01 M urea solutions. Total dose given 3.73 kGy.

Table 1
Equilibrium swelling percent of CAMA hydrogel systems

Dose (kGy)	0.01 M Urea				0.03 M Urea			
	00	20	40	60	00	20	40	60
MA (mg):								
Equilibrium swelling (S%)								
2.00	901	1642	3400	5210	923	1560	2996	5212
2.60	839	1546	2994	4963	785	2198	3340	4705
3.73	872	1389	2086	3593	765	1624	2502	3806
4.65	768	1445	2372	3944	758	1583	2367	3275
5.20	826	935	2386	2624	754	1406	2501	3064
5.71	670	1501	2201	2390	669	1262	2247	2660



Acrylamide/maleic acid (CAMA) hydrogels

Scheme 1. Possible binding mechanism of CAMA hydrogel systems.

possible binding mechanism was presented. As it can be seen from Scheme 1, more hydrophilic groups in the CAMA get more swelling of the CAMA hydrogels.

The increase in the amount of absorbed dose lessens the number of small chains. Thus, hydrogels which exposed higher doses have higher crosslink density than hydrogels that exposed lower doses. This means that high amount of adsorbed dose decreases the number of average molar mass between crosslinks, while low

amount of adsorbed dose increases the number of average molar mass between crosslinks.

On the other hand, the values of the equilibrium swelling percent of swollen in urea solutions CAMA hydrogels are bigger than the hydrogels swollen in water. The values of the hydrogels swollen in water were between 655% and 2810% [18]. The reason for this difference is the hydrophilic character of urea molecules. Urea molecule has got more hydrophilic sites, as NH_2 and $\text{C}=\text{O}$. When urea molecules interacted with much water, there was much swelling than swelling values in water also. That is why, urea molecules have got hydrophilic groups, more swelling values have been observed when the hydrogels swollen were in aqueous urea solutions. Here, the main characteristic effect is the hydrophilic character of urea molecules. So, more hydrophilic groups in the aqueous urea solutions get more swelling of the CAMA hydrogels. In the presence of urea, swelling of CAMA hydrogels can easily follow the change of the hydrogen-bonded structure of water and polymer-solvent interaction.

3.2. Swelling kinetics

In order to examine the controlling mechanism of the swelling processes, several kinetic models are used to test

experimental data. The large number and array of different chemical groups on the CAMA chains (e.g., amine, amide, carbonyl, carboxyl or hydroxyl) imply that there are many types of polymer–solvent interactions. It is probable that any kinetics is likely to be global. From a system design viewpoint, a lumped analysis of swelling rates is thus sufficient to the practical operation.

A simple kinetic analysis is a second order equation in the form of

$$\frac{dS}{dt} = k_{2,S}(S_{eq} - S)^2, \quad (2)$$

where $k_{2,S}$ is the rate constant of swelling and S_{eq} (or $S_{eq}\%$) denotes the swelling percent at equilibrium. After definite integration by applying the initial conditions $S = 0$ at $t = 0$ and $S = S$ at $t = t$, Eq. (2) becomes

$$\frac{t}{S} = A + Bt, \quad (3)$$

where A is reciprocal of initial swelling rate r_0 or $1/k_{2,S}S_{eq}^2$ and B is inverse of the degree of swelling at equilibrium [19,20].

To test the kinetics model, t/S vs. t graphs are plotted and representative graphs are illustrated in Fig. 2. The calculated kinetic parameters are tabulated in Table 2.

As can be seen from Table 2, kinetics model is in good agreement with swelling experiments, since, as depicted in Table 2, $S_{eq}\%$ (theoretical) or $S_{eq}\%_{max}$ is increased with MA content and decreased with irradiation doses. Here, the swelling rate constant is increased with irradiation doses content and decreased with MA. This is plausible since the hydrophilicity of the network is enhanced with the extent of MA groups in structure (Scheme 1). However, the increase in the absorbed dose makes the structure tighter for water to diffuse, in spite of its high hydrophilic content. So it is important to note that the extent of irradiation dose determines the swelling rate by increasing hydrophilicity, but reduced the molar mass between crosslinks.

So, these two phenomena compete to determining the rate of swelling. Here, again, there is no important difference between swelling kinetics parameters in different concentrations of aqueous urea solutions, too.

3.3. Swelling rate coefficients

Swelling characteristics, particularly the rate of aqueous swelling or water or/and aqueous solutions uptake, were followed by some methods.

Fig. 3 shows the equilibrium swelling percent, $S\%$, for the CAMA hydrogels vs. the square root of immersion time for the first 60% of the fractional uptake [21]. Excellent linear correlations were observed. Linear slopes of all CAMA hydrogel systems swelling behaviors in Fig. 3 were assumed to represent relative swelling rate coefficients ($k_{0.5}$). The swelling rate coefficients are tabulated in Table 3. Swelling rate coefficients of CAMA hydrogels linearly increased by increasing the MA contents and they decreased with the irradiation dose. Furthermore, it can be said that the hydrogels swell with increase of MA than with increase of irradiation dose. As it can be seen in Table 3, there are no important differences between swelling rate coefficients ($k_{0.5}$) of the hydrogel systems at different urea concentrations.

3.4. Diffusion

When a glassy hydrogel is brought into contact with water, water diffuses into the hydrogel and the network expands resulting in swelling of the hydrogel. Diffusion involves migration of water into pre-existing or dynamically formed spaces between hydrogel chains. Swelling of the hydrogel involves larger segmental motion resulting, ultimately, in increased separation between hydrogel chains.

Analysis of the mechanisms of water diffusion into swellable polymeric systems has received considerable

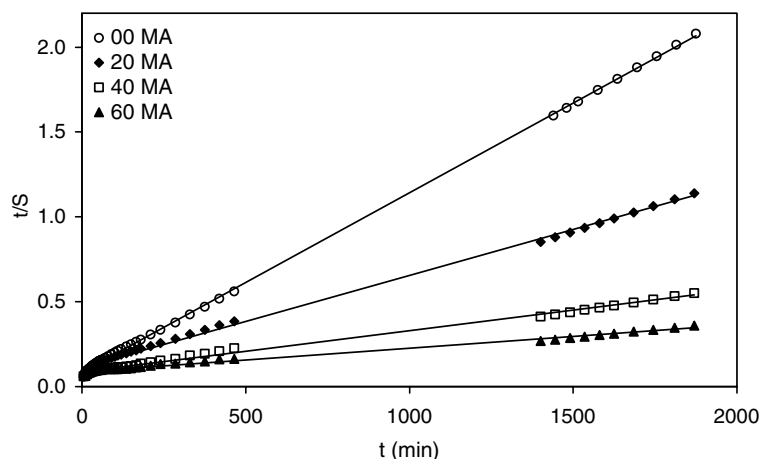


Fig. 2. Swelling kinetics curves of CAMA hydrogels in 0.01 M urea solutions. Total dose given 2.00 kGy.

Table 2
Swelling kinetics parameters of CAMA hydrogel systems

Dose (kGy)	0.01 M Urea				0.03 M Urea			
	00	20	40	60	00	20	40	60
<i>The initial swelling rate: r_0 (dS/dt)₀; $g_{\text{water}}/g_{\text{gel}}$ min</i>								
2.00	11.71	8.88	11.64	11.35	12.42	11.88	9.52	11.75
2.60	10.89	13.32	13.55	13.81	11.24	11.57	15.55	17.06
3.73	13.21	9.90	15.55	15.36	13.83	14.79	14.47	16.61
4.65	19.31	10.96	11.45	9.71	18.15	11.04	9.09	13.77
5.20	12.77	8.26	14.90	10.78	9.09	11.66	15.31	12.42
5.71	9.90	14.99	11.95	11.92	9.62	13.91	18.59	15.63
<i>The swelling rate constant: $k_s \times 10^6$; $g_{\text{gel}}/g_{\text{water}}$ min</i>								
2.00	13.15	2.61	0.69	0.22	13.18	4.13	0.70	0.23
2.60	14.20	4.81	1.14	0.34	16.71	1.88	1.06	0.54
3.73	16.00	4.31	3.02	0.88	21.94	4.89	1.86	0.86
4.65	31.17	4.47	1.57	0.37	29.75	3.69	1.17	0.95
5.20	17.19	8.22	2.15	1.15	14.42	5.08	2.00	0.97
5.71	20.26	5.88	1.97	1.63	19.68	7.80	3.17	1.78
<i>The theoretical equilibrium swelling: $S\%_{\text{max}}$; $g_{\text{water}}/g_{\text{gel}}$</i>								
2.00	943	1845	4115	7194	971	1695	3676	7092
2.60	877	1664	3448	6329	820	2481	3831	5618
3.73	909	1515	2268	4167	794	1739	2793	4405
4.65	787	1567	2703	5155	781	1730	2793	3817
5.20	862	1003	2632	3058	794	1515	2770	3584
5.71	699	1597	2463	2703	699	1335	2421	2959

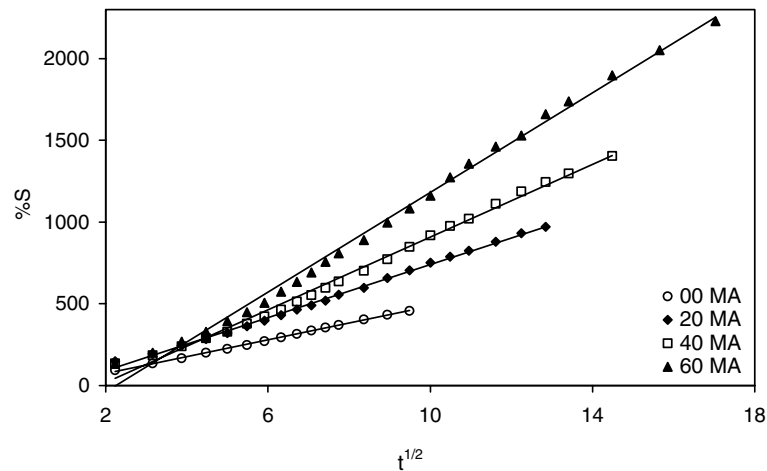


Fig. 3. Plots of swelling rate for CAMA hydrogels in 0.03 M urea solutions. Total dose given 3.73 kGy.

Table 3
Swelling rate coefficients ($k_{0.5}$) of CAMA hydrogels

Dose (kGy)	0.01 M Urea				0.03 M Urea			
	00	20	40	60	00	20	40	60
	$k_{0.5}$							
2.00	54.5	67.6	115.5	150.2	55.9	78.0	96.1	162.5
2.60	49.5	84.3	121.0	151.75	49.2	91.0	141.2	173.4
3.73	54.7	63.5	107.4	135.9	51.3	81.3	111.2	152.5
4.65	58.2	72.3	97.1	113.9	57.3	75.0	84.6	131.9
5.20	49.7	53.3	110.3	97.4	42.1	70.0	117.5	116.4
5.71	39.4	83.1	86.4	93.7	38.9	71.9	115.7	116.5

attention in recent years, because of important applications of swellable polymers in biomedical, pharmaceutical, environmental, and agricultural engineering.

The following equation is used to determine the nature of diffusion of penetrant into hydrogels:

$$F = kt^n, \quad (4)$$

where F is the fractional uptake at time t , k is a constant incorporating characteristic of the macromolecular network system and the penetrant, and n is the diffusional exponent, which is indicative of the transport mechanism. Eq. (4) is valid for the first 60% of the fractional

uptake. Fickian diffusion and Case II transport are defined by n values of 0.5 and 1, respectively. Anomalous transport behavior (non-Fickian diffusion) is intermediate between Fickian and Case II. They are reflected by n between 1/2 and 1 [22].

For radiation induced hydrogels, $\ln F$ vs. $\ln t$ graphs are plotted and representative results are shown in Fig. 4. Diffusion exponents (n) and diffusion constants (k) are calculated from the slopes and intercepts of the lines, respectively, and are listed in Table 4.

Table 4 shows that the number determining the type of diffusion (n) is over 0.50. They are between 0.51 and 0.80. Hence, the diffusion of water into the super water-retainer hydrogels is generally found to have a non-Fickian character [20,22]. When the diffusion type is anomalous behavior, the relaxation and diffusion time are of the same order of magnitude. As solvent diffuses into the hydrogel, rearrangement of chains does not occur immediately.

Diffusion constants of CAMA hydrogels are between 0.5×10^{-2} and 6.8×10^{-2} . Diffusion constants increase with the increase of dose, but they have been seen

decreasing with increase content of MA. The reason for these effects is the hydrophilic characteristics of MA.

The study of diffusion phenomena of water in hydrogels is of value in that it clarifies polymer behavior. For hydrogel characterization, the diffusion coefficients can be calculated by various methods. The short time approximation method is used for the calculation of diffusion coefficients of CAMA hydrogels [18]. The short time approximation is valid for the first 60% of initial swelling.

The diffusion coefficients of the cylindrical CAMA hydrogels are calculated from the following relations [20]:

$$F = 4 \left[\frac{Dt}{\pi r^2} \right]^{1/2} - \pi \left[\frac{Dt}{\pi r^2} \right] - \frac{\pi}{3} \left[\frac{Dt}{\pi r^2} \right]^{3/2} + \dots, \quad (5)$$

where D is in $\text{cm}^2 \text{s}^{-1}$, t in s and r is the radius of a cylindrical polymer sample. A comparison of Eqs. (4) and (5) shows the semi-empirical equation (4) with $n = 0.5$ and $k = 4(D/\pi r^2)^{1/2}$.

For hydrogels, F vs. $t^{1/2}$ plots are constructed and representative results are shown in Fig. 5. The diffusion

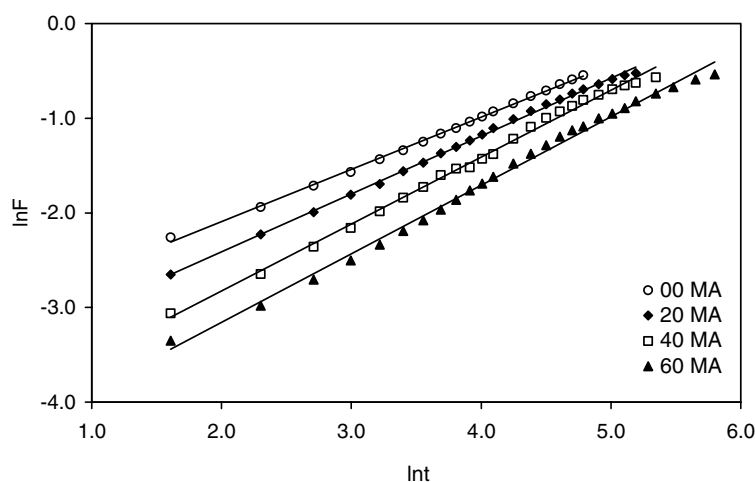


Fig. 4. Plots of $\ln F$ vs. $\ln t$ for CAMA hydrogels in 0.03 M urea solutions. Total dose given 5.20 kGy.

Table 4
Diffusion exponents (n) and diffusion constants (k) of CAMA hydrogels

Dose	2.00 kGy		2.60 kGy		3.73 kGy		4.65 kGy		5.20 kGy		5.71 kGy	
	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	$k (\times 10^2)$
<i>0.01 M Urea</i>												
00	0.59	3.6	0.57	3.9	0.56	4.4	0.52	6.8	0.51	5.5	0.51	5.3
20	0.66	1.6	0.67	2.1	0.60	2.6	0.67	2.0	0.75	1.5	0.61	3.0
40	0.74	0.8	0.71	1.1	0.67	2.0	0.72	1.2	0.68	1.6	0.61	2.0
60	0.78	0.5	0.73	0.7	0.71	1.1	0.74	0.6	0.70	1.1	0.64	1.7
<i>0.03 M Urea</i>												
00	0.59	3.7	0.60	3.8	0.56	4.9	0.54	6.2	0.55	4.1	0.52	5.1
20	0.68	1.9	0.66	1.6	0.57	3.3	0.68	1.7	0.61	2.6	0.60	3.2
40	0.69	1.0	0.74	1.0	0.67	1.6	0.70	1.1	0.71	1.4	0.65	2.2
60	0.80	0.5	0.74	0.8	0.73	1.0	0.78	0.8	0.72	1.0	0.67	1.7

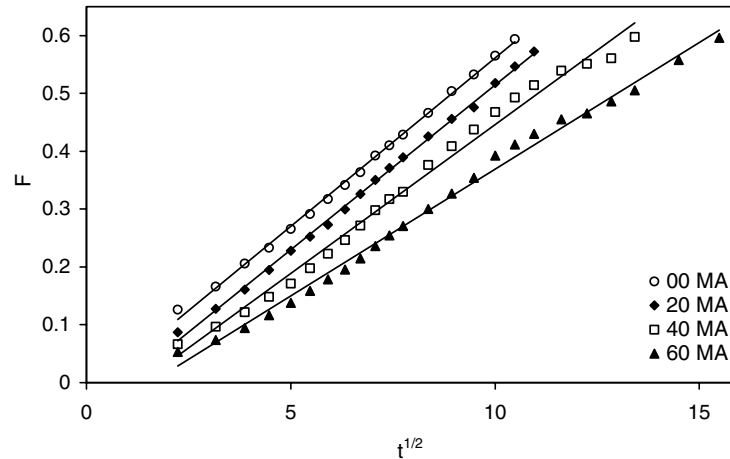


Fig. 5. Plots of F vs. $t^{1/2}$ for CAMA hydrogels in 0.03 M urea solutions. Total dose given 5.71 kGy.

Table 5
Diffusion coefficients ($\text{cm}^2 \text{s}^{-1}$) of CAMA hydrogel systems

Dose (kGy)	2.00	2.60	3.73	4.65	5.20	5.71
MA (mg):	$D (\times 10^6)$	$D (\times 10^6)$	$D (\times 10^6)$	$D (\times 10^6)$	$D (\times 10^6)$	$D (\times 10^6)$
<i>0.01 M Urea</i>						
00	56.2	61.5	60.5	108.4	73.8	83.2
20	58.8	93.3	83.3	82.5	92.1	111.0
40	84.5	83.4	86.8	82.1	113.3	69.9
60	89.2	59.7	88.0	63.0	73.1	98.0
<i>0.03 M Urea</i>						
00	73.84	31.84	30.55	36.58	25.22	24.39
20	31.64	22.67	28.89	29.71	24.70	32.49
40	19.48	34.57	33.32	22.50	38.78	39.80
60	26.67	27.73	31.52	34.15	31.42	28.79

coefficients were calculated from the slope of the lines. The values of diffusion coefficient determined for the hydrogels are listed in Table 5.

Table 5 shows that the values of the diffusion coefficient of the CAMA hydrogels vary from 56.2×10^{-6} to $113.3 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ for 0.01 M urea solutions and from 19.5×10^{-6} to $73.8 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ for 0.03 M urea solutions. Here, at 0.01 M urea solutions, diffusion of urea/water is bigger than the diffusion at 0.03 M urea concentration.

3.5. Equilibrium urea/water content

The urea/water absorbed by CAMA hydrogels is quantitatively represented by the equilibrium urea/water content (EUWC) [23], where

$$\text{EUWC} = \frac{w_{\text{eq}} - w_0}{w_{\text{eq}}} \quad (6)$$

Here, w_{eq} is the weight of the swollen gel at time t (equilibrium) and w_0 is the weight of the dry gel at time 0. The values of EUWC of all CAMA hydrogel systems were calculated. The values of EUWC of the hydrogels are

tabulated in Table 6. All EUWC values of the hydrogels (0.8829–0.9812) were greater than the percent water content values of the body about 0.60 (or 60%). Thus, the CAMA hydrogels exhibited fluid contents similar to those of living tissues. As it can be seen in Table 6, there are no important differences between EUWC of the hydrogel systems at different urea concentrations.

3.6. Urea/water sorption rate

Other important diffusion parameter can be 'urea/water sorption rate constant', K_{uw} . According to the water sorption equation [11,24]

$$-\ln[1 - (m_t/m_s)] = K_{\text{uw}}t + E, \quad (7)$$

where t is sorption time, K_{uw} is urea/water sorption rate constant, m_t is the sorption urea/water amount at time (t), m_s an equilibrium sorption urea/water amount at equilibrium and E is a constant. The plots of $-\ln(1 - F)$ vs. t , where $F = m_t/m_s$, are shown in Fig. 6. The urea/water sorption rate constants of the CAMA hydrogels having different MA contents are calculated from the slope of the plots and they are tabulated in Table 7.

Table 6
Equilibrium urea/water content (EUWC) of CAMA hydrogel systems

Dose (kGy)	0.01 M Urea				0.03 M Urea			
	00	20	40	60	00	20	40	60
<i>Equilibrium urea/water content (EWUC)</i>								
2.00	0.9002	0.9426	0.9714	0.9812	0.9022	0.9398	0.9677	0.9812
2.60	0.8935	0.9392	0.9677	0.9803	0.8870	0.9565	0.9709	0.9792
3.73	0.8971	0.9328	0.9542	0.9729	0.8845	0.9420	0.9616	0.9744
4.65	0.8848	0.9353	0.9595	0.9753	0.8835	0.9406	0.9595	0.9704
5.20	0.8920	0.9034	0.9598	0.9633	0.8829	0.9336	0.9616	0.9684
5.71	0.8702	0.9376	0.9565	0.9598	0.8699	0.9266	0.9574	0.9638

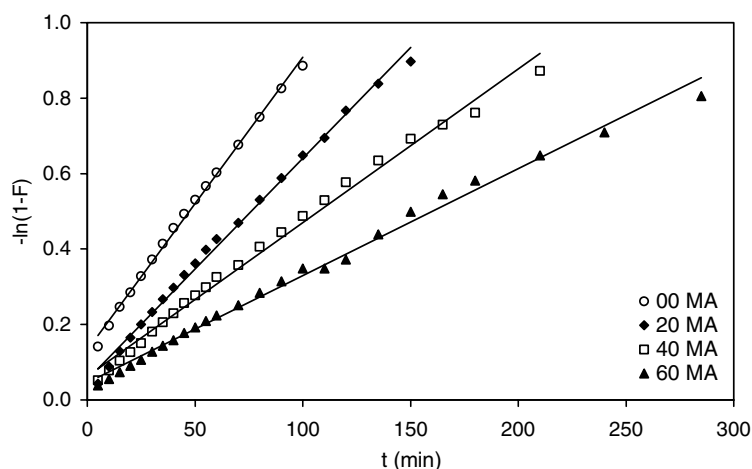


Fig. 6. Plots of $-\ln(1-F)$ vs. t for CAMA hydrogels in 0.01 M urea solutions. Total dose given 5.20 kGy.

Table 7
Urea/water sorption rate constants (K_{uw}) of CAMA hydrogel systems

Dose (kGy)	0.01 M Urea				0.03 M Urea			
	00	20	40	60	00	20	40	60
$K_{uw} (\times 10^3)$								
2.00	7.2	3.4	2.5	1.7	7.3	4.8	2.1	1.9
2.60	7.1	5.6	3.1	2.2	7.8	3.4	3.4	2.6
3.73	8.0	4.3	5.0	3.3	9.1	5.1	3.9	3.1
4.65	12.1	4.8	3.3	1.7	11.8	4.6	2.6	3.1
5.20	7.8	5.9	4.1	2.8	6.5	4.8	4.3	2.9
5.71	7.5	6.0	3.4	3.2	7.2	6.4	5.6	4.2

They are changed among ranges 1.7×10^{-3} and 12.1×10^{-3} for 0.01 M urea concentration solutions and 2.6×10^{-3} and 11.8×10^{-3} . The results presented in Table 7 shows that urea/water sorption rate constant of acrylamide hydrogels is higher than that of CAMA hydrogels. It is seen that urea/water diffusion is more stable in acrylamide hydrogel systems. If MA contents are increased in CAMA hydrogels, the sorption rate of urea/water amount is decreased. The reason for this may be the hydrophilic characteristics of MA. MA molecules may interact with water molecules, and sorption may be more slow. These results are parallel to the swelling kinetics parameters presented in Table 2, too.

4. Conclusion

The hydrogels showed high urea/water absorbency. The equilibrium swelling percent were changed between 669% and 5212%. The reason for high swelling percent of the CAMA hydrogels is the hydrophilic character of urea molecules and the capability of hydrogen bonding for urea molecules with water. It was seen that swelling of CAMA hydrogels in aqueous urea solutions increased with the increasing of content of MA. But, there have not been important differences of swelling results at different urea concentrations. The values of equilibrium urea/water contents of the hydrogel systems

were changed between 0.8699 and 0.9812. These data may be important for CAMA hydrogel systems as a bio-material. It can be concluded from the data presented in this paper that the CAMA hydrogels are appropriate matrix for pharmaceutical formulations and for biotechnological applications due to their favorable physico-chemical properties. The CAMA hydrogels reported can be used to carry substances in an aquatic, urea/water field for pharmaceutical, agricultural, environmental and biomedical applications.

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