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ARTICLE

Comparison between Viscosity and Surface Tension of Polyvinylpyrrolidone/ Silver Nanoparticle (PVP/ AgNP) Solutions and Polyethylene Glycol/ Silver Nanoparticle (PEG/ AgNP) Solutions

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Abstract: In the present study, viscosity and surface tension of Polyvinylpyrrolidone (PVP) solutions and Polyethylene glycol (PEG) solutions in water and nitric acid with different concentrations (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 %) of silver nanoparticles have been measured. However, the relative viscosity of PVP/ AgNP solutions increased from 2.245 to 2.585 and the relative viscosity of PEG / AgNP solutions increased from 1.150 to 1.204. Viscosity is a significant parameter during the electrospinning process. While the surface tension of the PVP/ AgNP solutions has changed from 0.052 Nm^{-1} to 1.46 Nm^{-1}, it has changed from 0.063 Nm^{-1} to 0.160 Nm^{-1} for PEG / AgNP solutions. In this paper, attempts were made to obtain improvements to the properties of samples by comparing them with the pure samples of polymers. I think that there are personal errors in the measurements. These results can be used in medical, industrial applications and in scientific studies.

Keywords: Polyvinylpyrrolidone (PVP), Polyethylene glycol (PEG), Silver nanoparticles (AgNPs), Viscosity (η), Surface tension (γ).

1. Introduction

Silver nanoparticles (AgNPs) have received enormous attention of researchers due to their extraordinary defense against a wide range of microorganisms and due to their drug resistance against commonly used antibiotics [1]. Silver nanoparticles might exhibit additional antimicrobial capabilities not exerted by ionic silver, because of their small size and large surface to volume ratio, which lead to both chemical and physical differences in their properties compared with their bulk counterparts. AgNPs can be produced with various sizes and shapes depending on the fabrication method, among which the most widely used is the method of chemical reduction [2].

Polyvinylpyrrolidone (PVP) is a completely nontoxic polymer and has a long polyvinyl backbone [3]. It serves as an excellent capping agent, especially for noble metal particles. It is soluble in water as well as in physiological solutions [3]. Several studies have used Polyvinylpyrrolidone (PVP) as the carrier medium in various fields of application that include the formation of nanoparticles or nanofibers [4]. Noting that PVP has been recognized by FDA (Food and Drug Administration), USA, it is widely used as a drug carrier to increase drug solubility [4].

Polyethylene glycol (PEG) is a linear polyether of ethylene glycol [3]. PEG molecules are synthetic, highly water soluble, inert polymers that are produced in a wide range of molecular weights [5]. PEGs of various molecular weights have been widely used in consumer care products, such as laxatives, toothpaste and hair shampoos [5]. Polymer blends can be defined as physical mixtures of two or more homo-polymer or copolymers,

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which interact with secondary forces such as hydrogen bonding with no covalent bonding. Polymer blends are prepared by many methods. Among them, solution blending is very simple and brisk [6]. The polymer blends include both crystalline and amorphous polymers and the mixing of two chemically dissimilar polymers is miscible or independent on the thermodynamics of mixing [6]. The precise definition of viscosity is based on laminar, or nonturbulent, flow. Laminar flow is characterized by the smooth flow of the fluid in layers that do not mix. Turbulent flow, or turbulence, is characterized by eddies and swirls that mix layers of fluid together. Viscosity is, essentially, fluid friction. Like friction between moving solids, viscosity transforms kinetic energy of (macroscopic) motion into heat energy. Viscosity is a fundamental characteristic property of all liquids. Viscosity is a measure of internal resistance presence in each real fluid causing the fluid to oppose the dynamic variation of its motion and therefore restricting its tendency to flow. Dynamic viscosity is defined as the ratio of shear stress (force over cross sectional area) to the rate of deformation [7].

Liquids possess some properties, like density, viscosity, surface tension …etc. Also, the shape of drops is governed by the property of surface tension [8]. Surface tension is the property of the liquid that shows the strong cohesiveness of the liquid molecules, indicating the dissimilarity of the phases at the interface [9]. Surface tension, which is strongly influenced by the nature of the solvent from the polymer solution, is a very important factor in electrospinning. This is why the correct selection of the solvent is critical, not only to obtain a homogeneous solution of the polymer, but also to obtain the right surface tension [9].

2. Experimental

2.1 Samples

PVP, PEG and Ag nanoparticles used in the present work were supplied by Sigma-Aldrich, GmbH. The two types of polymer solutions (PVP solutions and PEG solutions) with different concentrations (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 %) of silver nanoparticles were prepared by dissolving a polymer in twice-distilled water at room temperature[10] and the different concentrations of silver nanoparticles were dissolved in the same amount of nitric acid, then mixed with polymer solutions [10].

2.2 Measurements

2.2.1 Viscosity Measurements

In determining the efflux time of the solutions, the methodology stated by ASTM (1989) was used. The efflux time for solvents and polymers/ silver nanoparticle solutions was measured by glass capillary viscometer. The measured values have been expressed in terms of relative (η_r), specific(η_{sp}) and intrinsic $([\eta])$ as follows [11]:

$$\eta_r = \frac{t_{solution}}{t_{solvent}} \quad (1)$$

$$\eta_{sp} = \eta_r - 1 \quad (2)$$

$$[\eta] = \lim_{C\to\infty} \frac{\eta_{sp}}{C} \quad (3)$$

where C is the mass concentration of Ag nanoparticles in nitric acid [11].

2.2.2 Surface Tension Measurement

Using the drop- weight method, a counted number of drops were collected and the average mass of a drop found. The mean radius of the orifice was determined, then the surface tension against air was expressed by the measured values as follows [12]:

$$\gamma = \frac{mg}{2\pi r} \quad (4)$$

where m = average mass of a drop, g = acceleration of gravity and r = internal radius of the tube used (4mm). All measurements have been conducted at a temperature of 25 (± 0.1) ^{o}C.

Surface tension force (F) and surface tension energy (E) can be calculated by Eq. (5) and Eq. (6), respectively [13].

$$F = 4 \pi r \gamma \quad (5)$$

$$E = \gamma A \quad (6)$$

where A is the surface area of the drop.

3. Results and Discussion

3.1 Viscosity

Fig. 1 shows a plot of PVP and PEG relative viscosity values against mass concentration of silver nanoparticles. This plot demonstrates that viscosity increases monotonically with the increase of concentration. Furthermore, the plot indicates that the viscosity values of PEG solutions are less than the viscosity values of PVP solutions. Thus, it is clear that silver nanoparticle concentrations produce changes in the viscosity of all solutions. Viscosity is a significant parameter during the electrospinning process [14]. When viscosity is increased, which means that there will be a higher amount of polymer chain entanglement in the solution, the charges on the electrospinning jet will be able to fully stretch the solution with the solvent molecules distributed among the polymer chains [15]. This is probably due to the greater resistance of the solution to be stretched by the charges on the jet [15].

The plots in Fig. 2 agree with Schulz-Blaschke equation for PVP solutions and PEG solutions.

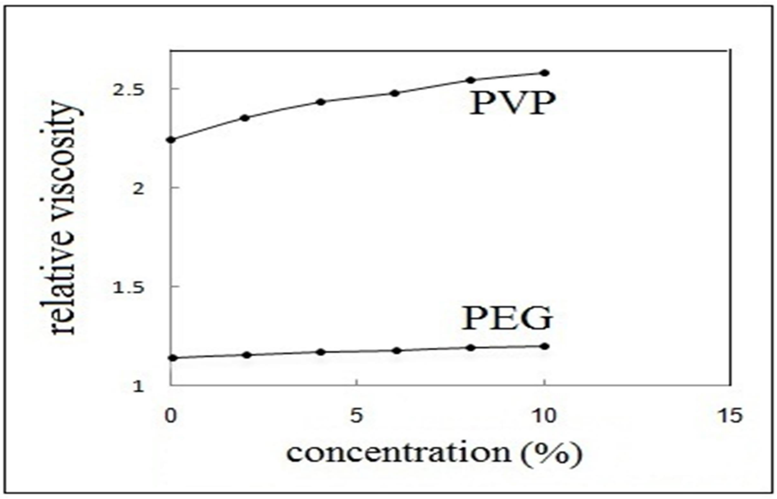

FIG. 1. Relative viscosity *vs*. concentration of Ag nanoparticles for PVP solutions and PEG solutions at 25°C.

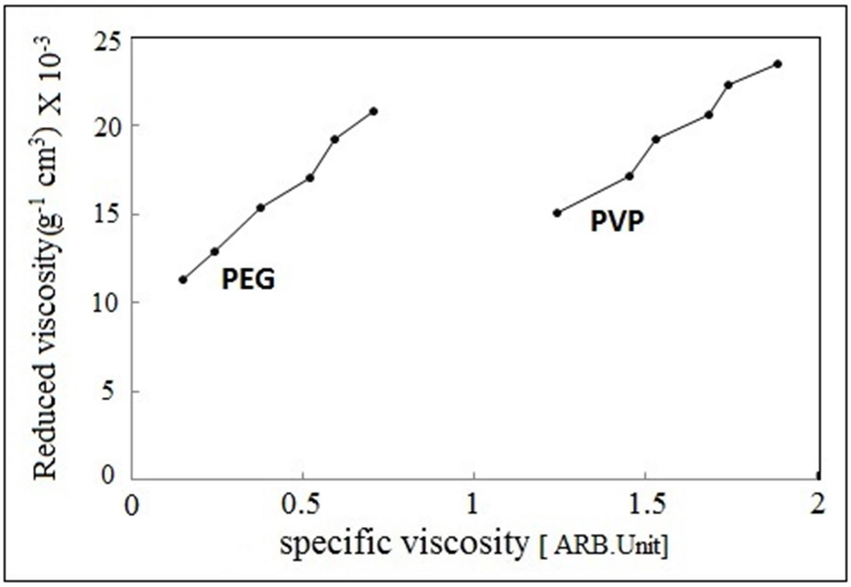

FIG. 2. Reduced viscosity *vs*. specific viscosity for PVP solutions and PEG solutions at 25°C.

$$\eta_{red} = [\eta] + K_{sb} [\eta] \eta_{sp} \qquad (7)$$

where η_{red} = reduced viscosity, $[\eta]$ = intrinsic viscosity and K_{sb} = Schulz-Blaschke constant [11]. Fig. 3 shows a plot of Schulz–Blaschke constant k_{sb} values against flow time. It reflects how far the values of Schulz–Blaschke constant of the solutions increase with increasing the flow time. This could be attributed to scission on the polymer chains [11].

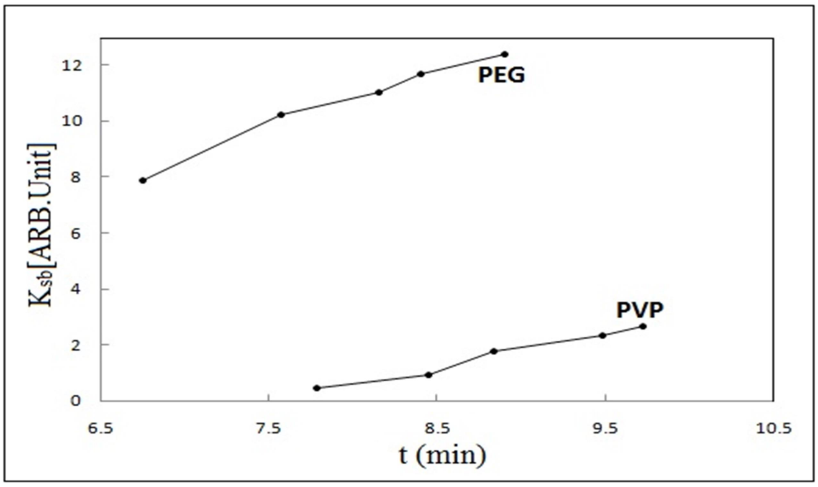

FIG. 3. Schulz-Blaschke constant *vs*. flow times of solutions.

3.2 Surface Tension

In Fig. 4, there are plots showing the surface tension of PVP/ AgNP solutions and PEG/ AgNP solutions against mass concentration of silver nanoparticles, where the solution surface tension increases with increasing the concentration of silver nanoparticles, but the surface tension values of PEG solutions are greater than the surface tension values of PVP solutions [16, 17].

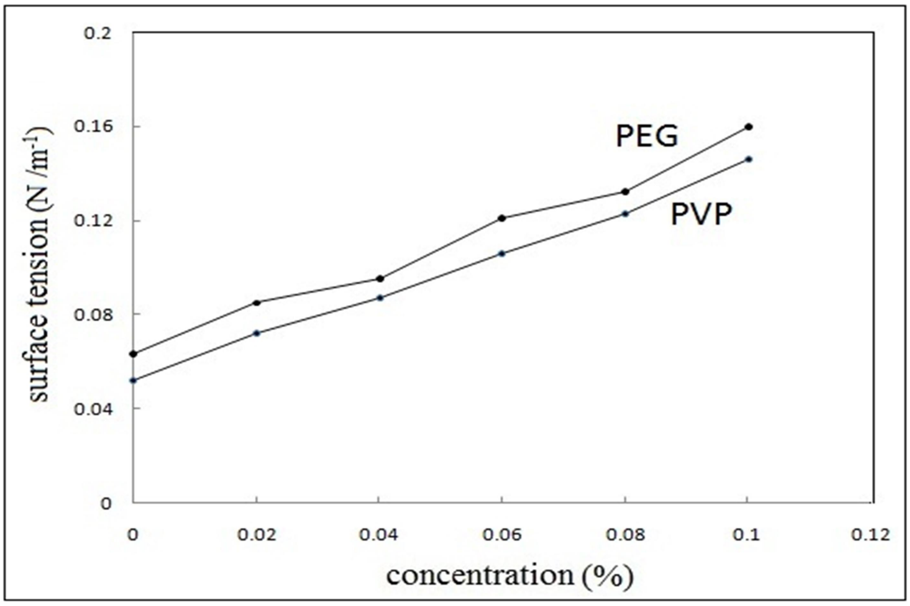

FIG. 4. Surface tension *vs*. concentration of Ag nanoparticles for PVP solutions and PEG solutions at 25°C.

Since the surface tension of the solutions increases with increasing the concentration of silver nanoparticles as shown in Fig. 4, the surface tension force and surface tension energy increase as shown in Fig. 5 and Fig. 6, respectively. As a result, a strong, cohesive force is exerted between the molecules, resulting in a higher surface tension of the solution [18]. When the concentration increases, the mean spacing between the molecules and the nanoparticles reduces [18]. Hence, an attractive van der Waals force is employed over the electrostatic repulsion force between the molecules, which increases the surface tension of the solution [18].

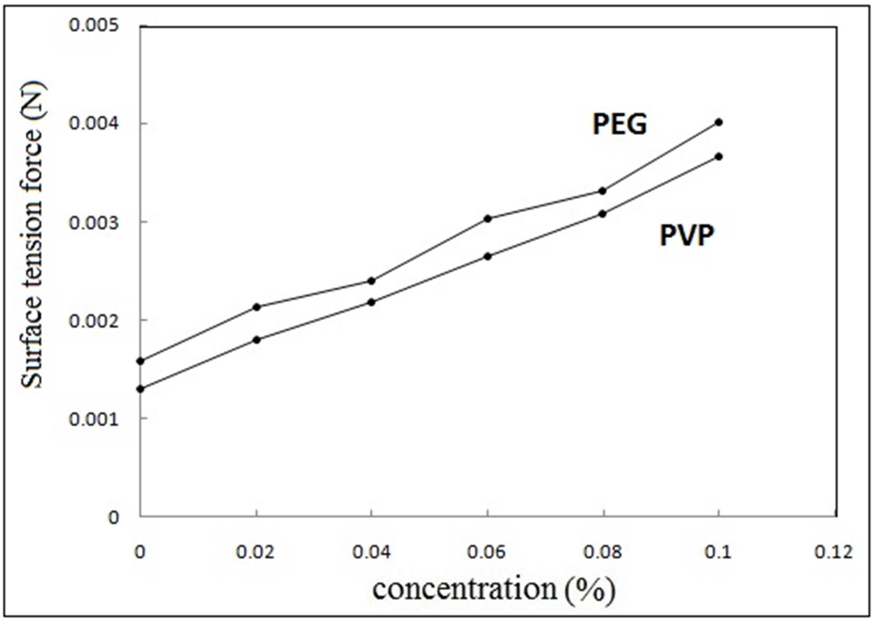

FIG. 5. Surface tension force *vs*. concentration of Ag nanoparticles for PVP solutions and PEG solutions at 25^{o}C.

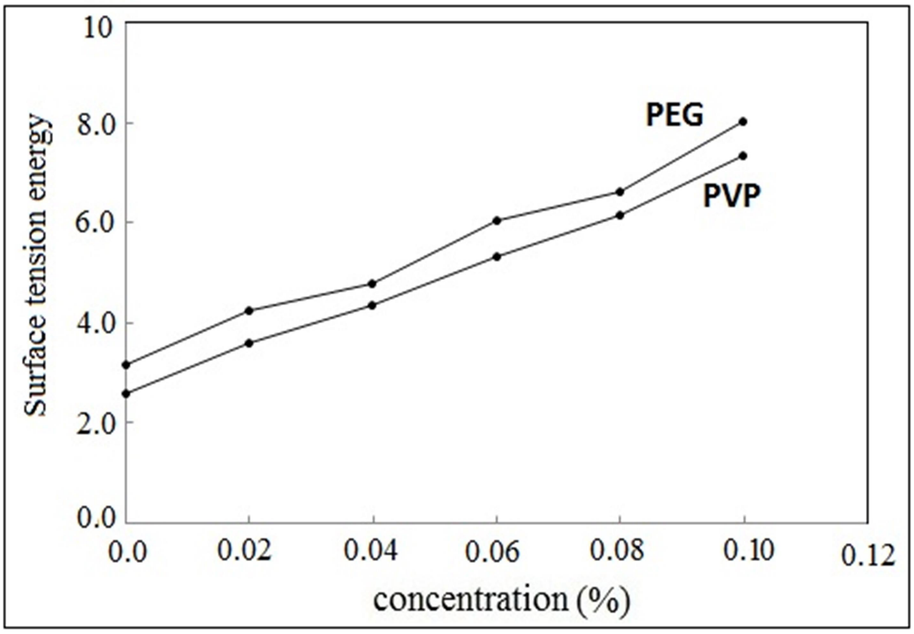

Fig. 6. Surface tension energy *vs*. concentration of Ag nanoparticles for PVP solutions and PEG solutions at 25^{o}C.

4. Conclusion

The graphics of the viscosity of solutions indicate increased viscosity with increased concentration, but PVP/ AgNP solutions have viscosities higher than those of PEG / AgNP solutions, noting that viscosity is a significant parameter during the electrospinning process.

While the surface tension of PEG/AgNP solutions is greater than the surface tension of PVP/AgNP solutions, as the surface tension increases by increasing the concentration, van der Waals forces are exerted, which increases the surface free energy and results in the enhancement of surface tension. These properties can be used in medical, industrial applications and scientific studies.

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