Swelling and Dye Sorption Studies of AAm/SA Hydrogels Crosslinked by Glutaraldehyde and Divinylbenzene

Ömer Barış Üzüm, Semiha Kundakci, H. Berna Durukan, Erdener Karadağ

Fen-Edebiyat Faculty, Department of Chemistry, Adnan Menderes University, TR-09010, Aydın, Turkey

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ABSTRACT: Highly swollen acrylamide (AAm)/sodium acrylate (SA) hydrogels were prepared by free radical solution polymerization in aqueous solution of AAm with SA as comonomer and two multifunctional crosslinkers such as glutaraldehyde (GL) and divinylbenzene (DVB). Water absorption and percentage swelling were determined gravimetrically. The influence of SA content in hydrogels was examined. Percentage swelling ratio of AAm/SA hydrogels was increased up to 2946–12,533%, while AAm hydrogels swelled up to 1326–1618%. The values of equilibrium water content of the hydrogels are between 0.9297–0.9921. Diffusion behavior was investigated. Water diffusion into hydrogels was found to be non-Fickian in character. Adsorption properties of AAm/SA hydrogels in aqueous thionin solution have been investigated. Finally, the amount of sorbed thionin per gram of dry hydrogel (q_e) was calculated to be 4.81×10^{-6}–11.69×10^{-6} mol thionin per gram for hydrogels. Removal efficiency (RE%) of the AAm/SA hydrogels was changed range 37.03–68.82%.
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Key words: Swelling; acrylamide/sodium acrylate hydrogel; glutaraldehyde; divinylbenzene; dye adsorption

INTRODUCTION

In recent years polymeric gels (hydrogels) are the objects of intensive studies. Highly swollen polymers or copolymers are highly hydrophilic, three-dimensional crosslinked polymeric structures that are able to swell in the aqueous environment. Hydrogels are crosslinked, macromolecular polymer networks immersed in water, synthesized to exhibit large volumetric swelling in response to a variety of environmental stimuli. Although many naturally occurring polymers may be used to produce this type of materials, the structural versatility available in synthetic hydrogels has given them distinctive properties, which in turn have enhanced their practical utility. Hydrogels have special properties due to their intermediate state between a liquid and a solid. The ability to absorb and to store much water and water solutions make hydrogels as unique materials for a variety of applications. Hydrogels may be conveniently described as hydrophilic polymers that are swollen by water, but do not dissolve in water. They are three-dimensional crosslinked polymeric structures that are able to swell in the aqueous environment. Crosslinked polymers capable of imbibing large volumes of water have found widespread applications in bioengineering, biomedicine, and food industry and water purification and separation process. Because of characteristic properties such as swell ability in water, hydrophilicity, biocompatibility, and lack of toxicity, hydrogels have been utilized in a wide range of biological, medical, pharmaceutical, environmental applications.[1–4]

Hydrogels can be prepared by simultaneous copolymerization and crosslinking of one or more monofunctional and one multifunctional monomer or by crosslinking of a homopolymer or copolymer in solution. Hydrogels are synthesized using either chemical reagents or irradiation.[5–7] In recent years, considerable research has been done on the characterization and swelling behavior of hydrogels prepared by simultaneous free-radical copolymerization and crosslinking in the presence of an initiator and a crosslinking agent. Because of the presence of carboxylic acid side groups, the swelling behavior of copolymeric acrylamide hydrogels is highly dependent on the surrounding medium.[8–14]

Here, glutaraldehyde (GL) and divinylbenzene (DVB) have been used as the crosslinking agents. In recent years, GL use has been widened to prepare crosslinked polymer gels for bioseparations, including electrophoresis networks, size-exclusions membranes, and also in the development of new drug release agents for biomedical purposes. It has been reported that DVB use as the crosslinking agent for drug diffusion study for pH-sensitive hydrogel membranes, too.[15,16]

Correspondence to: E. Karadağ (ekaradag@adu.edu.tr).
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Some studies have been reported on the use of hydrogels or hydrophilic characteristic crosslinked polymers or copolymers as adsorbents for the adsorption of dyes from their aqueous solutions. The use of polymer hydrogels for the removal of dyes from aqueous media has been continued to attract considerable attention in recent years. Polyacrylamide based hydrogels find many applications such as purification of wastewater and metal extraction.[17–21]

In this present research, it was of interest to increase the water absorption capacity of AAm hydrogels with vinyl functional groups containing chemical reagents such as sodium acrylate (SA) via free radical solution polymerization method with new two crosslinkers such as GL and DVB. The aim of this study is to investigate the water and dye sorption properties of AAm hydrogels with addition of an anionic monomer such as SA. Then, swelling properties, and diffusional and network properties of these hydrogels were studied.

EXPERIMENTAL

Materials

Acrylamide–sodium acrylate (AAm/SA) hydrogels were prepared by free radical crosslinking copolymerization of AAm monomer (Merck, Darmstad, Germany) with addition of an anionic comonomer such as SA (Aldrich Chemical, Milwaukee, US) and two multifunctional crosslinkers such as GL (Fluka Chemie AG, Buchs, Switzerland) and DVB (Fluka Chemie AG, Buchs, Switzerland) by chemical crosslinking polymerization.[22] The initiator, ammonium persulphate (APS) and the activator *N,N,N′,N′*-tetramethylethylenediamine (TEMED) were also supplied by Merck, and used as the redox initiator pair. All chemicals were used as received. Cationic dye, Thionin (Lauths violet, LV), was obtained from Aldrich Chemical, (Milwaukee). Some properties of dye are listed in Table I.

Copolymer preparation

To prepare highly swelling AAm/SA hydrogel systems, AAm weighing 1 g was dissolved in 1 mL aqueous solutions containing 00, 20, 40, 60, and 80 mg SA. For the synthesis, 0.25 mL of 1% concentration crosslinker solution was added to this aqueous solution. Then, 0.20 mL of APS (5 g/100 mL water) and 0.25 mL of TEMED (1 mL/100 mL water) were added to the solution. The solutions were placed in PVC straws of 3 mm diameter. Fresh hydrogels obtained in long cylindrical shapes were cut into pieces of 3–4 mm in length. They were washed and thoroughly rinsed with distilled water, blot dried with filter paper, dried in air and vacuum, and stored for swelling studies.

FT-IR spectra of AAm/SA hydrogels

To structurally characterize, FT-IR analyses were made. Spectra were taken on KBr discs by using VARIAN FTS 7000 FT-IR spectrophotometer.

Swelling and diffusion

Chemically crosslinked dried copolymeric hydrogels were accurately weighed and transferred into water. Water uptake with respect to time was obtained by periodically removing the samples from water, quickly blot drying, and reweighing. The measurements were conducted at 25°C ± 0.1°C in a water bath.

The percentage swelling, (S%), of the hydrogels in distilled water was calculated from the following relation:

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

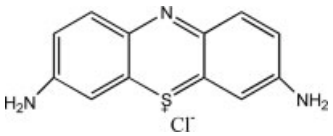
where m_t is the mass of the swollen gel at time t and m_o is the mass of the dry gel at time 0 (before swelling). Diffusion characteristics, equilibrium water content, etc. were calculated by using swelling data.

Sorption studies

Solutions of different dye concentration ranging from 3.5×10^{-6} to 2.5×10^{-5} mol L^{-1} in distilled water were prepared. AAm/SA hydrogel containing 60 mg SA was used in a known volume of dye solution until equilibrium was reached. For SA effect on the dye sorption, dye solution of concentration of 2.5×10^{-5} mol L^{-1} was used.

After sorption, dye solution was separated by decantation from the hydrogels. Concentration of

TABLE I
Some Properties of the Dye

Dye	Chemical structure	λ_{mak} (nm)	Molar mass (g mol^{-1})	Color index no.
Thionin (Lauths Violet) (LV)		598	287,34	52000

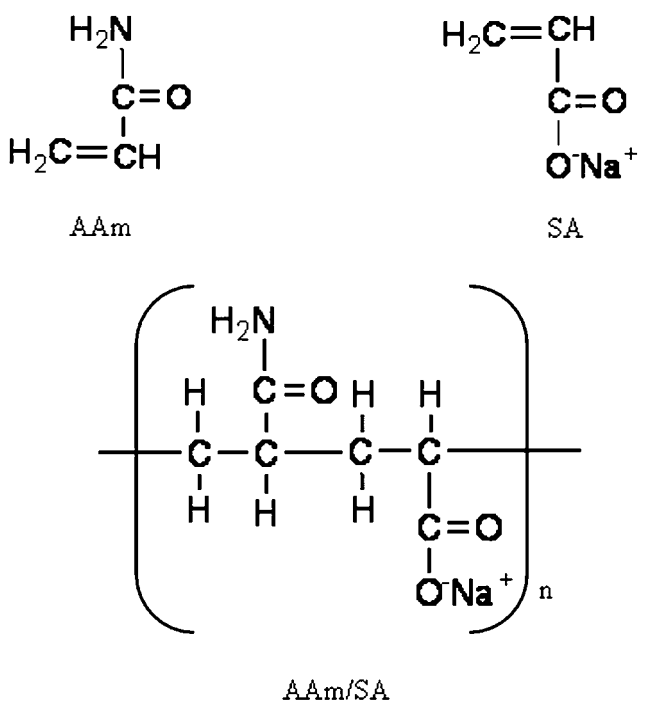
dye solutions was detected by spectrophotometric method. Spectrophotometric measurements were carried out using a Shimadzu UV 1601 model UV–Vis spectrophotometer at ambient temperature. The absorbance of these solutions were read at wavelength 598 nm. Distilled water was chosen as the reference. The equilibrium concentrations of the cationic dye solutions were determined by means of precalibrated scales. The amounts of dye sorbed were determined from the initial and final concentrations of the solutions, calculated from the calibration curve.

RESULTS AND DISCUSSION

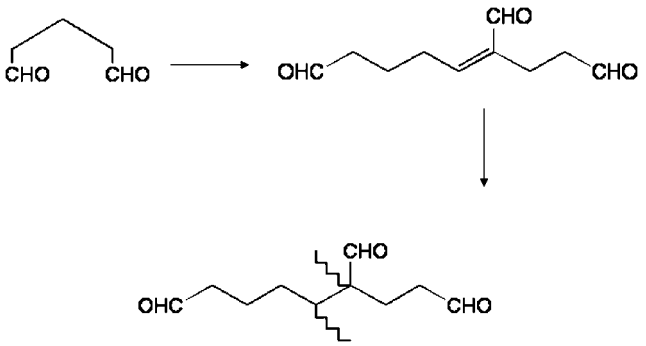
To have high swelling capability, hydrophilicity, and ability to adsorb cationic species, SA was added to AAm. AAm/SA hydrogels were prepared by free radical solution polymerization. Two crosslinkers such as GL and DVB have been used for crosslinking. A mechanism for the polymerization and simultaneous crosslinking was suggested (Schemes 1–3).[22] Dried AAm/SA copolymers are glassy and very hard, but swollen gels are soft. The crosslinked copolymers are obtained in the form of cylinders. Upon swelling the hydrogels were strong enough to retain their shape.

FT-IR analysis

To understand binding and crosslinking of AAm/SA hydrogels during polymerization, FT-IR spectra



Scheme 1 Possible binding mechanism of AAm/SA hydrogel systems.

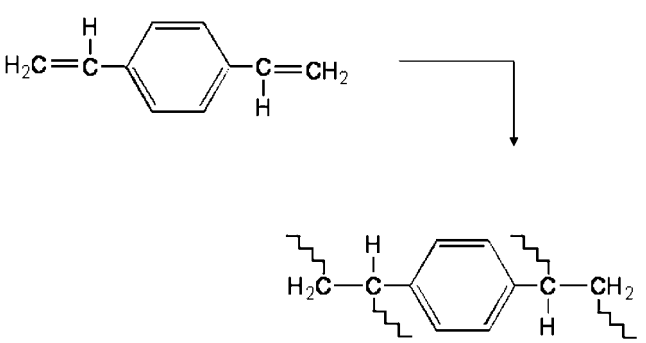


Scheme 2 Possible crosslinking mechanism of glutaraldhyde.

of the hydrogels were evaluated and are presented in Figures 1 and 2. The spectra of the hydrogels crosslinked by GL are similar to the spectra of the hydrogels crosslinked by DVB. In the FT-IR spectra of the hydrogels, the bands at about 1600–1700 and 3100–3500 cm^{-1} are important. The bands at about 1600–1700 cm^{-1} could be attributed to a shift in stretching vibration associated with hydrogen that is bonded directly to an overtone of the strong carbonyl absorption. The peak at 1650–1660 cm^{-1} is the carbonyl group and related to amide groups and at 1500–1600 cm^{-1} is the N—H bonding vibration. The much broader absorption peaks in the regions of 3100 cm^{-1} and/to 3500 cm^{-1} are N—H bands and related to ''polymeric'' bands. The broad peak 3500 cm^{-1} is characteristic peak of primary amine. It is thought that the peaks at 1200 cm^{-1} are C—N bands, and the peaks at 2850 and 1400 cm^{-1} show —CH_2— groups on the polymeric chain. The characteristic absorption peak of SA units is shown at approximately 1705 cm^{-1} due to carboxylate anion of SA groups. The peaks observed in the FT-IR spectra confirm the presence of AAm and SA.

Swelling

The water uptake of initially dry hydrogels was followed for a period of time, gravimetrically. Swelling curves of the hydrogels were constructed and swelling isotherms are shown in Figures 3 and 4.



Scheme 3 Possible crosslinking mechanism of DVB.

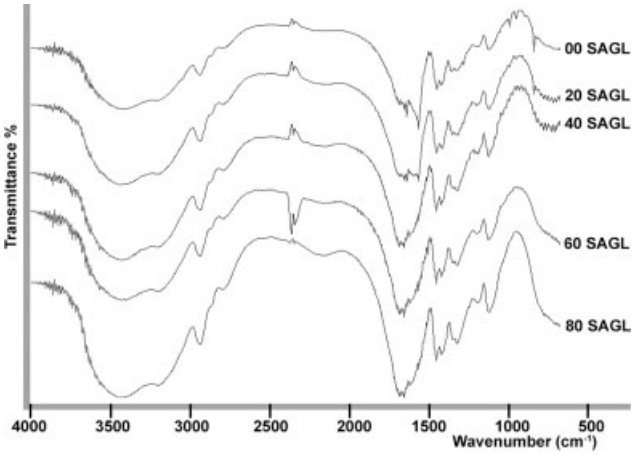


Figure 1 FT-IR spectra of AAm/SA hydrogels crosslinked by GL including of various contents of SA.

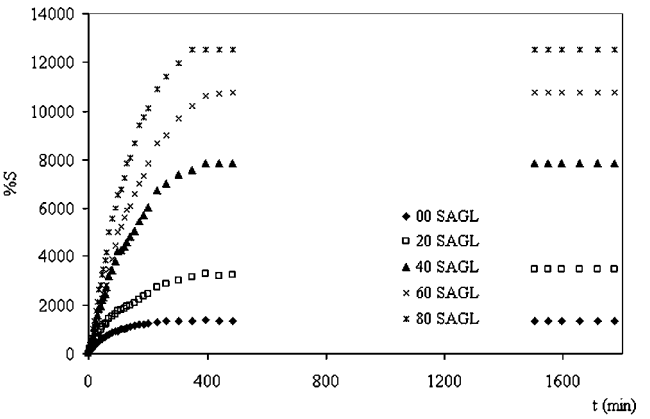


Figure 3 Swelling isotherms of AAm/SA hydrogels crosslinked by GL.

Figures 3 and 4 show that swelling increases with time up to certain level, then levels off. This value of swelling may be called the equilibrium swelling percentage (S_{eq}%). S% values of AAm/SA copolymers are used for the calculation of swelling characterization parameters. S_{eq}% of AAm/SA copolymers is given in Table II.

Table II shows that S_{eq}% of AAm are 1326–1618%, but S_{eq}% of AAm/SA hydrogels are 2946–12,533% with the incorporation of SA groups into AAm chains. It is well known that the swelling of a hydrogel is induced by the electrostatic repulsion of the ionic charges of its network. The ionic charge content is important. SA contain ionic units (—COONa). Salts of weak acids are decomposed by water with the formation of free acid and free base, and the process of hydrolysis is reversible. The salt group is almost completely ionized, and a large number of hydrophilic groups occur.[14,22] Hydrophilicity of AAm/SA copolymers becomes greater than that of AAm, so, the swelling of AAm/SA copolymers is greater than the swelling of AAm hydrogels. In Table II, S_{eq}% of the hydrogels increased with the SA content in the copolymers. S_{eq}% of AAm/SA hydrogels is higher than S% of pure AAm hydrogels. The reason of this is the hydrophilic groups on the SA. The more hydrophilic groups in the AAm/SA get the more the swelling of the AAm/SA hydrogels.

Equilibrium water content

The water absorbed by AAm/SA hydrogels is quantitatively represented by the Equilibrium water content (EWC),[23–25] where

$$\mathrm{EWC} = \frac{m_s - m_o}{m_s} \tag{2}$$

Here, m_s is the mass of the swollen gel at time t (equilibrium), and m_o is the mass of the dry gel at time 0. The EWC values of all AAm and AAm/SA hydrogel systems were calculated. The values of EWC of the hydrogels are tabulated in Table II.

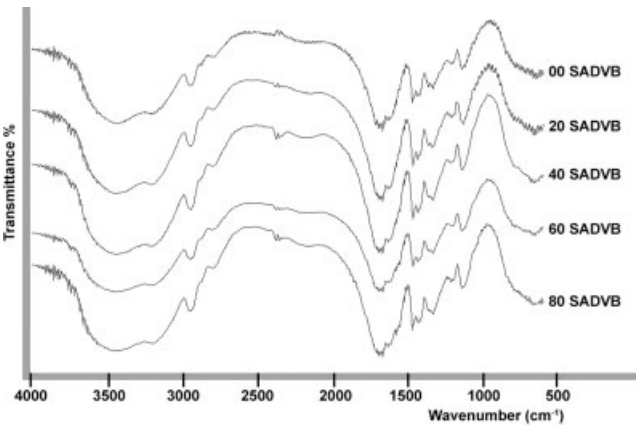


Figure 2 FT-IR spectra of AAm/SA hydrogels crosslinked by DVB including of various contents of SA.

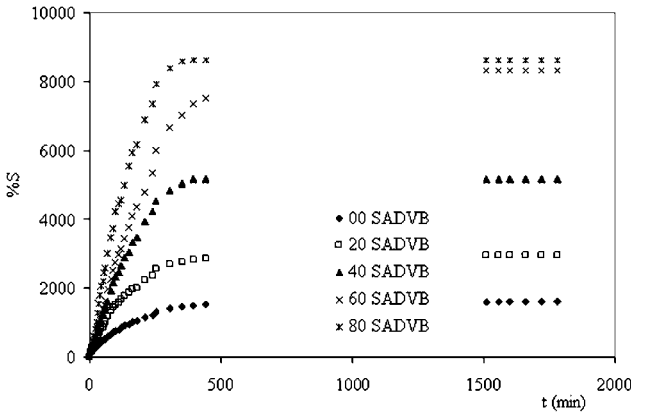


Figure 4 Swelling isotherms of AAm/SA hydrogels crosslinked by DVB.

TABLE II
Equilibrium Swelling Percentage and Equilibrium Water Content Values of AAm/SA Hydrogel Systems

SA/mg	0	20	40	60	80
S_{eq}%					
GL	1326	3467	7848	10758	12533
DVB	1618	2946	5180	8322	8608
Equilibrium water contents (EWC)					
GL	0.9297	0.9720	0.9874	0.9908	0.9921
DVB	0.9418	0.9672	0.9811	0.9881	0.9885

Swelling kinetics

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 AAm/SA 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[26]

$$\frac{dS}{dt} = k_{2,S}(S_{-}S_t)^2 \tag{3}$$

where $k_{2,S}$ is the rate constant of swelling and S denotes the degree of swelling at equilibrium. After definite integration by applying the initial conditions $S = 0$ at $t = 0$ and $S = S_t$ at $t = t$, eq. 5 becomes

$$\frac{t}{S} = A + Bt \tag{4}$$

where A is reciprocal of initial swelling rate r_o or $1/k_{2,S}S^2$ and B is inverse of the degree of swelling at equilibrium.

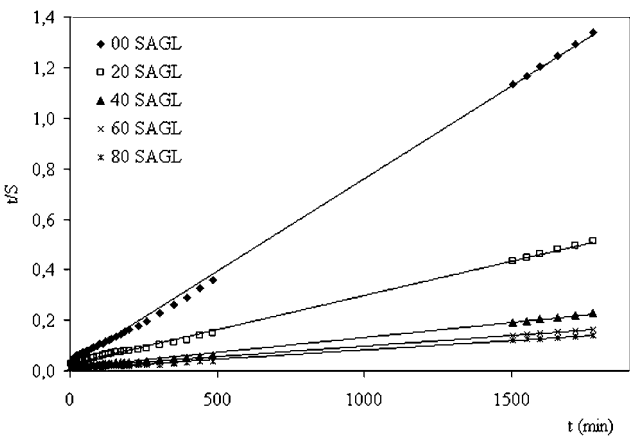


Figure 5 Swelling rate curves of AAm/SA hydrogels crosslinked by GL.

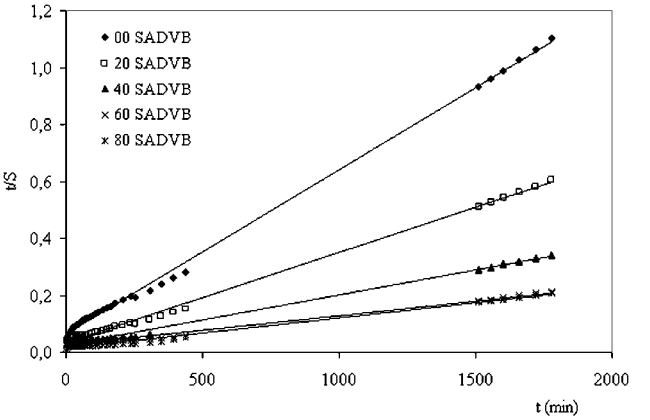


Figure 6 Swelling rate curves of AAm/SA hydrogels crosslinked by DVB.

To test the kinetics model, t/S versus t graphs are plotted and representative graphs are illustrated in Figures 5 and 6. The calculated kinetic parameters are tabulated in Table III.

As can be seen from Table III, kinetics model is agreement with swelling experiments, since, as depicted in Table II, S (S%) is changed with SA content. Again, the initial swelling rate is changed with SA content. This may be plausible since the ionic content of the network is enhanced with the extent of SA groups in structure. It may be important to note that extent of SA determines the swelling rate by increasing hydrophilicity.

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 con-

TABLE III
Swelling Rate Parameters of AAm/SA Hydrogel Systems

SA/mg	0	20	40	60	80
The initial swelling rate, r $(dS/dt)_o$; g_{water}/g_{gel} (min)					
GL	35.97	34.36	80.65	81.97	120.63
DVB	15.43	28.33	36.36	38.76	71.94
The swelling rate constant, $k_s \times 10^6$; g_{gel}/g_{water} (min)					
GL	19.38	2.49	1.14	0.59	0.66
DVB	5.12	2.83	1.11	0.41	0.81
The theoretical equilibrium swelling, S_{max}(%); g_{water}/g_{gel}					
GL	1362	3717	8403	11765	13550
DVB	1736	3165	5714	9709	9434

siderable 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 water into hydrogels.[27,28]

$$F = \frac{M_t}{M_s} = kt^n \tag{5}$$

Where F is the fractional uptake at time t. Here, M_t and M_s are the mass uptake of the water at time t and the equilibrium, respectively. Equation 5 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. That is reflected by n between 0.5 and 1.[27,28] The values of n and k were calculated from the slope and the intercept of the plot of ln F against ln t, respectively.

For chemically crosslinked hydrogels, ln F versus ln t graphs are plotted and representative results are shown in Figures 7 and 8. Diffusional exponents, n and diffusion constant, k are calculated from the slopes and intercepts of the lines, respectively, and are listed in Table IV.

Table IV shows that the number determining the type of diffusion, n is over 0.50. Hence the diffusion of water into the super water-retainer hydrogels is generally found to have a non-Fickian character.[28] 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.[28]

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.

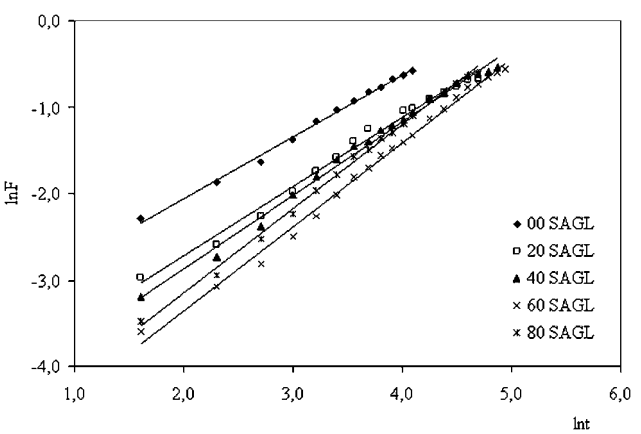


Figure 7 Swelling kinetic curves of AAm/SA hydrogels crosslinked by GL.

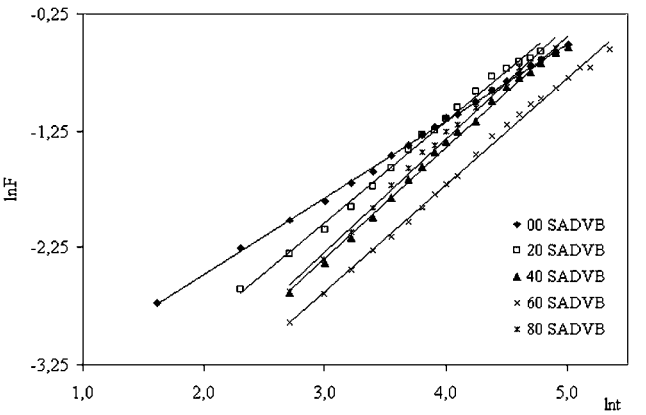


Figure 8 Swelling kinetic curves of AAm/SA hydrogels crosslinked by DVB.

The diffusion coefficient D, of the water was calculated using the following equation[29]:

$$D = \pi r^2 \left(\frac{k}{4}\right)^{1/n} \tag{6}$$

Where D is in cm^2 s^{-1}, r is the radius of a cylindrical polymer sample, n is the diffusional exponent and k is a constant incorporating characteristic of the macromolecular network system and the penetrant. The values of diffusion coefficient determined for the hydrogels are listed in Table IV. Table IV shows that the values of the diffusion coefficient of the AAm/SA hydrogels vary from 3.17×10^{-4} cm^2 s^{-1} to 49.81×10^{-4} cm^2 s^{-1}.

Sorption

To observe the sorption of thionin, AAm/SA hydrogels were placed in aqueous solutions of thionin and allowed to equilibrate for four days at 25°C. At the end of this period AAm/SA hydrogels in thionin solutions showed the dark coloration.

For equilibrium sorption studies, the amount of sorption per unit mass of the adsorbent can be inves-

TABLE IV
Some Diffusion Parameters of AAm/SA Hydrogel Systems

SA/mg	0	20	40	60	80
Diffusional exponents, n					
GL	0.71	0.80	0.85	0.97	0.97
DVB	0.66	0.86	0.94	0.91	0.97
Diffusion constants ($k \times 10^2$)					
GL	3.1	1.3	1.0	0.5	0.7
DVB	2.3	1.0	0.6	0.5	0.6
Diffusion coefficients ($D \times 10^4$)					
GL	5.35	8.78	22.10	23.07	49.81
DVB	3.17	10.66	15.25	13.97	29.84

TABLE V
Some Adsorption Parameters of AAm/SA Hydrogel Systems

SA/mg	20	40	60	80
$q_e \times 10^6$				
GL	5.17	8.92	8.98	11.69
DVB	4.81	7.35	9.04	8.81
K_d				
GL	0.64	1.53	1.69	1.97
DVB	0.59	1.44	2.03	1.94
RE%				
GL	38.87	60.25	62.89	66.37
DVB	37.03	56.96	65.69	68.82

tigated. The amount (mol) of sorption per unit mass of the AAm/SA hydrogels were evaluated by using the following equation:

$$q_e = \frac{(C_o - C)v}{m} \tag{7}$$

Where q_e is the amount (mol) of dyes sorbed onto unit dry mass of the AAm/SA hydrogels (mol g^{-1}), C_o and C are the concentration of the dye in the initial solution and the aqueous phase after treatment for a certain period time, respectively, (mol L^{-1}), v is the volume of the aqueous phase (L) and m is the amount of dry AAm/SA hydrogels (g).

The amount of thionin sorbed onto unit dry mass of the gel was calculated for uptake of dye within the hydrogel in 3.0×10^{-5} mol thionin in L of aqueous solutions, and presented in Table V. Table V presents that the amount of thionin sorbed onto unit dry mass of AAm/SA hydrogels (5.17×10^{-6}–11.69×10^{-6} mol g^{-1} for AAm/SA/GL, and 4.81×10^{-6}–8.81×10^{-6} mol g^{-1} for AAm/SA/DVB, q_e are increased. The amount of dyes sorbed onto unit dry mass of the AAm/SA hydrogels gradually increased with the increase of content of SA in the hydrogels. Equilibrium thionin adsorption isotherm of AAm/SA hydrogels is presented in Figures 9 and 10. To Figures 9 and 10, the amount of sorption thionin per unit mass of the AAm/SA hydrogels is increased with the increasing concentration of thionin. This result is an expected phenomena.

Removal efficiency (RE%) of the AAm/SA hydrogels was calculated by following equation

$$\text{RE\%} = \frac{C_o - C}{C_o} \times 100 \tag{8}$$

RE% of the AAm/SA hydrogels is changed among 37.03–68.82% (Table V).

Partitioning of dissolved constituents between an aqueous phase and adsorbents in waters and sediments has commonly been described by an empirical partition coefficient that simply relates the total concentration of a dissolved species to the total concentration of the adsorbed species[30]:

$$K_d = \frac{(C_o - C)}{C} \tag{9}$$

where K_d is empirical partition coefficient at equilibrium. C_o and C were defined earlier. Partition coefficients of thionin between dye solution and hydrogels were calculated, and are shown in Table V. In Table V, it is shown that the values of partition ratio of AAm/SA hydrogels containing of 20 mg SA are small than the values of partition ratio of AAm/SA hydrogels containing of 80 mg SA. So, it can be said that AAm/SA hydrogels having increasing, or high content of SA is good adsorbent for thionin, or dye solutions.

The ionic charge content in the polymeric structure is important. SA contain ionic units (—COONa). The swelling degree of the hydrogels increases due to increase of the hydrophilic units on hydrogel structure (Schemes 1–3). Therefore AAm/SA hydrogels

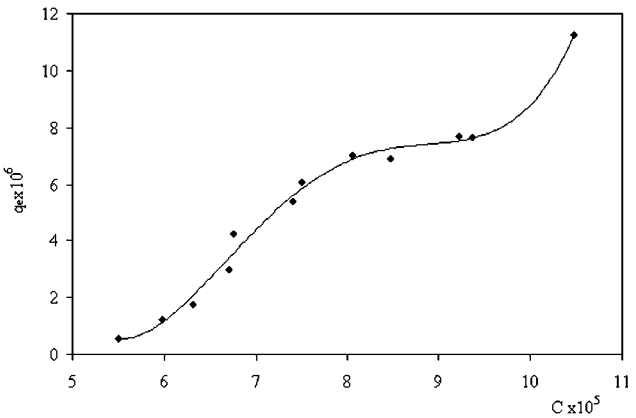


Figure 9 Equilibrium sorption isotherms for the dye on AAm/SA hydrogels crosslinked by GL.

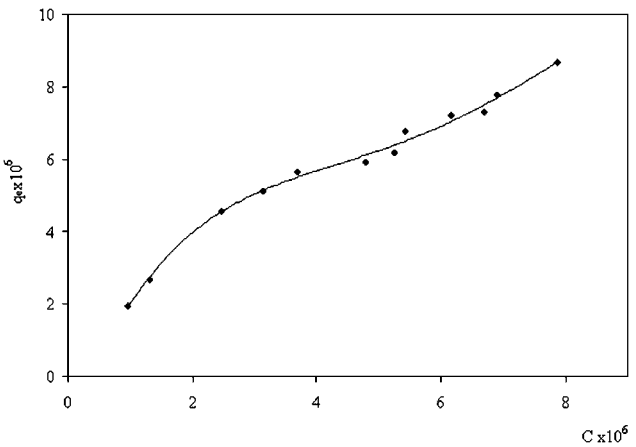
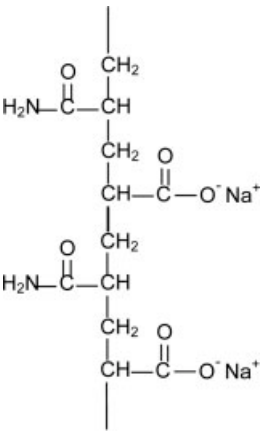
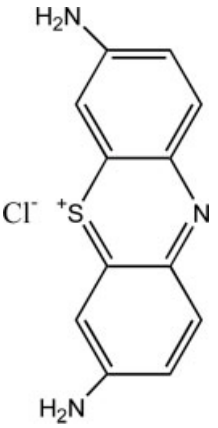


Figure 10 Equilibrium sorption isotherms for the dye on AAm/SA hydrogels crosslinked by DVB.

TABLE VI
Possible Noncovalent Interactions in the Binding of Thionin by AAm/SA Hydrogels

Copolymer chain	Thionin	Interaction type	Copolymer	Dye
		Hydrogen bonding	N and O atom C=O, methine, methyl	H atom Amine
		Hydrophobic	Hydrogen atom	Benzene ring
		Dipole–dipole	Amide group	Benzene ring
		Dipole-induced dipole	Amide group	Polarisable aromatic group

have many ionic groups that can increase interaction between the dye molecules and anionic groups of hydrogels.

There can be many reasons for noncovalent interactions in the binding of thionin by AAm/SA hydrogels. These interaction types are represented as possible interactions in Table VI. The main interactions between the hydrogel and the cationic dye may be hydrophobic and hydrogen bonding. Specially, hydrogen bonding will be expected to occur between amine groups and nitrogen atoms on the dye molecules and the amine and carbonyl groups on the monomer unit of crosslinked polymer. Hydrophobic effects are especially aqueous solutions interactions, which in the present case will involve that aromatic ring on the dye molecules and the methine and methyl groups on the gel. There can be some other interactions such as dipole–dipole and dipole-induced dipole interactions between the dye molecules and the hydrogel chains.

The results of swelling studies are parallel character to the results of sorption studies. Both of them, it can be seen that swelling or sorption capability of AAm/SA hydrogels are increased with increasing SA content in copolymeric structure. The most important effect is hydrophilicity of copolymeric gels. Hydrophilicity of AAm/SA copolymers becomes greater than that of AAm, when addition of SA to the copolymeric structure.

CONCLUSIONS

Incorporation of hydrophilic group containing chemicals such as SA in AAm hydrogels can be obtained successively by free radical solution polymerization method. Two multifunctional crosslinker such as GL and DVB used at the polymerization process. The hydrogels showed high water absorbency (percentage swelling ratio range 1326–12,533%) and high equilibrium water content (0.9297–0.9921). It was seen that swelling of AAm/SA hydrogels increased with the increasing of content of SA.

The present work has given the quantitative information on the binding/adsorbing characteristic of thionin with AAm/SA hydrogels. AAm/SA hydrogels have sorbed the monovalent cationic dye such as thionin, while AAm hydrogels do not. The moles of sorbed thionin per gram of dry hydrogel, q_e were calculated. RE% of thionin for AAm/SA hydrogels is changed among 37.03–68.82%. At the end of this study, it is seen that chemically crosslinked AAm/SA hydrogels may be used a sorbent for removal of some agents and dye molecules. This is under investigation for the separation and selectivity of special species. The utilization of these types of hydrogels, in biomedicine, controlled drug delivery, pharmaceuticals, agriculture, biotechnology, environment, sorption, separation, purification, immobilization, and enrichment of some species makes hydrogel more popular.

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