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Temperature Responsive Gels Based on Pluronic F127 and Poly(vinyl alcohol)

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ABSTRACT: Aqueous mixtures of Pluronic F127 and poly(vinyl alcohol) (20% polymer concentration in the system) were prepared and investigated by rheology and laser particle size distribution, in order to obtain temperature responsive gels for biomedical applications. The influence of the gelation conditions and system composition on the viscoelastic parameters and particle size distribution (which are very sensitive to the sol–gel transition process) was followed. The investigations realized at physiological temperature (37 °C) showed the thixotropic profile of the gels, the yield stress induced by the Pluronic presence, and the high elasticity evidenced in the creep-recovery tests.

1. INTRODUCTION

The gelation of aqueous solutions is presently one of the most exciting phenomena involved in various applications. The possibility of obtaining strong physical gels by cryogenic treatments of polymer solutions has been known since the 1970s,[1] but interest in the physical gelation of natural or synthetic polymers has received more attention in recent years.[2–4]

In thermoreversible gelation, a fluid solution is converted into a rigid medium of infinite viscosity, and this process can be reversed by changing temperature. Among several physical properties, viscoelastic properties change dramatically during the gelation process of a polymer solution: the system is liquid-like before cross-linking and after the gelation point its behavior becomes solidlike. Beyond the gelation point, a physical network is formed and it continuously develops with increasing cross-linking density.

Poly(vinyl alcohol) (PVA) is a water-soluble polymer having a large number of hydroxyl groups which give rise to inter- and intramolecular hydrogen bonding. Hydrogen bonds related to the number of hydroxyl groups have a strong influence on PVA properties, such as high water solubility, a wide range of crystallinity, and high crystal modulus.[5] PVA is a suitable polymer for biocompatible materials because its hydroxyl groups can establish interactions with other functional groups. At concentrations higher than 1%, PVA in aqueous solutions is in the entangled state and aggregated supramolecular structures can be formed. These structures contain amorphous and crystalline parts, the mutual ratio of which depends on experimental conditions during the preparation of solutions, and predominantly on the dissolution temperature. Aqueous PVA solution shows various rheological behaviors with regard to temperature, molecular weight, degree of hydrolysis, and so on.[6,7]

Since PVA is prepared via the hydrolysis of poly(vinyl acetate), during which the acetate groups are progressively replaced by hydroxyls, the degree of hydrolysis of PVA is an important molecular parameter. It is thus natural that the degree of hydrolysis has a significant influence on the rheological properties of PVA as the difference in chemical composition gives rise to different physical properties.

PVA in aqueous solutions exhibits a complexation ability with complementary polymers.[8] The final properties of a polymeric blend commonly depend on the properties of its polymeric components, the composition, and, mainly, the miscibility of the polymers. In some cases, by synergistic effects, such combinations may possess unique properties that are different from those of the individual components. Based on their unique properties, such as controlled swelling and release capabilities,[9] there is a great potential in utilizing these complexes in a wide range of biomedical applications (packaging, pharmaceutical preparations, surgical implants, controlled drug delivery systems, etc.).

Most PVA solutions like PVA/water are well-known to form thermoreversible gels by lowering the temperature. The stereoregularity of PVA affects the properties of a gel; i.e., aqueous solutions of syndiotactic PVA form hard elastic gels more easily than those of atactic PVA. The number of segments participating in the junction of PVA gel increases with syndiotacticity, and it is remarkably higher than the values of atactic PVA. The phase separation in PVA solutions is favored as syndiotacticity increases.[10] Also, the melting point of syndiotactic PVA gel is higher than those of atactic PVA gels.[11] A PVA gel was used for recovering copper(II) in aqueous solutions containing cupric sulfate (0.4–0.7 wt % in $CuSO_4 \cdot 5H_2O$).[12]

Pluronic F127, $H-(OC_2H_4)_n(OC_3H_6)_m(OC_2H_4)_n-OH$ (also known as poloxamer 407), is a triblock linear copolymer consisting of poly(ethylene oxide) (PEO) blocks (70%) and poly(propylene oxide) (PPO) blocks (30%). At low temperatures, PPO blocks have only weak hydrophobic properties. With increasing temperature, PEO groups are dehydrated and promote the aggregation to micelles. The hydrophobic PPO blocks are located in the micellar core, and the PEO blocks form the hydrophilic shell. A systematic study concerning the aggregation and phase diagrams of poly(ethylene oxide)–poly(propylene

oxide)—poly(ethylene oxide) triblock copolymers in aqueous solutions was reported by Wanka and co-workers.[13]

Pluronics are widely used in industry as detergents, dispersants, stabilizers, foaming agents, emulsifiers, etc. Pharmaceutical formulations based on Pluronic F127 present an excellent potential as drug delivery systems.[14−16] The incorporation of drugs into Pluronic micelles results in increased circulation time and enhanced metabolic stability because the outer hydrophilic PEO chains of Pluronic protect drugs from external conditions. Therefore, Pluronic micelles have attracted much attention as carriers for drug delivery.[17−19]

At high concentrations of copolymers, the aqueous solutions exhibit a dramatic change of the viscoelastic moduli and become gels (soft solids). Gels based on Pluronic F127 in which were incorporated different drugs have been used for treating dry eye syndrome, corneal edema, or red eye, as a synovial fluid or dental gel for treating patients with sensitive gum and teeth, as a vehicle for silver salts to treat burns or for intramuscular and subcutaneous administration of drugs, and as ocular delivery systems for pilocarpine,[20] for generating implants.[21] Higuchi et al.[22] achieved temperature-dependent detachment of cells from Pluronic gels. Also, Pluronic F127 was activated using carbonyldiimidazole and immobilized on the surface of a lysine-coated polystyrene tissue culture flask.[23]

In this study, new materials with improved characteristics are prepared by mixing PVA and Pluronic F127 in aqueous solutions and their rheological properties are investigated in order to design thermoresponsive materials with potential biomedical applications.

2. EXPERIMENTAL SECTION

2.1. Materials and Sample Formulation. The macromolecular compounds used in this study were PVA and Pluronic F127. Pluronic F127 ($M_w = 12.6 \text{ kg} \cdot \text{mol}^{-1}$) was purchased from Sigma and used as received without any further purification. PVA ($M_w = 76 \text{ kg} \cdot \text{mol}^{-1}$, 98−99% hydrolyzed) was purchased from LOBA Feinchemie AG (Austria Chemical Companies) and also used as received without any further purification. Deionized water was obtained with a Millipore-Q water purification system.

In the present paper, when we refer to a PVA/Pluronic F127 binary mixture, the index "1" corresponds to PVA, whereas the index "2" corresponds to Pluronic F127. Thus, w_2 represents the Pluronic F127 weight fraction in the polymer mixture. The concentration of polymer is expressed in weight percentage (% w/w).

PVA, 20%, was dissolved in Millipore water at 200 rpm and 80 °C for 1 day. Pluronic F127 was dissolved in Millipore water and stirred at 4 °C and 200 rpm in order to obtain a clear solution of 20%.

Before each rheological test, the Pluronic F127 solution was mixed with the PVA solution for obtaining a given weight fraction. PVA solution was cooled at 4 °C in an ice−water bath; then Pluronic F127 solution was gradually added. In order to ensure that the polymers were well mixed and the system became homogeneous, the entire solution was mixed at 4 °C for 60 min at 200 rpm.

Aqueous solutions with w_2 of 0.125, 0.25, 0.5, and 0.75 were prepared and freshly used for the investigations. In addition, samples of PVA ($w_2 = 0$) and Pluronic F127 ($w_2 = 1$) were investigated under the same experimental conditions.

2.2. Measurements. Aqueous solutions of the two polymers and their mixtures in the above specified ratios were tested on a Bohlin CVO rheometer equipped with a Peltier device for temperature control. The measurements were made with parallel-plane geometry with a gap of 500 μm, with the upper plate having a radius of 30 mm. Two milliliters of the homogeneous solution was poured on the lower plate of the rheometer at 4 °C for each determination. Prior to oscillatory measurements, the amplitude sweep tests were made at a constant frequency (ω) of 1 rad·s^{-1} at two temperatures, 5 and 37 °C, in order to establish the linear viscoelastic range for polymer solutions and gels.

The gelation process was followed in temperature sweep experiments (shear stress of 1 Pa and oscillation frequency of 1 rad·s^{-1}) at different heating rates of 0.5, 1, and 2 °C·min^{-1}; the starting temperature was 4 °C and the maximum temperature reached was 80 °C.

The gelation process was also investigated at the physiological temperature (37 °C) by using aqueous solutions prepared at 4 °C and kept at this temperature before the experimental tests were started. When the temperature of 37 °C was reached, the dynamic properties were followed as a function of time at a constant shear stress of 1 Pa and oscillation frequency of 1 rad·s^{-1}. Also, frequency sweep tests were carried out at 37 °C for the prepared gels in the frequency range from 0.01 to 100 rad·s^{-1} at a constant shear stress of 1 Pa. Also, steady shear measurements were performed at different temperatures.

The particle size distribution was determined by using a dynamic light scattering technique (Zetasizer Model Nano ZS (Malvern Instruments, U.K.)) with a red laser at 633 nm (He/Ne). The system uses noninvasive backscatter (NIBS) technology wherein the optics are not in contact with the sample, with backscattered light being detected. The use of NIBS technology reduces multiple scattering effects and consequently size distributions in higher concentrations of sample can be measured. This is the system for which the Mie method is applied over the whole measuring range from 0.6 nm to 6 μm.

3. RESULTS AND DISCUSSION

In the oscillatory deformation tests, the measured complex shear modulus (G^*) can be followed through its real and imaginary components, i.e.

$$G^*(t) = G'(t) + iG''(t) \tag{1}$$

where the elastic (or storage) modulus G' is a measure of the reversibly stored deformation energy and the viscous (or loss) modulus G'' represents a measure of the irreversibly dissipated energy during one cycle.

The loss factor, tan δ

$$\tan \delta = \frac{G''}{G'} \tag{2}$$

is a dimensionless parameter associated with the degree of viscoelasticity of the sample, being a measure of the ratio between the lost energy and the stored energy in a cyclic deformation.

Creep and recovery tests allow the differentiation between viscous and elastic responses when the viscoelastic material is subjected to a step constant stress (creep) and then the applied stress is removed (recovery). During the creep test, the stress causes a transient response, including the elastic and the viscous contributions. By following the recovery phase after the release of the applied stress, one can separate the total strain into the

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instantaneous elastic part, the recovered elastic part, and the permanently viscous part.

In a creep test at a constant stress τ is assigned and the time-related strain (γ) is measured. This can be expressed by the following relationship:
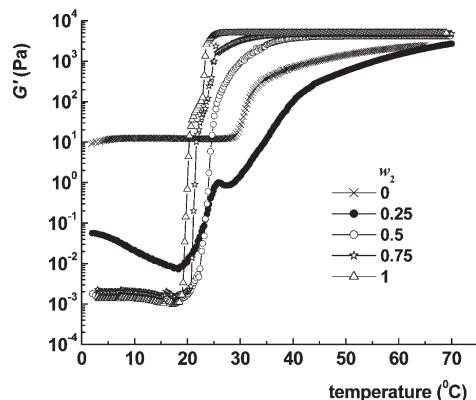
$$\gamma(t) = J(t)\tau \qquad (3)$$

Figure 1. Dependence of G' on temperature for samples with different compositions in the polymer mixture $(1\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}, 1\ \mathrm{rad}\cdot\mathrm{s}^{-1}, 1\ \mathrm{Pa})$.
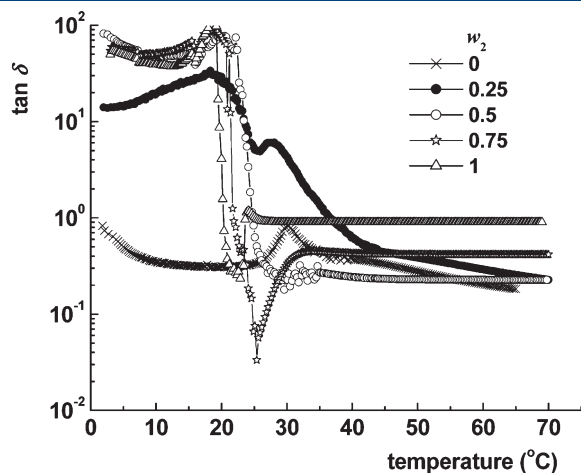

Figure 2. Variation of tan δ as a function of temperature for samples with different compositions in the polymer mixture $(1\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}, 1\ \mathrm{rad}\cdot\mathrm{s}^{-1}$ and $1\ \mathrm{Pa})$.

3.1. Effect of Polymer Mixture Composition on Sol—Gel Transition Temperature. Figure 1 shows the evolution of the elastic modulus, G', as a function of the temperature for a heating rate of $1\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}$, for 20% solutions of PVA ($w_2 = 0$), Pluronic F127 ($w_2 = 1$), and their mixtures ($w_2 = 0.25, 0.5,$ and 0.75). At low temperatures, excepting the PVA sample, all systems present a liquidlike behavior. The PVA sample has a high molecular weight and its 20% solution is a high entangled solution, and for this reason G' presents a high value. When adding Pluronic in the PVA solution ($w_2 = 0.25$), there is a high decrease of G' below 19 °C and its dependence on temperature is more pronounced.

By increasing the temperature above 19 °C, a discontinuity can be observed for the systems with $w_2 \geq 0.5$, and in a very narrow range of temperature, the viscoelastic moduli show a sharp increase. Thus, G' increases more than 7 orders of magnitude and reaches a constant level, denoted G'_∞. In the same time, G'' also exhibits a sharp discontinuity, but not so high as compared with G': the maximum increase up to G''_∞ is 4 orders of magnitude.

The loss tangent (tan δ) dependence on the temperature for different compositions of the polymer mixture offers a clear image of the phenomena (Figure 2). This behavior was attributed to a sol—gel tansition, when the system evolves from a liquidlike (high loss tangent values) state to a solidlike one (low tan δ values). PVA solution keeps nearly constant the viscous to elastic ratio; G' and G'' values are very close and no transition phenomena can be observed.

The sol—gel transition phenomenon is thermoreversible, but the gels need more time to reach the liquid state by decreasing the temperature; i.e., the same behavior can be found for a lower rate of cooling. If the gels with $w_2 \geq 0.5$ are suddenly cooled at 4 °C, in approximately 600 s they "melt". A higher content of PVA makes the thermal response slower in both senses: at increasing or at decreasing the temperature (Figures 1 and 2).

3.2. Effect of Heating Rate on Sol—Gel Transition Temperature. *3.2.1. Viscoelastic Behavior.* In order to illustrate the influence of the heating rate on the sol—gel transition phenomenon, Figures 3 and 4 show the evolution of the viscoelastic parameters for a constant polymer composition, $w_2 = 0.25$ at three different heating rates. The transition phenomenon occurs in a narrow temperature range for a low heating rate ($0.5\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}$), and it is very slow when the temperature increases faster, with $2\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}$.

For $w_2 = 0.25$, Figure 1 evidences a small maximum at 26.5 °C that could be explained by a competition between the formation
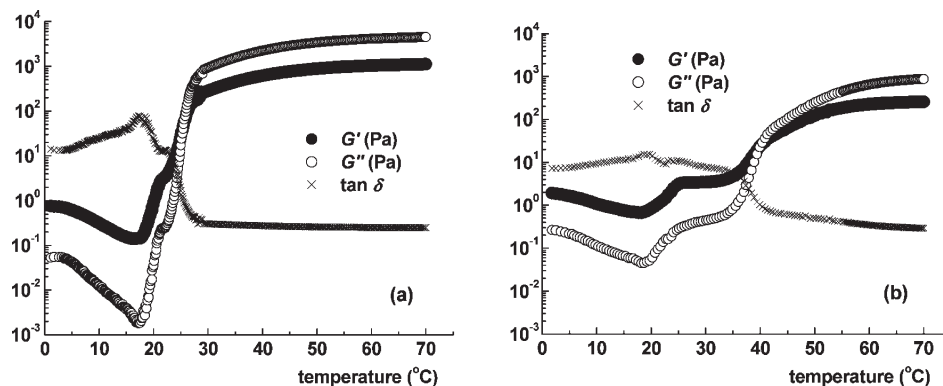

Figure 3. Variation of viscoelastic parameters $(G', G'',$ and tan $\delta)$ as a function of temperature $(1\ \mathrm{rad}\cdot\mathrm{s}^{-1}, 1\ \mathrm{Pa})$ for $w_2 = 0.25$ and different heating rates: (a) $0.5\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}$ $(G'_\infty = 4982\ \mathrm{Pa};\ G''_\infty = 1220\ \mathrm{Pa};\ G''_\infty/G'_\infty = 0.245)$ and (b) $2\ ^{\circ}\mathrm{C}\cdot\mathrm{min}^{-1}$ $(G'_\infty = 967\ \mathrm{Pa};\ G''_\infty = 267\ \mathrm{Pa};\ G''_\infty/G'_\infty = 0.276)$.

of the polymer/polymer interactions and their distruction due to thermal motion. The maximum is less pronounced for a smaller heating rate (0.5 °C·min^{-1} in Figure 3a): the chains have enough time to develop polymer/polymer interactions through $-OH$ groups and the system undergos a more sharp sol−gel transition. For a higher heating rate, i.e., 2 °C·min^{-1} (Figure 3b), this maximum is not evidenced and the sol−gel transition seems to have two steps: a first step up to 36 °C when the viscoelastic parameters slowly change with increasing temperature and a second one for which the change rate increases and the gelation occurs. A clearer image of the influence of the heating rate is depicted in Figure 4. The gel state is reached at lower temperature for a slow heating rate.

The most important characteristics of the gelation process for different heating rates and compositions in the polymer mixture are given in Tables 1 and 2. A stronger influence of the heating rate for higher content of PVA in the polymer mixtures can be
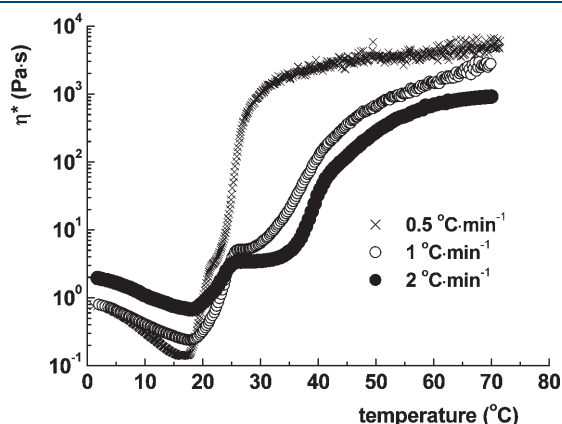

Figure 4. Variation of complex viscosity as a function of temperature for $w_2 = 0.25$ and different heating rates (1 rad·s^{-1}, 1 Pa).

observed. Also, the entangled solution of 20% PVA undergoes a transition (tan δ shows a maximum), but no gelation, in the investigated range of temperature $G' > G''$. The Pluronic based formulations give reversible gelation as a function of temperature.

3.2.2. Particle Size Distribution. Laser diffraction and scattering method is an useful method to estimate the particle size distribution for different polymer suspensions.[24,25] This is mainly due to the ease, noninvasive character, high reproducibility, and flexibility of the method for measuring the molecule and particle sizes, typically in the submicrometer region.[8] In the present study, dynamic light scattering measurements were carried out in order to evidence the gel formation in correlation with rheological measurements.

Figure 5 illustrates the size distribution of the mixture studied as well as the evolution of the particle size registered as a function of the temperature for a sample with $w_2 = 0.25$.

The dependence of the hydrodynamic radius on the temperature shows a small transition around 6 °C and a major change of the particle size around 21 °C when the gel is formed. Above this temperature the hydrodynamic radius of gyration cannot be measured because after the sol−gel transition there is only one giant macromolecule. The gel−sol transition requires more time in systems with a high PVA content.

For the sample with $w_2 = 0.75$, when the quantity of Pluronic is 3 times higher than that of PVA, the behavior is completely different. The gel formation is not at a very well defined temperature or domain. The permanent rearrangements due to dynamics of the physical interactions between the chains determine a nonmonotonic dependence of the particle sizes on temperature (see the inset in Figure 6). By cooling the system, after a heating cycle from 3 to 49 °C, clear evidence of the gel−sol transition can be observed around 19 °C (the phenomenon is delayed). The thermal treatment determines a monotonic dependence of the particle size on temperature when the system is submitted to a cooling process (Figure 7). Also, the thermoreversibility of the gelation process was evidenced more easily for this system.

Pluronics behave as nonionic surfactants and aggregate into micelles above a certain temperature, called the critical micellization temperature, which depends on the copolymer concentration.[26,27]

The increase of the temperature determines the breaking of the hydrogen bonds of PPO leading to an increase of hydrophobicity,[28] while the PEO remains hydrophilic. The spherical micelles of $H-(OC_2H_4)_n(OC_3H_6)_m(OC_2H_4)_n-OH$ have a hydrophobic core (PPO) and a hydrophilic shell (PEO) when the ratio n/m is greater than 0.5.[13]

Table 1. Transition Temperatures for Different Heating Rates ($G' = G''$ and tan $\delta = 1$)

w_2	0.5 °C·min^{-1}	1 °C·min^{-1}	2 °C·min^{-1}
0	28[a]	30[a]	32.2[a]
0.25	24.1	36.7	39.9
0.5	22.1	24.7	30.8
0.75	21.0	22.3	23.8
1	19.6	20.1	20.5

[a] The solution of 20% PVA undergoes a transition for which tan δ shows a maximum.

Table 2. Characteristics of the Gels Obtained in Temperature Sweep Tests (Heating Rate of 1 °C·min^{-1}) Compared with Those of Gels Obtained at 37 °C

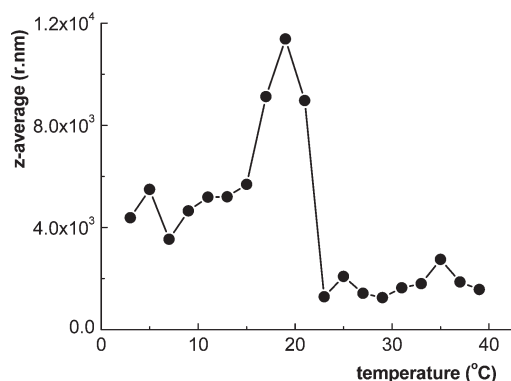|	1 °C·min^{-1}			37 °C				
w_2	G'_∞ (Pa)	G''_∞ (Pa)	G''_∞/G'_∞	G'_∞ (Pa)	G''_∞ (Pa)	G''_∞/G'_∞	yield stress (Pa)	hysteresis area (Pa·s^{-1})
0	3309	582	0.176	3535	1294	0.366	0.0	5133
0.125	3543	605	0.171	2000	650	0.325	0.69	7358
0.25	5899	922	0.156	3200	1090	0.315	1.11	14520
0.5	4183	950	0.227	2168	720	0.332	5	32236
0.75	4780	1987	0.416	7732	3294	0.426	7.15	13276
1	4930	4433	0.899	10597	9204	0.869	12.57	9805

Figure 5. Size distribution as well as evolution of particle size for aqueous solution of PVA/Pluronic F127 mixture with $w_2 = 0.25$ registered for different temperatures.
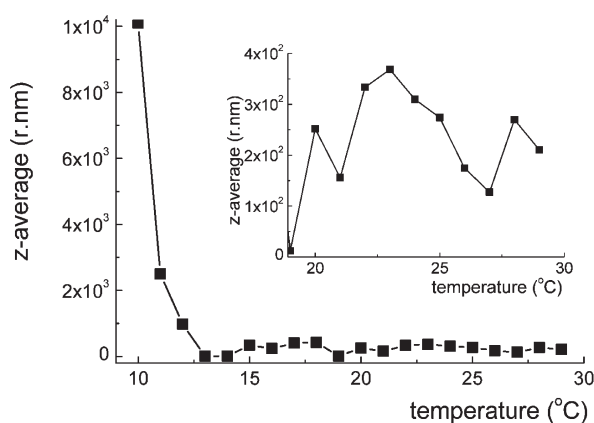

Figure 6. Size distribution and evolution of particle size of PVA/Pluronic F127 mixture of $w_2 = 0.75$ registered at increasing temperature. The inset shows an enlargement of the plot between 19 and 30 °C.
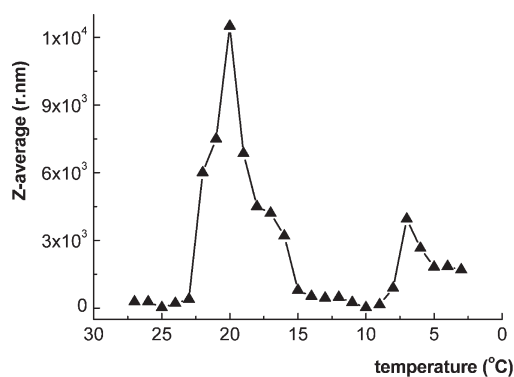

Figure 7. Size distribution and evolution of particle size of PVA/Pluronic F127 mixture of $w_2 = 0.75$ registered at decreasing temperature, after a heating cycle.

The observations concerning the gel formation through the evolution of the viscoelastic parameters as a function of the temperature are in good agreement with those resulted from the laser light diffusion method.

3.2.3. Investigation of Gelation at 37 °C. The rheological behavior of samples containing different contents of Pluronic in the PVA/Pluronic mixtures were investigated at body temperature (37 °C). First, the samples were put into the geometry of the
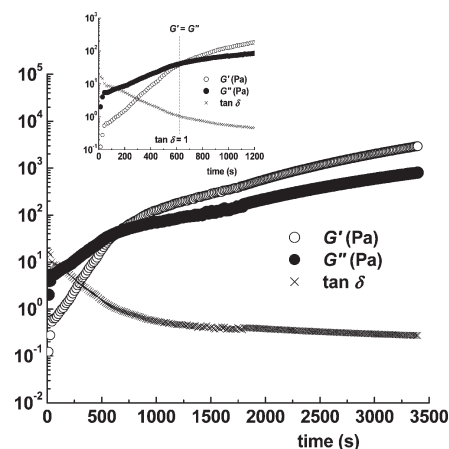

Figure 8. Gelation for the sample of $w_2 = 0.25$ at 37 °C. The sample was stored at 4 °C, and the test started when thermal equilibrium was reached. The inset shows an enlargement of the plot for the first 1200 s.
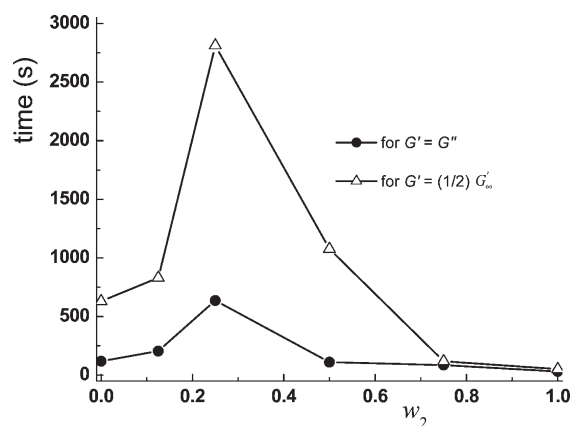

Figure 9. Dependence of the transition time as a function of binary PVA/Pluronic composition (w_2) at 37 °C. The samples were stored at 4 °C, and the measurement started when thermal equilibrium was reached.

rheometer at 4 °C and then heated to 37 °C when the evolution of the viscoelastic parameters was followed for an oscillation frequency of 1 rad·s^{-1} and a shear stress of 1 Pa. As an example, Figure 8 presents the variation of G', G'', and tan δ for the sample with $w_2 = 0.25$ after the temperature of 37 °C was reached.

One can observe that the viscoelastic moduli increase in time and after 621 s G' crosses G'' (tan δ =1); then G' exceeds G'' until both parameters reach a equilibrium value. The variation of time for which $G' = G''$ or $G' = (1/2)G'_\infty$ as a function of binary composition of PVA/Pluronic mixtures plotted in Figure 9 shows that high Pluronic content in the mixture determine a very fast gelation. The maximum crossover time was observed for the sample with $w_2 = 0.25$, considered an optimum composition for which the gelation slowly occurs at 37 °C.

Table 2 presents the values of G'_∞, G''_∞, and the G''_∞/G'_∞ ratio. By analyzing the final properties of the gels, it can be observed that for $w_2 = 0.25$ the gel presents the minimum value of the G''_∞/G'_∞ ratio, this composition being considered as optimum from the point of view of the gel application. Also, for a heating rate of 1 °C·min^{-1} the transition temperature is near the human body temperature (36.7 °C). In the case of gels with $w_2 = 0.75$ or $w_2 = 1$, even if the values of both moduli are high, the
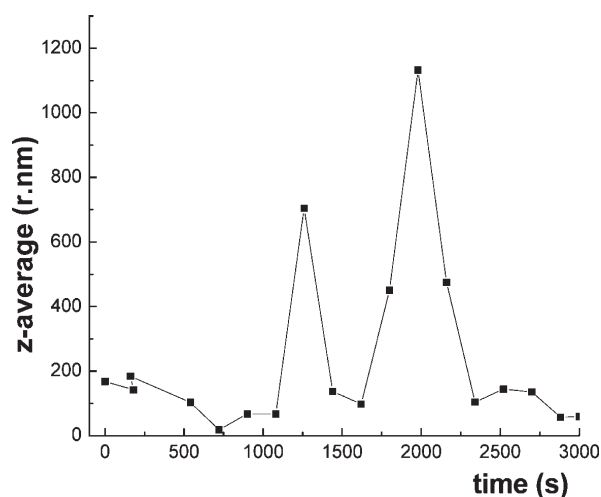
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Figure 10. Size distribution and evolution of particle size of PVA/Pluronic F127 mixture of $w_2 = 0.25$ registered at 37 °C as a function of time.
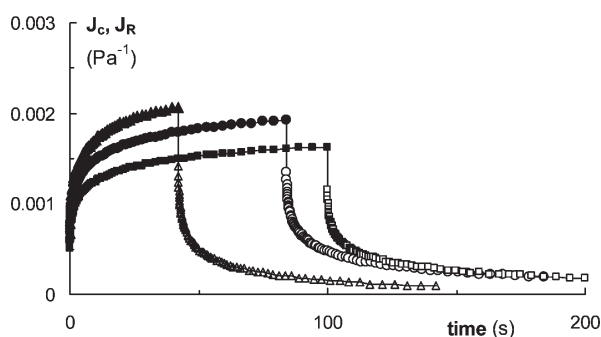

Figure 11. Creep (filled symbols) and recovery (open symbols) curves for the gel with $w_2 = 0.25$ at 37 °C for three successive cycles. The stress of 10 Pa was applied for 40, 80, and 100 s, respectively.

G''_∞/G'_∞ ratio is also high. In the absence of PVA, Pluronic gel is a weak gel.

Laser light diffusion method was also used to investigate the gelation at 37 °C. A clear curve was obtained only for $w_2 = 0.25$ (Figure 10); the gelation for other systems was very fast and it was not possible to perform the size distribution measurement.

3.2.4. Rheological Behavior of PVA/Pluronic F127 Gels at 37 °C. In frequency sweep tests, for the oscillation frequency in the $0.1-100$ rad·s^{-1} range, the viscoelastic moduli of the gels obtained at 37 °C keep nearly constant values (remain unchanged), $G' > G''$. The Cox—Merz rule is not applied when the shear viscosity as a function of the shear rate is represented on the same plot with the complex viscosity as a function of the oscillation frequency expressed in rad·s^{-1}. The complex viscosity is more than 10 times higher than the shear viscosity; η^* varies as $\omega^{-0.96}$ and $\eta^* \sim \dot{\gamma}^{-0.91}$.

The PVA gel does not present a yield stress at 37 °C. By increasing the Pluronic content, the yield stress increases (Table 2). Also, all gels show thixotropic behavior at 37 °C, with the maximum thixotropic area being observed for $w_2 = 0.5$ (Table 2).

In a creep test, when a step constant stress is applied for a period of time, the gel which is a viscoelastic material shows a time-dependent increase in strain. The material responds to the
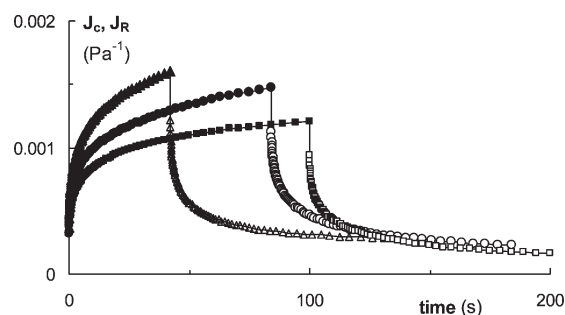

Figure 12. Creep (filled symbols) and recovery (open symbols) curves for the gel with $w_2 = 0.25$ at 37 °C for three successive cycles. The stress of 100 Pa was applied for 40, 80, and 100 s, respectively.

stress with a strain that increases until the material ultimately fails. Viscoelastic creep data can be presented by plotting the creep modulus (constant applied stress divided by total strain at a particular time) as a function of time.

Figures 11 and 12 show the curves which represent the viscoelastic response at two applied stresses (10 and 100 Pa, respectively) for the gel with $w_2 = 0.25$, obtained at 37 °C, in a creep test followed by recovery.

The creep curves comprise three parts: the instantaneous compliance, the retardation compliance, and the viscous compliance. When the applied stress is removed, the recovery process starts and first the instantaneous compliance is recovered, then the retardation compliance is recovered, and finally the viscous compliance remains. The high elasticity of the gels for the first cycle can be observed in Figure 11, where the recovered compliance represents 95% from the maximum value reached by the compliance in the creep test, while in Figure 12 this represents 90%.

4. CONCLUSION

Dynamic rheology is a powerful tool to monitor physical gelation and microstructural changes in a material without disruption of the microstructure if the experimental investigations are carried out at low deformations. The experimental determination and prediction of gelation are important for the processing of polymers, whereas the criticality of the phenomenon and the universality of the properties make gelation interesting from a fundamental point of view.

The main objective of the present paper was to prepare polymer gels which are responsive to environmental conditions. We have tried to identify thermally reversible formulations with low toxicity for pharmaceutical and medical purposes. The main interest was to realize a sol—gel transition around 37 °C, in a optimum time which should be on the order of hundreds of seconds.

The formulations based on PVA—Pluronic F127 having 20% polymer concentration in aqueous solution are in a liquidlike state at low temperature (the storage temperature was 4 °C). By increasing the temperature above 20 °C, they can undergo a transition to a solidlike behavior. The gelation achieved by increasing the temperature is reversible upon cooling, but the rate of transformation is slower in the second case. Physical interactions established very quickly by increasing the temperature need a longer period to vanish when the temperature decreases. Thus, the sol—gel transition for the gels is thermoreversible and its

kinetics is easily controlled by composition. The discussion was concentrated on the influence of the gelation conditions and system composition on the rheological parameters which are very sensitive to the sol−gel transition process. The observations concerning the gel formation resulted from the evolution of the viscoelastic parameter function of the temperature are in agreement with those obtained by the laser light diffusion method.

The gelation time and the rheological characteristics at 37 °C were also investigated. Thixotropic profiles showed a maximum area for the Pluronic weight fraction of 0.5, whereas the yield stress is dependent on the Pluronic content in the binary polymer mixture.

Creep and recovery tests allow the differentiation between viscous and elastic responses. The gels are highly elastic materials, and recovered compliance represents more than 90%.

By combining the properties of PVA and Pluronic F127, new materials with improved characteristics can be obtained. Temperature responsive gels based on these two polymers present a high dissolution capacity by dilution or cooling. They are liquids below room temperature and gels at body temperature. The PVA/Pluronic formulation with 0.25 weight fraction of Pluronic was considered as optimum from the point of view of the gel application (G''_∞ / G'_∞ ratio presents the minimum value).

Temperature sensitive gels represent one of the most interesting stimuli-responsive polymer materials used for drug delivery applications. The main reason for their use is the fact that body or body-site temperature may change with fever or local infections.

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