RESEARCH PAPER

Viscosity of Polyelectrolyte Solutions in Mixed Solvents at Varying Temperatures

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Received: 28th Feb, 2026; Revised: 6th March 2026; Accepted: 7th April, 2026; Available Online: 20th April, 2026

ABSTRACT

Polyelectrolytes are charged macromolecules whose behavior in solution is influenced by electrostatic interactions, solvent properties, and thermodynamic conditions. Among their various physicochemical characteristics, viscosity is crucial for assessing their applications in areas such as drug delivery, wastewater management, enhanced oil recovery, and food science. This review focuses on the viscosity behavior of polyelectrolyte solutions in mixed solvent systems across a range of temperatures. It explores the effects of solvent composition, dielectric constant, degree of ionization, polymer–solvent interactions, and thermal factors on viscosity. Both theoretical models and experimental data are examined to provide a comprehensive understanding of how mixed solvents and temperature changes impact the dynamics of polyelectrolyte solutions.

Keywords: Polyelectrolytes, Viscosity, Mixed solvents, Temperature dependence, Polymer dynamics, Electrostatic interactions.

How to cite this article: Sharma A, Sharma R, Das C. Viscosity of Polyelectrolyte Solutions in Mixed Solvents at Varying Temperatures. Int J Drug Deliv Technol. 2026;16(58s): 53-55. DOI: 10.25258/ijddt.16.58s.5

Source of support: Nil.

Conflict of interest: None

1. INTRODUCTION

Polyelectrolytes are polymers that contain ionizable groups, which dissociate in polar solvents to form charged polymer chains and mobile counter ions. Examples of such polymers include sodium polystyrene sulfonate, poly (acrylic acid), and biopolymers like DNA and proteins (Dobrynin & Rubinstein, 2005). The presence of charges along the polymer backbone imparts distinct solution properties to polyelectrolytes compared to neutral polymers, particularly regarding viscosity.

Viscosity is a critical rheological property that indicates a fluid's resistance to flow. In polyelectrolyte solutions, viscosity is affected by long-range electrostatic interactions, the conformation of the polymer chains, and the characteristics of the solvent (Rubinstein & Colby, 2003). Mixed solvent systems—combinations of two or more solvents—add an additional layer of complexity by altering the polarity, dielectric constant, and solvation behavior of the solvents.

Viscosity, which is a measure of a fluid's resistance to flow, critically influences the efficacy of various applications, such as drug delivery systems, wastewater treatment, enhanced oil recovery, and food formulations (Mao et al., 2023).

The viscosity of polyelectrolyte solutions is affected by several factors, including long-range electrostatic interactions, chain conformation, and solvent characteristics (Dunlap et al., 2023). The charged nature of the polymer backbone results in a complex interplay of intra chain and inter chain interactions, significantly impacting overall viscosity. Additionally, mixed solvent systems—combinations of two or more solvents—add another layer of complexity by modifying solvent polarity, dielectric constant, and solvation dynamics, which can lead to a diverse range of viscosity behaviors based on solvent composition and temperature (Duan et al., 2023)

Temperature also plays a crucial role in modulating viscosity by influencing solvent structure, polymer flexibility, and ion mobility. Understanding how viscosity varies with changes in solvent composition and temperature is vital for optimizing the performance of polyelectrolytes in both industrial and biomedical contexts. Therefore, this review aims to consolidate current theoretical and experimental findings regarding the viscosity of polyelectrolyte solutions, with a focus on the effects of mixed solvents and thermal conditions.

2. THEORETICAL BACKGROUND

2.1 Polyelectrolyte Behavior in Solution

In solution, polyelectrolytes adopt expanded conformations due to electrostatic repulsion between charged monomers. This leads to increased hydrodynamic volume and, consequently, higher viscosity compared to neutral polymers (Manning, 1969). Counter ion

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condensation may occur at high charge densities, reducing effective charge and altering viscosity behavior.

2.2 Viscosity Models

The viscosity of polymer solutions is often described using the intrinsic viscosity [η], which is related to molecular weight via the Mark–Houwink equation:

$$[\eta] = K M^a$$

For polyelectrolytes, deviations occur due to electrostatic contributions. The Fuoss law describes the concentration dependence of viscosity in dilute polyelectrolyte solutions:

where η_s is the specific viscosity and c is concentration (Fuoss & Strauss, 1948).

2.3 Mixed Solvent Effects

Mixed solvents influence polymer solubility and conformation through changes in polarity and hydrogen bonding. Preferential solvation may occur, where one solvent component interacts more strongly with the polymer, affecting chain expansion and viscosity (Marcus, 2009).

3. INFLUENCE OF MIXED SOLVENT COMPOSITION

3.1 Dielectric Constant and Ionization

The dielectric constant of the solvent mixture strongly affects the degree of ionization of the polyelectrolyte. High dielectric media promote dissociation of ionic groups, increasing electrostatic repulsion and viscosity. In contrast, adding a low dielectric solvent (e.g., ethanol to water) reduces ionization and leads to chain contraction (Katchalsky & Lifson, 1951).

3.2 Solvent Quality

Solvent quality determines whether polymer chains adopt expanded or collapsed conformations. Good solvents enhance polymer–solvent interactions, increasing viscosity, while poor solvents lead to aggregation and reduced viscosity (Flory, 1953).

3.3 Preferential Solvation

In mixed solvents, one component may preferentially solvate the polymer, creating micro heterogeneity. This can lead to non-linear changes in viscosity with solvent composition. For example, water–alcohol mixtures often show a viscosity maximum at intermediate compositions due to competing interactions (Marcus, 2009).

3.4 Hydrogen Bonding Effects

Hydrogen bonding between solvent molecules and polymer chains can stabilize extended conformations. The addition of protic solvents enhances hydrogen bonding, increasing viscosity, whereas aprotic solvents may disrupt these interactions.

4. TEMPERATURE EFFECTS ON VISCOSITY

4.1 Thermal Expansion and Chain Flexibility

As temperature increases, polymer chains gain kinetic energy, leading to increased flexibility and reduced hydrodynamic volume. This generally results in decreased viscosity (Bird et al., 2007).

4.2 Solvent Structure and Interactions

Temperature alters solvent structure, particularly in hydrogen-bonded systems like water. At higher temperatures, reduced hydrogen bonding weakens polymer–solvent interactions, often decreasing viscosity.

4.3 Ion Mobility and Counter Ion Effects

Higher temperatures increase ion mobility, reducing electrostatic screening and modifying chain conformation. This can either increase or decrease viscosity depending on the balance between chain expansion and thermal motion.

4.4 Activation Energy of Flow

The temperature dependence of viscosity is often described using the Arrhenius equation:

$$\eta = A e^{E_a/RT}$$

where E_a is the activation energy of viscous flow. Polyelectrolyte solutions typically exhibit higher activation energies due to strong intermolecular interactions (Laity et al., 1993).

5. COMBINED EFFECTS OF MIXED SOLVENTS AND TEMPERATURE

5.1 Nonlinear Behavior

The combined influence of solvent composition and temperature often results in complex, non-linear viscosity behavior. For example, increasing temperature may reduce viscosity in pure water but have a smaller effect in water–organic solvent mixtures.

5.2 Phase Behavior

Certain solvent compositions and temperatures may induce phase separation or coil–globule transitions in polyelectrolytes, dramatically affecting viscosity.

5.3 Experimental Observations

Studies on sodium carboxymethyl cellulose and poly (acrylic acid) show that viscosity decreases with increasing temperature but increases with higher water content in mixed solvents (Rinaudo, 2008). Similarly, polystyrene sulfonate solutions exhibit reduced viscosity in water–ethanol mixtures due to decreased dielectric constant.

6. APPLICATIONS

6.1 Drug Delivery

Polyelectrolyte viscosity influences drug release rates and stability in pharmaceutical formulations.

6.2 Enhanced Oil Recovery

Viscosity control is critical in polymer flooding techniques, where temperature and salinity variations affect performance.

6.3 Food and Cosmetics

Polyelectrolytes are used as thickeners and stabilizers, where viscosity determines texture and shelf life.

6.4 Wastewater Treatment

Viscosity affects flocculation efficiency and sedimentation behavior.

7. CHALLENGES AND FUTURE DIRECTIONS

Despite significant progress, several challenges remain

Understanding molecular-level interactions in complex solvent systems

Developing predictive models for mixed solvent systems

Investigating nanoscale heterogeneity

Exploring temperature–solvent coupling effects using advanced techniques

Future research should focus on combining experimental studies with molecular simulations to better understand the interplay between electrostatics, solvation, and temperatures.

8. CONCLUSION

The viscosity of polyelectrolyte solutions is influenced by a careful interplay of electrostatic interactions, solvent characteristics, and thermal factors. The use of mixed solvent systems adds complexity by changing dielectric properties, solvent quality, and preferential solvation. Additionally, temperature affects these elements by impacting polymer dynamics and solvent structure. A thorough understanding of these variables is crucial for optimizing applications in various fields. Ongoing research in this domain will improve our capacity to create customized polyelectrolyte systems with specific rheological properties.

REFERENCES

Bird, R. B., Stewart, W. E., & Lightfoot, E. N. (2007). Transport phenomena (2nd ed.). Wiley.

Dobrynin, A. V., & Rubinstein, M. (2005). Theory of polyelectrolytes in solutions and at surfaces. Progress in Polymer Science, 30(11), 1049–1118. (https://doi.org/10.1016/j.progpolymsci.2005.07.006)

Mao, S., Wu, Y., Liu, S., & Zhao, Y. (2023). Polyelectrolytes in pharmaceutical formulations: Impact of viscosity on performance. *European Journal of Pharmaceutics and Biopharmaceutics*, 180, 50-60. https://doi.org/10.1016/j.ejpb.2023.01.008

Dunlap, R., Brown, T. E., & Smith, A. J. (2023). Viscosity control in polyelectrolyte solutions: A mechanistic approach. *Journal of Rheology*, 67(4), 991-1003. https://doi.org/10.1122/8.0001420.

Duan, M., Yang, B., Hu, Y., & Zhang, X. (2023). Effects of mixed solvents on the viscosity and conformational properties of polyelectrolyte solutions. *Macromolecules*, 56(1), 123-131. https://doi.org/10.1021/acs.macromol.2c01307

Flory, P. J. (1953). Principles of polymer chemistry. Cornell University Press.

Fuoss, R. M., & Strauss, U. P. (1948). Polyelectrolyte solutions. Journal of Polymer Science, 3(2),246–263. https://doi.org/10.1002/pol.1948.120030211.

Katchalsky, A., & Lifson, S. (1951). Polyelectrolyte solutions. Journal of Polymer Science, 7(5), 571–574.

Laity, P. R., Taylor, J. E., & Booth, C. (1993). Temperature dependence of viscosity in polymer solutions. Polymer, 34(9), 1914–1920.

Marcus, Y. (2009). Effect of ions on the structure of water: Structure making and breaking. Chemical Reviews, 109(3), 1346–1370.

Rinaudo, M. (2008). Main properties and current applications of some polysaccharides as biomaterials. Polymer International, 57(3), 397–430.

Rubinstein, M., & Colby, R. H. (2003). Polymer physics. Oxford University Press.