Synthesis and Swelling Characteristics of pH and Thermo-responsive Interpenetrating Polymer Network Hydrogel Composed of Poly(vinyl alcohol) and Poly(acrylic acid)

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SYNOPSIS

The swelling behavior of novel pH- and temperature-sensitive interpenetrating polymer networks (IPNs) composed of poly(vinyl alcohol) (PVA) and poly(acrylic acid) (PAAc) in water was investigated. The PVA/PAAc IPN hydrogels were synthesized by UV irradiation, followed by a repetitive freezing and thawing process by which PVA hydrogel networks were formed inside of cross-linked PAAc chains. The swelling behaviors of these IPNs were analyzed in buffer solution at various pH and temperature ranges. Swelling ratios of all IPNs were relatively high, and they showed reasonable sensitivity to both pH and temperature. Hydrogels showed both the positive and negative swelling behaviors depending on PAAc content. IPN46 showed the positive temperature-sensitive swelling behavior and its stepwise changes in swelling ratio was about 1.8 and 2.0 obtained between 25 and 45°C at pH 7, and between pH 4 and 7 at 35°C, respectively. The positive temperature dependence is attributed to the formation and dissociation of hydrogen bonding complexes between PVA and PAAc. These IPNs are expected to show a pH- and temperature-sensitive drug release according to the stepwise behavior at this temperature region.

INTRODUCTION

Hydrogel of stimuli responsive polymers have promising potential as materials which show structural and physical changes to environmental signals such as temperature,[1-2] pH,[3-7] ionic concentration,[8] electric field,[9-10] and light.[11] Numerous attempts to control swelling changes in hydrogel through external modulation by stimuli have been reported. Recently, polymer hydrogels have been studied for various applications, including drug delivery systems or mechanical actuators.[12-13] Among these, pH and thermosensitive polymers receive much attention because these two factors are the most available environments inside the human body.

Much of the fundamental swelling behaviors of the hydrogels has been investigated since Tanaka[14] suggested the swelling theory with respect to the change in temperature. The thermosensitive hydrogel could be described as either a positive or a negative temperature sensitive system. In a positive temperature sensitive system, hydrogels with upper critical solution temperature (UCST) shrink by cooling below the UCST, while the hydrogels with lower critical solution temperature (LCST) contract by heating above the LCST in a negative temperature sensitive system.

In an aqueous system, the temperature dependence of swelling of a polymeric gel is closely related to the temperature dependence of polymer–water and polymer–polymer interaction. Investigations of polymer–water interaction have been reported by many researchers. Hoffman et al.,[15] and Yoshida et al.[16] have studied polymeric hydrogels such as a cross-linked poly(N-isopropylacrylamide) (PNIPAAm) hydrogel, showing LCST at 30–32°C, by

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which temperature-controlled on-off drug release systems have been developed. Furthermore, polymer–polymer interactions have been investigated by Bae et al.[17] using IPNs composed of poly(N-acryloylpyrrolidine) and poly(oxyethylene), which indicated that drastic swelling changes with changing temperature could be achieved by utilizing repulsive intermolecular interaction between polymer–polymer in combination with polymer–water interactions. On the other hand, Aoki et al.[18] and Katono et al.[19] reported positive temperature sensitive systems for IPNs consisting of poly(acrylic acid) (PAAc) and poly(N,N-dimethylacrylamide) (PDMAAm), and PAAc and poly(acrylamide-co-butylmethacrylate) (poly(AAm-co-BMA)), respectively; these showed attractive intermolecular polymer–polymer interaction—specifically, the complex formation by hydrogen bonding. The complex formation and dissociation in the IPNs could be expected to cause reversible shrinking and swelling changes.

In the case of pH as another external signal to stimuli-sensitive hydrogel, Nishi and Kotaka[20] and Yao et al.[21] have studied pH-sensitive hydrogels. Charged polymeric networks have been recognized as useful matrices for drug delivery because their volume changes in response to variation of the pH. The main driving force responsible for volume change is the ionic repulsion between charged groups incorporated in the gel matrix. Such hydrogels have been applied to fabricate a glucose-sensitive insulin release device,[22-23] an osmotic insulin pump, and site-specific drug delivery in the gastrointestinal tract.[24]

Our previous studies reported on the pH and temperature sensitive hydrogels[25-26] and membranes,[27] respectively. In the present study on the PVA/PAAc IPNs, we wish to report on the better positive temperature-dependent polymer hydrogels, which simultaneously show pH-dependent swelling changes. Park and Hoffman[24] and Kim et al.[28] combined these two properties by synthesizing pH- and temperature-sensitive hydrogels. Besides, there have been several investigations on hydrogel or membrane composed of PVA and PAAc.[29-32] In particular, Gudeman and Peppas recently reported pH-sensitive IPNs of PVA and PAAc.[33-34] Hydrogels, however, rarely showed both temperature and pH sensitivity. They only considered pH or electric sensitive materials due to ionic repulsion between anionic charged groups of PAAc, which contain carboxyl groups that become ionized at pH values above its pKa of 4.7. PVA was adopted simply because of its strength, processibility, and long-term temperature and pH stability.

Recent research shows that PVA that is heated to dissolve, then frozen and thawed, forms a matrix of physically cross-linked polymeric chain to produce a highly elastic gel.[35] This PVA gel is stable at room temperature and retains its original shape but can be extended to six times its initial size. Properties of PVA gels depend on the molecular weight, concentration of aqueous solution, temperature, time of freezing, and the number of freeze-thaw cycles. The PVA gel also has been observed for biomedical and pharmaceutical materials because the gels are innocuous and noncarcinogenic but have good biocompatibility.

In this study, we would like to report on the preparation and swelling properties of novel pH- and temperature-dependent PVA/PAAc IPN hydrogels by unique UV freezing–thawing method. We expect our PVA/PAAc IPN hydrogels show drastic swelling changes by external pH and temperature according to repulsion of ionic groups and formation–dissociation of hydrogen bonds between two polymers.

EXPERIMENTAL

Materials and Reagents

Acrylic acid monomer was purchased from Junsei Chemicals Co. and was purified by inhibitor remove column (Aldrich Chem. Co.) to eliminate hydroquinone inhibitor. PVA (DP = 2500, degree of deacetylation = 99%) was purchased from Shinetsu Co. Methylenebisacrylamide (MBAAm) as a crosslinker and 2,2-dimethoxy-2-phenylacetophenone (DMPAP) as a photoinitiator were purchased from Aldrich Chem. Co.

IPN Hydrogel Preparation

PVA/PAAc IPNs were prepared by a sequential method by which crosslinked PAAc chains were formed inside of PVA solution due to UV irradiation, followed by freezing–thawing. The whole synthetic scheme is detailed in Figure 1. PVA was dissolved in water at 80°C to make 10 wt % PVA aqueous solution. Acrylic acid monomer solution containing 0.2 wt % photoinitiator, DMPAP, and 0.5 mol % crosslinking agent, MBAAm, was mixed with PVA aqueous solution in which the weight ratios of the equivalent amount of vinyl alcohol residue in PVA to acrylic acid monomer becomes 6 : 4, 5 : 5, and, 4 : 6. Composition ranges were selected based on our previous study.[25-26] The mixed solutions were then poured onto the glass plate, exposed to the radiation from a 450 W UV lamp (Ace Glass Co.) for 1 h under nitrogen gas atmosphere, frozen at −50°C for 6 h,

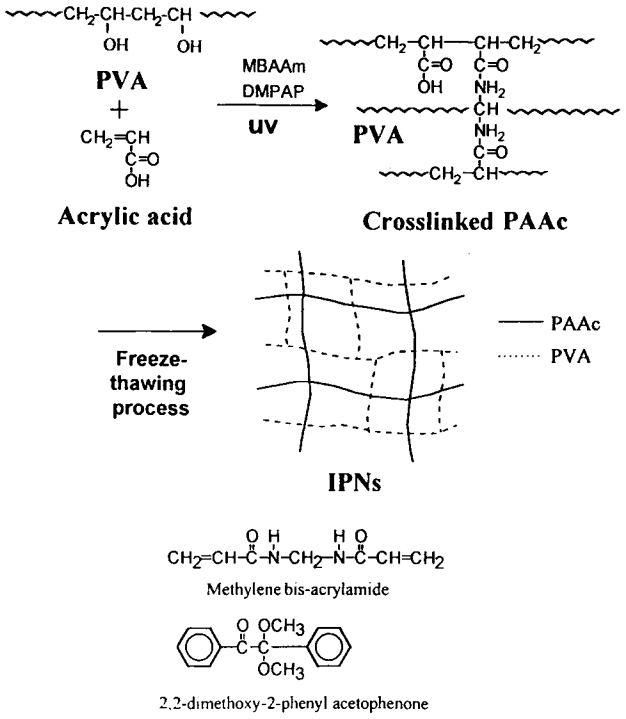

Figure 1 PVA/PAAc IPNs by UV irradiation and the freezing–thawing process.

and thawed at room temperature for 2 h. Freezing–thawing cycles were repeated 8 times to get elastic PVA/PAAc IPN hydrogels. The feed composition and designation of IPN gels are listed in Table I. IPN64, IPN55, and IPN46 denote the weight composition of vinyl alcohol unit and acrylic acid monomer content in IPNs when they are prepared. Therefore, the real composition could be slightly different from the first ones because the samples were washed by water to remove any residual acrylic acid monomer after whole synthetic procedure.

Characterization and Swelling Measurements

Fourier transform infrared (FTIR) spectroscopy (Nicolet Model Magna IR 550) was used to confirm the hydrogen bondings between PVA and PAAc in the IPNs. For the swelling kinetics measurement, the IPNs disk (2.3 cm outer diameter and 3 mm thick) were soaked in pH 7 buffer solution at temperature ranging from 25 to 45°C. Then gels were removed from the buffer solution, and the water on the surface was blotted out by filter paper. The hydrogels were weighed every hour at a fixed temperature until the hydrated weight reached a constant value. This weight was used to calculate the equilibrium water swelling ratio. The swelling ratio of an IPN was defined as the ratio of the weight of the absorbed water to that of the dry polymer.

$$Q = \frac{(W_w - W_d)}{W_d} \tag{1}$$

where W_w, W_d, and $(W_w - W_d)$ are the weights of a swollen sample, dry polymer, and absorbed water, respectively.

To investigate swelling behavior in variation to pH, the disk samples were swollen in several buffer solutions of pH 2, 4, 7, and 9 at 35°C in the same way as mentioned above. After equilibration at a certain pH, gels were reequilibrated at a higher pH. The pH-dependent stepwise swelling behavior was also studied by alternatively changing pH between 4 and 7. The samples were immersed for 3 h in each solution and weighed at time intervals of one hour.

In the case of temperature-dependent swelling behavior, weight changes of IPNs hydrogels were measured every 3 h after immersing the samples in pH 7 buffer solution, followed by an increase of temperature after every 3 h by 5°C increment from 25 up to 45°C. For an investigation of the oscillatory swelling behavior by temperature, IPN hydrogels were first equilibrated in water at 25°C, then the temperature was changed between 45 and 25°C. After immersing for 3 h at each temperature, the volume was measured every hour.

Table I Sample Preparation and Designation of PVA/PAAc IPNs

Sample[a]	PAAc Content (mol %)	Mass of Acrylic Acid (g)	Mass of MBAAm[b] (g)[b]	Mass of DMPAP[c] (g)[c]
IPN64	40	2.16	0.023	0.0043
IPN55	50	3.26	0.035	0.0065
IPN46	60	4.89	0.052	0.0098

[a] Each mixed solution was prepared using 20 g of 10 wt % PVA aqueous solution.
[b] 0.5 mol % of MBAAm was dissolved in acrylic acid.
[c] 0.2 wt % of DMPAP was also dissolved in acrylic acid.

RESULTS AND DISCUSSION

The preparation method of hydrogels from PVA/PAAc IPNs was investigated and reported in our previous studies.[25-26] In our preliminary experiments, we have tried several methods to prepare IPNs, noted as chemical, sequential, and simultaneous methods, in which PAAc was thermally polymerized at 50°C. These methods were named by procedure to combine PVA with acrylic acid. Samples from these methods, however, need some improvements to become stimuli-responsive hydrogels.

We first tried a method similar to the chemical method, in which PVA hydrogels prepared by the freezing–thawing process were immersed in acrylic acid monomer solution containing a photoinitiator and a crosslinker and exposed to UV radiation. The hydrogels resulting from this method showed only a slight sensitivity to temperature. This result indicated the possibility of preparing temperature-sensitive hydrogels composed of PVA/PAAc IPNs. It was thought that the reason why the hydrogel showed only a small temperature sensitivity was that the polymerization and crosslinking reaction occurred only on the surface because PVA hydrogels as an initial gel were so opaque that UV could not penetrate through these hydrogels.

The sequential method by UV irradiation, followed by the freezing–thawing we used in the present study, would be a breakthrough and a novel method to prepare stimuli-sensitive polymer hydrogel. This technique, used to prepare IPNs, was successful in providing the desired crosslinked hydrogel. An important experimental parameter varied during the IPN preparation was the composition of PVA and PAAc, whose effects on swelling behavior will be discussed later. The IPN hydrogels were subsequently used in swelling studies for evaluation of their response to changes in external pH and temperature.

IPNs composed of PVA and PAAc are expected to be the temperature-sensitive hydrogels since these IPNs are considered to have hydrogen bonding due to PAAc as the proton donor and PVA as the proton acceptor. FTIR spectroscopy is one of the powerful techniques used to investigate a multicomponent system because it provides information on the polymer–polymer interaction, as well as on each component. The present study by the FTIR has revealed the existence of hydrogen bondings between PVA and PAAc in IPNs.

Figure 2 shows the FTIR spectra for PVA, IPN, and PAAc samples. Stretching vibration of hydroxyl groups in PVA appeared at 3445 cm^{-1}. The —OH stretching band in IPNs is not only changed in its shape but also shifted to a lower frequency ranges at around 3417 cm^{-1}, indicating that a strong hydrogen bonding interaction should occur between —OH of PVA and —COOH of PAAc in these IPNs. Stretching vibration spectrum of carboxyl groups of PAAc appears at 1720 cm^{-1}, while that of IPNs also shifted to a lower frequency of 1713–1718 cm^{-1} with reduced intensity. According to FTIR analysis, hydrogen bonds between PVA and PAAc exist to some degree. It was expected that hydrogen bonds should affect the reversible positive swelling changes with temperature.

Swelling kinetics of IPNs are plotted in Figure 3. First, IPNs were freeze-dried to obtain the weight of dried polymer, W_d, as a basis for calculating the swelling ratio. Then IPNs were put into pH 7 buffer solution at temperatures of 25, 30, 35, 40, and 45°C for 20 h each; thereafter, their swelling amount was measured every hour. All IPNs reached their equilibrium after 20 h, but IPN 64, whose PVA content is greater than its PAAc content, reached its equilibrium rapidly compared to IPN 46, which contained more PAAc. The more PAAc in the IPNs, the higher the swelling ratio. This result is summarized in Figure 4. The swelling ratios of PVA and PAAc homopolymer are about 14.4 and 36.5, respectively, but the swelling ratio of IPN 64 containing 40 mol % of PAAc is 9.6, which is even lower than that of the PVA homopolymer. This is caused by crosslinked IPN structure, which has intermolecular interactions between two polymers in hydrogel. The swelling ratios of IPN 55 and IPN 46 increase again with PAAc content but are still much lower than PAAc homopolymer.

To obtain the basic information on temperature-dependent swelling behavior of IPNs, the swelling ratio of each PVA and PAAc homopolymer hydrogel was also investigated and plotted in Figure 5. The initial swelling ratio of PAAc at 10°C is 33, which is much higher than that of PVA (17). Furthermore, the swelling degree of PVA hydrogels decreases with increasing temperature in opposition to the increase of the swelling degree of PAAc with temperature. PAAc hydrogels show a typical positive swelling change with temperature indicating UCST behavior, but PVA hydrogels display negative swelling behavior typically observed in other polymeric systems, such as PNIPAAm. In the present case, the swelling degree of PVA hydrogels decreases because the interaction between polymeric chains become stronger and the chemical affinity with water is weaker as temperature increases.

The swelling kinetics, plotted against square root of time in Figure 6, show both Fickian and non-

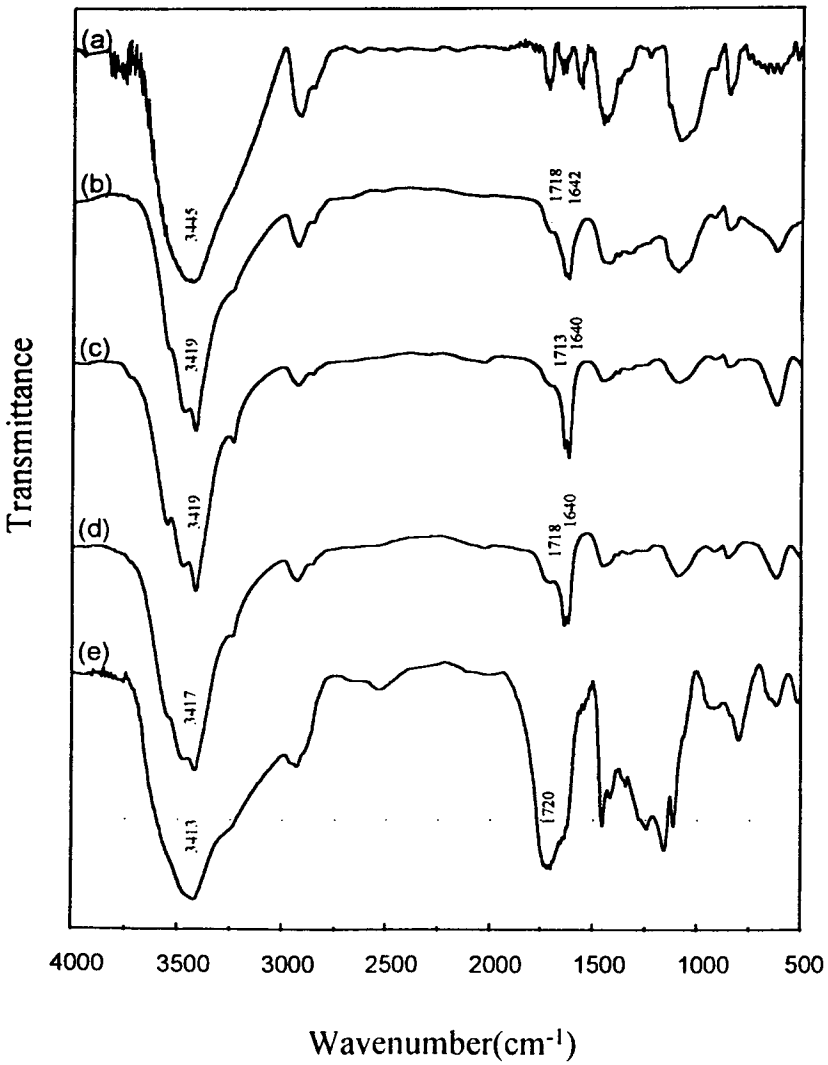

Figure 2 FTIR spectrum of PVA, IPN 64, IPN 55, IPN 46, and PAAc.

Fickian swelling behavior of the samples. The swelling kinetics of dynamic gel processes have been studied by many researchers, who suggested collective diffusion of polymer networks rather than simple diffusion of water as the swelling mechanism.[36,37] In the case of sorption of diffusing substance based on Fick's second law, the weight change of hydrogel slabs can be expressed by the following equation using Laplace transforms[38]:

$$\frac{M_t}{M_\infty} = 4\left(\frac{Dt}{l^2}\right)^{1/2} \times \left[\frac{1}{\pi^{1/2}} + 2\sum_{n=1}^{\infty}(-1)^2 \text{ierfc}\left(\frac{nl}{2(Dt)^{1/2}}\right)\right] \quad (2)$$

where M_t and M_∞ are the total amount of diffusing substance at time t and after infinite time ($t = \infty$) and D and l are diffusivity of the polymer networks and final equilibrium thickness of sample, respectively. This equation can be adopted differently according to the value of M_t/M_∞ as follows:[36]

$$\text{when } \frac{M_t}{M_\infty} > 0.6 \quad \frac{M_t}{M_\infty} = 1 - \frac{8}{\pi^2}\exp\left[\frac{-\pi^2 Dt}{l^2}\right] \quad (3a)$$

$$\text{and } 0 < \frac{M_t}{M_\infty} < 0.6 \quad \frac{M_t}{M_\infty} = 4\left(\frac{Dt}{\pi l^2}\right)^{1/2} \quad (3b)$$

Based on Fick's second law of diffusion, the transient changes of absorbed water in hydrogels with swelling for short times can be expressed as eq. (3b). From the theoretical prediction based on eq. (3b), hydrogels should initially absorb water in proportion to the square root of time if their swelling kinetics

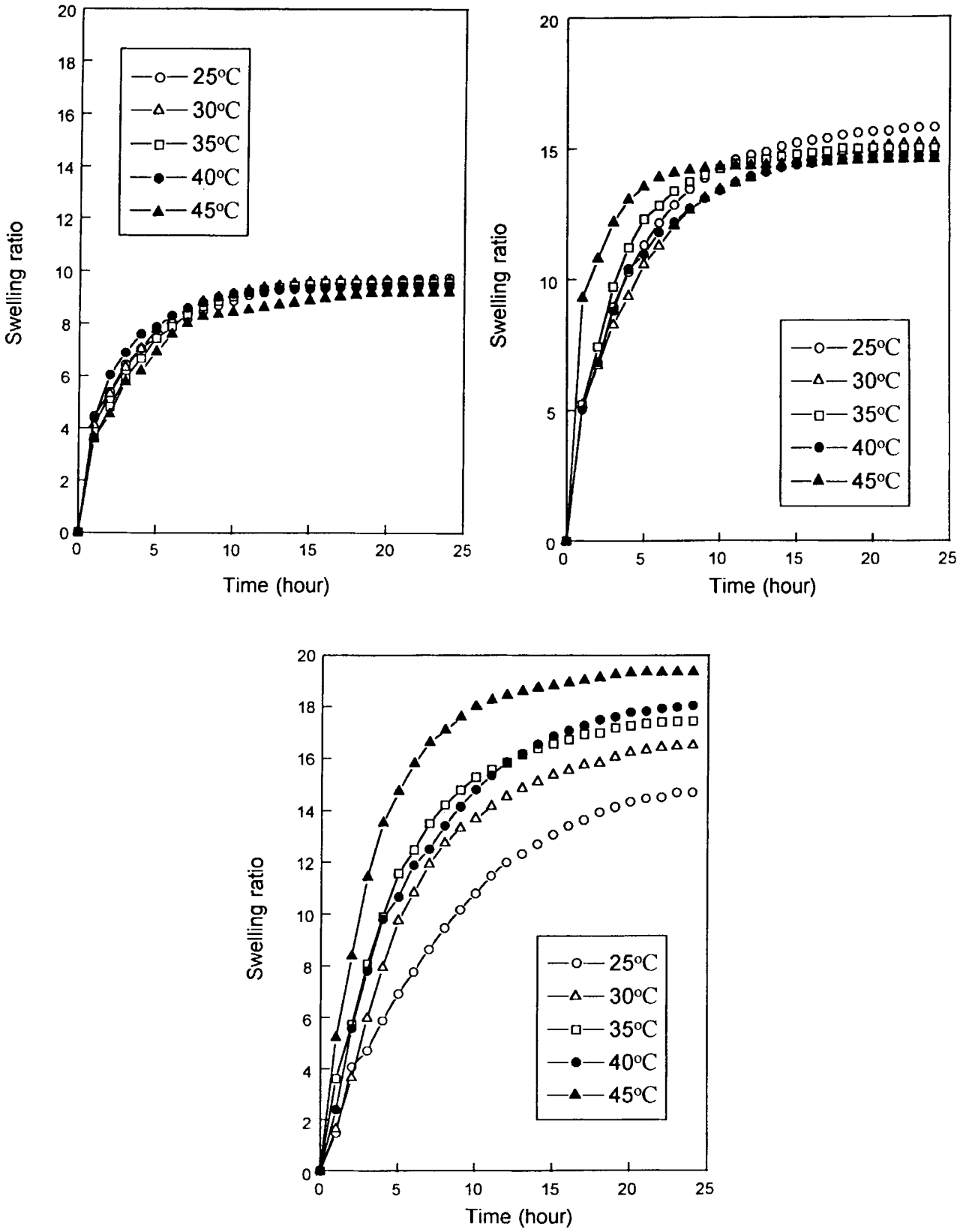

Figure 3 Swelling kinetics of (a) IPN 64, (b) IPN 55, and (c) IPN 46 at pH 7 at 25, 30, 35, 40, and 45°C.

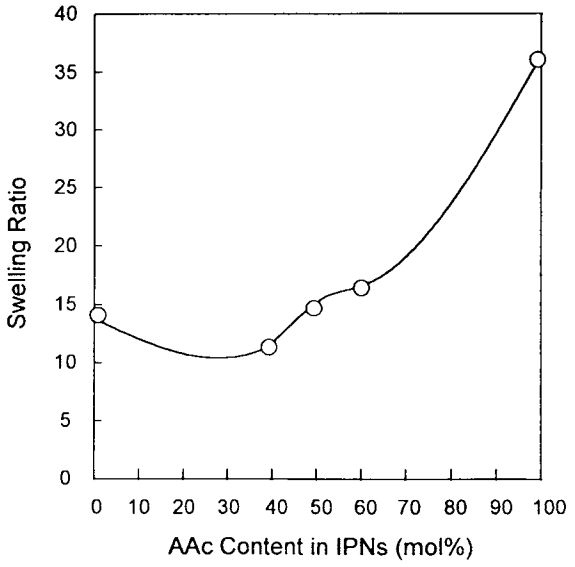

Figure 4 Effect of acrylic acid content in IPNs on swelling ratio at 30°C.

are dominated by Fickian mode. In Figure 6(a) and (b), all samples of IPN 64 and samples of IPN 55 at 25 and 30°C exhibit this relationship. In this case, the swelling kinetics for these hydrogels are apparently described by Fickian diffusion processes. However, the others showed non-Fickian sigmoidal patterns of Case II diffusion, which could imply an initial lag time due to other effects except diffusion. Figure 6(c) showed sigmoidal curves in the whole temperature range for IPN 46, which contained abundant PAAc in the hydrogel. During the swelling process in pH 7 buffer solution, which penetrates inside the dry hydrogel, carboxyl groups in PAAc form carboxylate ions and cause an increase in free volume by ionic repulsion, resulting in a drastic increase of absorbed water. In contrast, IPN 64, containing less PAAc than IPN 46, has little chance for ionic repulsion to take place, and the swelling process depends mainly on diffusion. In the more complicated case of IPN 55, which has the same amount of PVA and PAAc, dissociation of hydrogen bonding with temperature contributes to swelling behavior in addition to ionic repulsion. Assuming that all hydroxyl groups in PVA and carboxyl groups in PAAc are involved in the formation of hydrogen bonds, samples at 25 and 30°C swell through diffusion process only, because hydrogen bonds may not be destroyed at low temperature. Meanwhile, samples at 35, 40, and 45°C absorb water exhibiting sigmoidal patterns because the dissociation of hydrogen bondings at higher temperature generate carboxylate ions to cause ionic repulsion.

Temperature-dependent swelling behaviors at pH 7 are shown in Figure 7. Measurements were carried out with hydrogels after immersing the samples for 20 h at 25°C. The swelling ratios of IPN 64, IPN 55, and IPN 46 were 9.74, 15.21, and 15.73, respectively. As was seen in swelling kinetics experiment, the more PAAc contained in IPNs, the higher the obtained swelling ratio. The swelling ratio of IPN 46 increased with temperature, showing a positive temperature sensitive system, while IPN 64 and IPN 55 exhibited negative temperature sensitive systems. The swelling behavior of IPN 64 and IPN 55 are similar to that of virgin PVA hydrogels. This is ascribable mainly to the swelling tendency of PVA itself rather than polymer–polymer interactions between PVA and PAAc, such as hydrogen bonding and ionic repulsion in PAAc. PVA content, even in IPN 55 hydrogels, is supposed to be greater than the PAAc content because residual acrylic acid monomer, which did not take part in polymerization during the synthesis of the IPNs, was removed from IPNs by washing after the whole procedure. Accordingly, the swelling changes in IPN 46 must be related to the hydrogen bonding between two polymers and ionic repulsion of carboxylate ion produced due to the breakage of hydrogen bondings, while those in IPN 64 and IPN 55 depend mainly on swelling tendencies of PVA composition.

In addition to the temperature-dependent swelling behavior, stepwise swelling behavior at pH 7 with

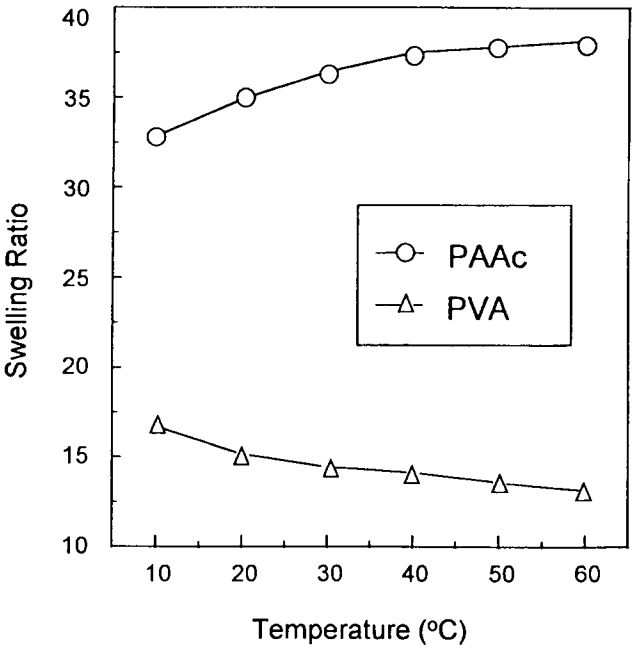

Figure 5 Swelling behaviors of cross-linked PVA and PAAc homopolymers at pH 7.

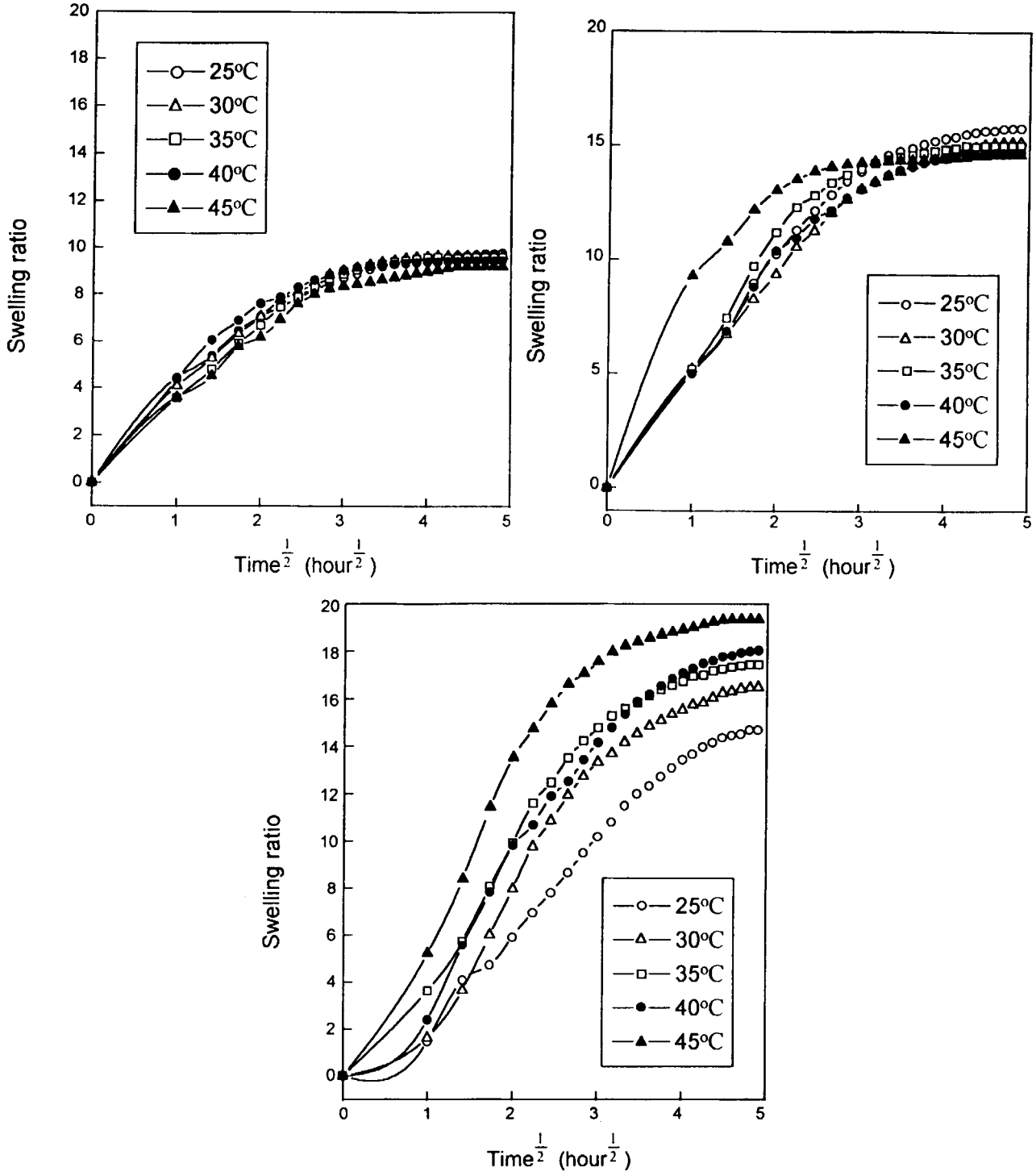

Figure 6 Swelling kinetics of (a) IPN 64, (b) IPN 55, and (c) IPN 46 against square root of time at pH 7 at 25, 30, 35, 40, and 45°C.

temperature alternating between 25 and 45°C was investigated to confirm the reversibility of the swelling process with temperature by measuring the swelling ratio every hour. Figure 8 presents such swelling data for IPNs samples. IPN 64 and IPN 55 show negative swelling changes as mentioned above. Their differences of swelling ratio range 0.9–0.5 and 0.6–1.3, respectively. The swelling degree of IPN 46

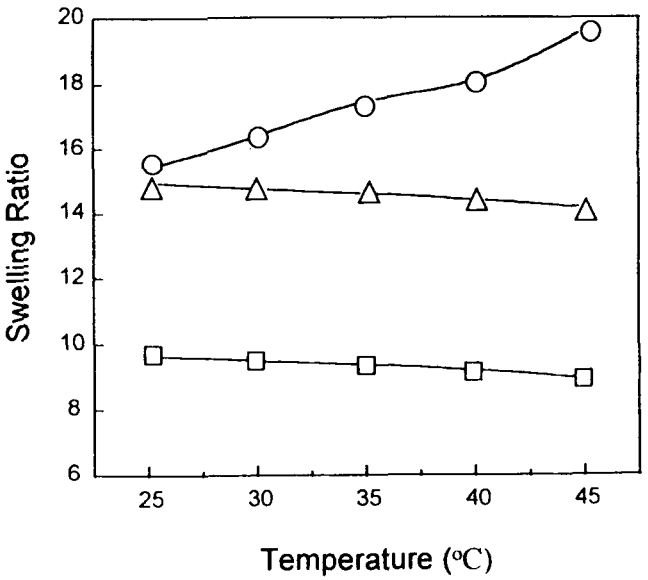

Figure 7 Temperature-dependent swelling behaviors of IPN 46 (○), IPN 55 (△), and IPN 64 (□) at pH 7 after EWC at 25°C.

is high at 45°C, while it is low at 25°C, and the difference of swelling ratio is pretty high ranging from 1.25 to 1.8. The total swelling ratio increases as time passes. This is attributed to the fact that the number of hydrogen bonds that may have been broken during the experiments are not fully recovered by temperature change.

Finally, pH-dependent swelling behaviors and stepwise swelling behaviors were observed at 35°C

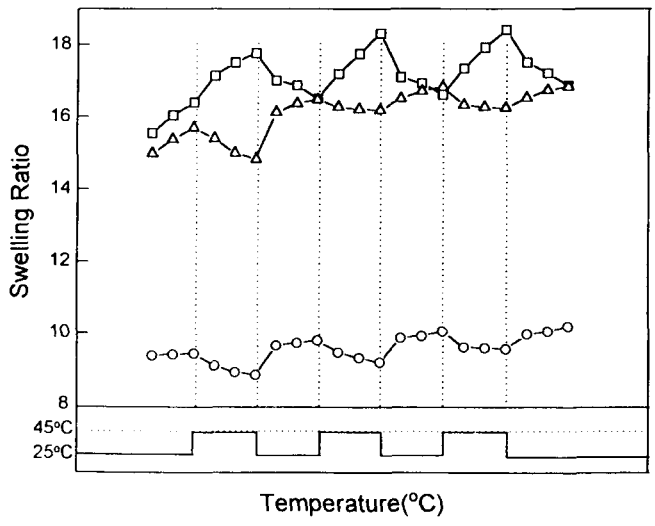

Figure 8 Temperature-dependent stepwise swelling behaviors of IPN 46 (○), IPN 55 (△), and IPN 64 (□) with alternating temperature between 25 and 45°C at pH 7.

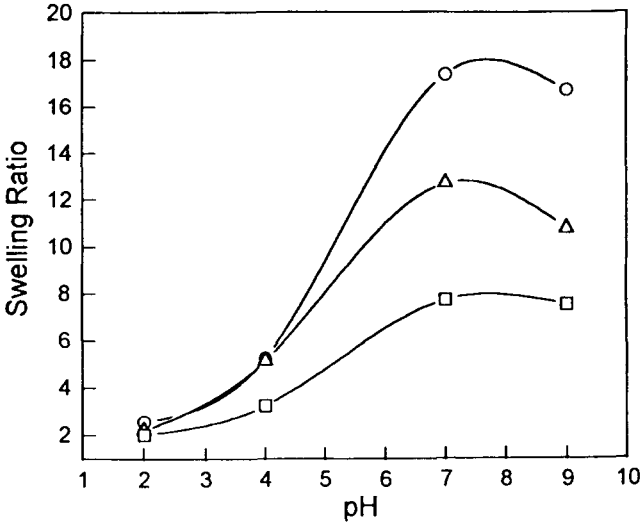

Figure 9 pH-dependent swelling behaviors of IPN 46 (○), IPN 55 (△), and IPN 64 (□) at 35°C.

with changes in pH (Figures 9 and 10). The pKa value of PAAc is 4.28.[39] Therefore at pH 2 and pH 4, PAAc is in the form of carboxylic acid that forms hydrogen bonds with hydroxyl groups in PVA and water and swells as temperature increases. However, at pH 7 and pH 9, PAAc forms carboxylate ion, which causes a repulsion between them. The swelling behavior of IPNs in buffer solutions of pH 2, 4, 7, and 9 are seen in Figure 9. At pH 2 and 4 buffer solutions, carboxyl groups in PAAc associate and form hydrogen bonding with PVA chains; thus, the swelling ratios are small. Carboxylate ions formed at pH greater than 4, however, induce the repulsion between them; and the hydrogen bondings between

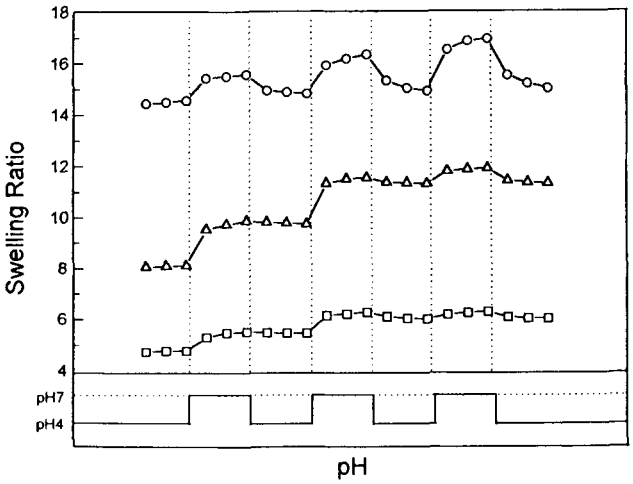

Figure 10 Temperature-dependent stepwise swelling behaviors of IPN 46 (○), IPN 55 (△), and IPN 64 (□) with alternating pH between 4 and 7 at 35°C.

PVA and PAAc should decrease, resulting in the increase of free volume in the matrix and, therefore, a rapid increase in swelling ratios. The small deswelling that occurred at pH 9 is considered to be due to an increase of ionic strength in buffer solution at pH 9, which might inhibit the polymer–water interactions inside the hydrogel matrix. Swelling ratios of IPN 64, 55 and 46 at pH 7, were 7.7, 12.7, and 17.4. This is in a good agreement with the result that increasing PAAc contents causes an increase of swelling ratio.

Oscillatory swelling behavior at 35°C with alternating pH between 4 and 7 is shown in Figure 10. Swelling ratio was measured in every hour, as pH switched every 3 h. Their swelling processes are proved to be reversible with pH changes, and the maximum difference of swelling ratio is up to 2.0 for IPN 46. Generally, the degree of swelling of samples depended on the amount of PAAc in the IPN and ranged from 5 to 17. However, swelling ratio differences between pH 4 and 7 were not significant, ranging from 0.9–1.8.

In summary, IPN hydrogels composed of PVA and PAAc show simultaneous pH and temperature sensitivity; moreover, their magnitude of swelling ratio was much greater than that we expected. Crosslinking degree of PAAc by UV irradiation was likely to be higher compared with the former methods we have tried. The positive and negative swelling behaviors could be switched by changing the composition of PVA and PAAc. Further experiments on drug release and solute permeation with these IPN hydrogels and membranes are ongoing, and these IPN hydrogels are expected to be a strong candidate for a self-regulating drug delivery system.

CONCLUSIONS

The IPN hydrogels composed of PVA and PAAc were successfully synthesized by a sequential method: UV polymerization of acrylic acid in the mixture of PVA and acrylic acid aqueous solution, followed by a freezing–thawing process to prepare elastic hydrogels. FTIR spectroscopy studies revealed the existence of hydrogen bonds between PVA and PAAc in IPNs. Swelling kinetics of IPNs showed that the higher the PAAc content in the IPN, the greater the swelling ratios were observed. Swelling kinetics plotted against square root of time showed both the Fickian and the non-Fickian behavior according to the composition of PAAc, which generates ionic repulsion and hydrogen bonding dissociation in IPNs. In an aqueous system, swelling behavior of polymeric gels by pH or temperature is related to the polymer–water and polymer–polymer interactions. The positive temperature-dependent swelling behavior was attributed to the formation and dissociation of the hydrogen bond between PVA and PAAc. IPN 46 exhibited positive swelling change with temperature, whereas IPN 64 and IPN 55 showed negative temperature sensitive systems due to strong interactions between PVA polymeric chains and weak chemical affinity between polymer–water as temperature increases. Temperature-sensitive stepwise swelling experiment showed that reversible swelling changes of all IPNs at temperature from 25 to 45°C, and their differences of swelling ratio were relatively high (about 1.0). Meanwhile, the different swelling behaviors of IPNs at various pH values were observed, and the pH-sensitive stepwise swelling behaviors were also obtained. PH-sensitive swelling behaviors were attributed mainly to ionic repulsion of carboxy groups in PAAc. The difference of swelling ratio of IPN 46 between pH 4 and 7 was as high as 2.0. Consequently, PVA/PAAc IPNs are sensitive to both pH and temperature and are strong candidates for drug delivery materials.

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