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ARTICLE

Exploring the Density, Viscosity and Physico-chemical Characteristics of Dextran in Aqueous Glycine: An Ultrasonic Analysis

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Abstract: The density (ρ), viscosity (η), and ultrasonic speed (U) of the systems of dextran with glycine in the aqueous medium were measured at 30, 35, 40, 45, and 50 ^{0}C. Ultrasonic interferometers were used to measure the ultrasonic speed at four distinct frequencies: 1, 5, 9, and 12 MHz. The acoustic parameters, namely, free volume, internal pressure, absorption coefficient, Rao's constant, and Wada's constant, were calculated using the measured density (ρ), viscosity (η), and ultrasonic speed (U). The variations of these parameters with temperature and frequency provided insights into molecular mobility, distinct types of intermolecular interactions, and the strength of solute–solvent interactions between dextran (0.5%) and glycine (2M). The findings regarding a structural reorganisation in the aqueous dextran solution were explained. The solute-solvent interactions were more significant across all temperatures used for the investigation. Changes in acoustic properties were minimal with frequency variation, suggesting that rapid molecular motion limits intermolecular interactions. This analysis provides detailed information regarding liquid solutions' physical and chemical behavior.

Keywords: Dextran, Glycine, Ultrasonic speed, Density, Viscosity, Acoustic parameters.

1. Introduction

Liquids can be studied using ultrasound to understand their physicochemical characteristics better. Ultrasonic measurements are frequently used to examine the molecular interactions in pure liquids, liquid mixtures, and ionic interactions in solutions containing single or mixed solutes [1-4]. Industrial and technological processes use the research of the solution properties of liquid mixtures that have polar and non-polar components. The thermodynamic characteristics and intermolecular interactions of binary mixtures are widely estimated via ultrasonic research. One of the physical characteristics that aids in comprehending the nature of the liquid state is the sound velocity. The thermodynamic characteristics such as free volume (V_f), internal pressure (P_i), absorption coefficient or attenuation coefficient (α), Rao's constant (R), and Wada's constant (W) can be calculated using the measured values of sound velocity (u), density (ρ), and viscosity(η) [5-7].

These deduced characteristics provide an easy way to examine liquid mixtures' thermodynamic properties, which is impossible with other approaches. When paired with other water resources, ultrasonic research is widely employed to study molecular interactions. Extensive research has focused on molecular interactions in various product forms and mixtures [8-10]. It is crucial to the advancement of molecular research. Due to its capacity to highlight the physicochemical behavior of the medium, ultrasonic technology has recently proven to be an invaluable tool for investigating the behavior of liquids and solids [11-13]. Nondestructive testing (NDT) typically utilizes

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it. NDT allows the assessment of material properties without causing any damage. This method uses a variety of business and scientific analyses to look into qualities without doing any harm. Common NDT methods include eddy current testing, low coherence interferometry, magnetic particle testing, radiography, and ultrasonic testing. Information on the structural and molecular alterations in liquid mixtures can be significantly increased using ultrasound techniques [14-18]. These techniques also offer helpful details regarding the mixing solution and its temperature dependency within the context of the theory of physical acoustics [19-22]. The ultrasonic speed technique is a fascinating and valuable method for examining the physicochemical characteristics of liquids, electrolytic solutions, and polymeric solutions [23-25].

The medical, pharmaceutical, leather, textile, chemical, and solvent solutions sectors all use these solutions extensively. For their applications in these industries, the study, comprehension, and analysis of the thermodynamic properties of mixtures and liquid solutions are crucial [26-27]. A critical test to determine a substance's qualities is how well ultrasonic waves penetrate it. Variations in temperature and concentration help understand the structure and the numerous connections of bound molecular complexes and other relevant molecular processes. Using the velocity and associated acoustic parameters, we can characterize the thermodynamic, physical, and chemical properties of liquid mixtures, such as molecule association and dissociation [28-30]. In the present study, an effort has been made to examine how dextran (0.5%) interacts with a 2M glycine solution. At five different temperatures between 303 and 323 K and frequencies between 1 and 12 MHz, we have calculated acoustic characteristics such as V_f, P_i, α, R, and W. The only polysaccharide that is water-soluble is dextran. Many businesses, particularly the pharmaceutical industry, use dextran and its derivatives [31-35].

The organic molecule glycine has the chemical formula HO2CCH2NH2. Glycine is commonly used in our body's biological processes and is used by the body to produce proteins. Given the significance of dextran and glycine, a thorough investigation of dextran and glycine has been conducted in this study.

Continuing from our earlier research, we now combine glycine and dextran at room temperature. We have taken further efforts to effectively consider the physicochemical behavior of dextran at varying temperatures in glycine. Understanding thermal behavior, phase transitions, rheological properties, reaction kinetics, and processing aspects of polymer solutions under different thermal conditions is critical for various industrial and scientific applications involving polymers.

2. Materials and Methods

Materials

Dextran with a molecular weight of 70,000 Da (Hi-Media) was used at a concentration of 0.5% in freshly distilled water. Glycine (2M, Fisher Scientific) was used as the solvent. Both materials were of analytical reagent (AR) grade and were used without further purification [36–37].

Measurements

(a) *Ultrasonic velocity (U)*: Ultrasonic velocity measurements were conducted using an ultrasonic interferometer (Model M-84, M/SMittal Enterprises, New Delhi) at temperatures ranging from 30 to 50°C. Measurements were performed at four frequencies (1, 5, 9, and 12 MHz) with an accuracy of ±0.056% m.s-1.

The ultrasonic velocity in the medium was calculated based on the wavelength (λ) using the interferometer [20-21]. Measurements were made with a temperature accuracy of 0.1 K. The ultrasonic velocity was calculated as:

$$\lambda = \frac{2d}{n} \quad \text{or} \quad U = f.\lambda = \frac{2fd}{n}$$

where n is the number of anode current maxima (or minima) over a distance d, which is the total movement of the micrometer screw for a maximum or minimum deflection. f is the ultrasonic frequency.

(b) *Density (ρ)*: The density of the solution was measured using a 10 mL pycnometer [36–37] with a precision of 0.0001 kg m^{-3}. Measurements were averaged over three trials. The density was calculated as:

$$\rho_2 = \frac{w_2}{w_1}\rho_1$$

where w_1 and w_2 denote the weights of distilled water and the solution, respectively, and ρ_1 and

ρ_2 denote the densities of distilled water and the solution.

(c) *Viscosity measurement*: An Ostwald viscometer [36-37], standardized with distilled water, was used. The viscosity measurement is precise to 0.001 mN s m^{-2}. The viscosities of the solution were calculated.

The η was calculated using the standard equation:

$$\eta_2 = \eta_1 \left(\frac{t_2}{t_1}\right)\left(\frac{\rho_2}{\rho_1}\right)$$

where η_1 and η_2 are the distilled water and solution viscosities, and t_1 and t_2 are the respective flow times of water and the solution.

3. Theoretical Aspect

The acoustic and thermodynamic characteristics listed below were calculated as follows [38-39]:

Free volume: $V_f = \left(\frac{M_{eff}U}{K\eta}\right)^{\frac{3}{2}}$

Internal pressure: $P_i = bRT\left(\frac{k\eta}{U}\right)^{3/2}\left(\frac{\rho^{2/3}}{M_{eff}^{7/6}}\right)$

Attenuation coefficient: $\propto = \frac{8\pi^2\eta f^2}{3\rho U^3}$

Rao's constant: $R = \frac{M_{eff}}{\rho}U^{1/3}$

Wada's constant: $W = \frac{M_{eff}}{\rho}\beta^{-1/7}$

where M_{eff} is the effective molecular weight of the solution ($M_{eff} = \Sigma miXi$, where mi and Xi are the molecular weight and mole fraction of solute and solvent), b = 2 for all liquids, k = 4.281 × 10^9, f is the frequency of the medium's ultrasonic wave, and β is the adiabatic compressibility.

4. Results and Discussion

The ρ and η of dextran in glycine at temperatures 303, 308, 313, 318, and 323 K are presented in Table 1.

TABLE 1. ρ and η.

T in kelvin	(ρ) Kg.m^{-3}	(η) 10^{-3} N.s.m^{-2}
303	1055.482	1.129
308	1054.261	1.023
313	1052.431	0.955
318	1050.006	0.902
323	1045.998	0.831

TABLE 2. U and V_f.

T in kelvin	U m.s^{-1}				V_f ($10^{-3}m^3\cdot mol^{-1}$)			
	Frequency in MHz				Frequency in MHz			
	1	5	9	12	1	5	9	12
303	1613.000	1605.750	1602.450	1600.000	6.098	6.057	6.039	6.025
308	1622.000	1615.500	1612.350	1610.000	7.131	7.089	7.068	7.052
313	1628.000	1621.250	1620.000	1616.000	7.951	7.902	7.893	7.863
318	1632.267	1627.250	1624.950	1622.400	8.696	8.656	8.638	8.617
323	1635.000	1630.750	1629.000	1627.200	9.856	9.817	9.801	9.785

TABLE 3. P_i and α.

T in kelvin	P_i (10^3 N·m^{-2})				α (10^6(np·m^{-1})			
	Frequency in MHz				Frequency in MHz			
	1	5	9	12	1	5	9	12
303	132.70	133.00	133.14	133.24	6.371	159.474	525.297	929.054
308	127.93	128.19	128.32	128.41	5.469	137.043	450.199	792.583
313	125.24	125.50	125.54	125.70	5.019	126.729	413.838	733.980
318	123.30	123.49	123.58	123.68	4.593	116.440	381.718	673.582
323	119.82	119.98	120.04	120.11	4.173	105.410	343.526	609.527

TABLE 4. R and W.

T in kelvin	R (m^3mole^{-1})(m s^{-1})$^{1/3}$(10^{-3})				W (m^3mole^{-1})(N m^{-2})$^{1/7}$(10^{-3})			
	Frequency in MHz				Frequency in MHz			
	1	5	9	12	1	5	9	12
303	1.111	1.109	1.109	1.108	2.113	2.110	2.109	2.108
308	1.114	1.113	1.112	1.112	2.119	2.116	2.115	2.114
313	1.118	1.116	1.116	1.115	2.124	2.122	2.121	2.120
318	1.121	1.120	1.120	1.119	2.130	2.128	2.127	2.126
323	1.126	1.125	1.125	1.124	2.138	2.136	2.136	2.135

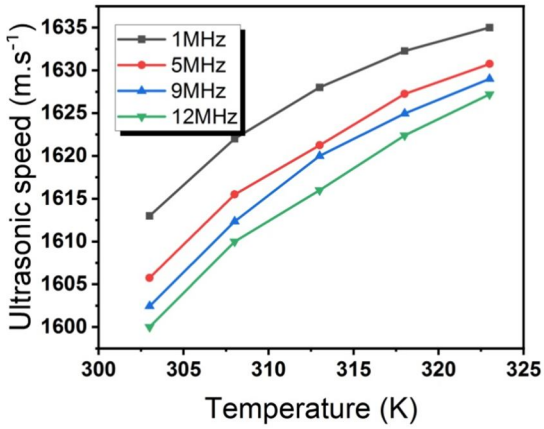

FIG. 1. Ultrasonic speed vs temperature.

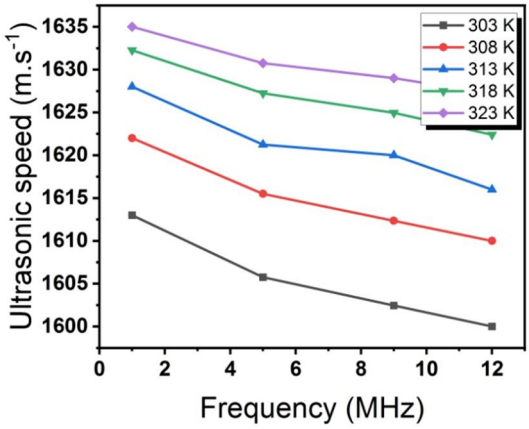

FIG. 2. Velocity vs frequency.

It has been found that when the temperature rises, ultrasonic velocity increases (Fig. 1). Ultrasonic velocity is found to increase with temperature at a specific frequency and to progressively decrease at frequencies between 5 and 9 MHz. This is because the polymer solution's structural alterations cause the intermolecular tensions to diminish. A drop in velocity like this suggests that there is a weak molecular interaction happening between the solvent and the liquid. When the frequency is low (1 MHz), however, the situation is the opposite. It shows structural readjustment, adding glycine to the polymer solution, which causes association in the component [40]. The association results from persistent dipoles in the water molecules, which induce dipoles. For temperature, ultrasonic velocity falls with increasing frequency due to increased agitation between molecules, which decreases speed at a higher frequency [41]; such a decrease in speed is a sign of a frail molecular connection between the molecules making up the solute and solvent. (Fig. 2).

The speed changes more with temperature for glycine compared to water. This suggests that there are more parts in a certain area, making the medium more packed and strengthening the interactions between dextran and glycine compared to water. The viscosity changes with temperature and the amount of solute in both water and glycine. Molecular forces, like hydrogen bonds and charge transfer complexes, play a role in this. Intermolecular forces, which are weak forces between charged particles, are present in water and glycine.

At a constant concentration of liquid components, free volume (V_f α $U^{3/2}$) increases with temperature because molecular velocity increases. It is observed that free volume increases (Fig. 3) and internal pressure decreases (Fig. 5) with an increase in the temperature of the solution. As expected, the solute and solvent molecules' constituent parts display the opposite trend from the internal pressure [42-44], pointing to a tenuous chemical link. That indicates that free volume is increasing because the molecules arrange themselves so that void space is more accessible. With increased temperature, internal pressure drops as the molecules' attraction forces weaken. As the molecules' intermolecular attraction wanes, internal pressure drops. Figs. 4 and 6 demonstrate that the free volume and internal pressure frequency exhibit minimal variation as the frequency increases, aligning with the frequency axis. This indicates that the free volume and internal pressure remain relatively constant with increasing frequency. At lower frequencies, these characteristics enable the waves to interact with a greater number of molecules by penetrating deeper into the solutions.

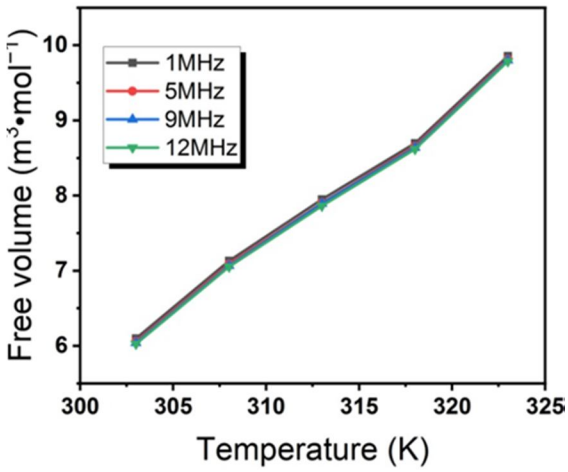

FIG. 3. Free volume vs temperature.

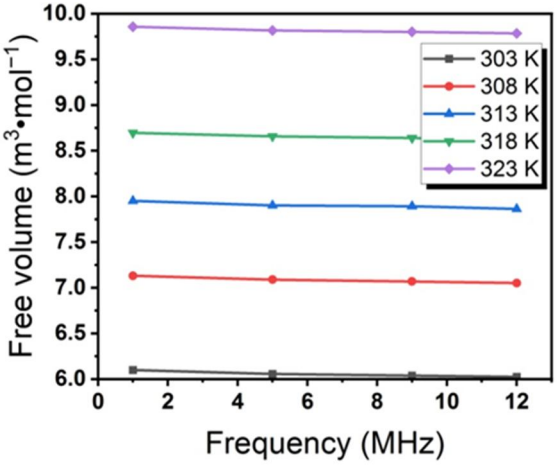

FIG. 4. Free volume vs frequency.

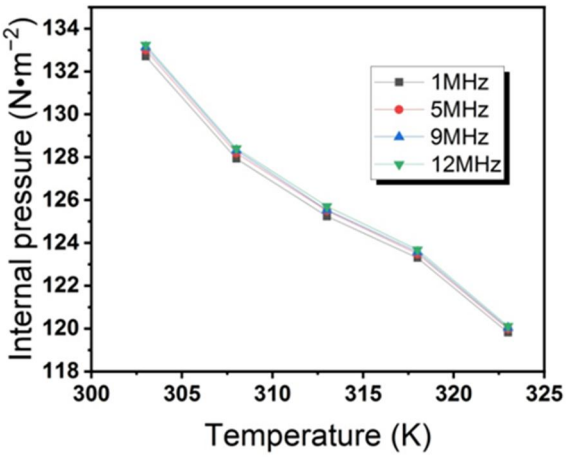

FIG. 5. Internal pressure vs temperature

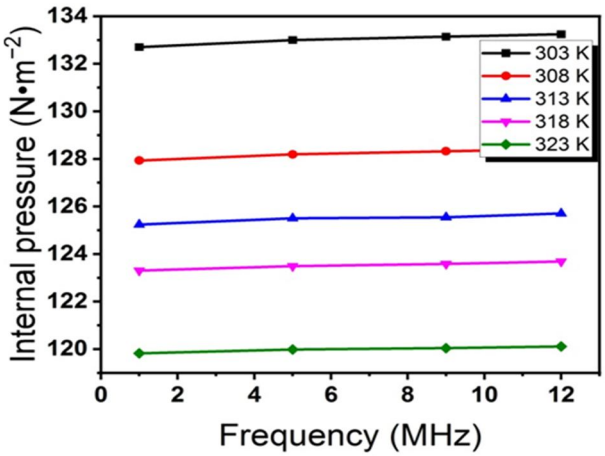

FIG. 6. Internal pressure vs frequency

Low-frequency ultrasound induces molecular rearrangements, increasing the free volume of the solutions. Conversely, it constrains the number of molecules that the waves may engage with at high frequencies by restricting their ability to penetrate deeply into the solutions. Thus, in comparison to low frequencies, high-frequency ultrasonic waves may exert a lesser impact on the available space for movement. Utilizing low-frequency ultrasound can induce cavitation in a material, wherein the oscillating pressure of the waves leads to the formation of tiny cavities or bubbles filled with vapor. The localized pressure waves generated upon the bursting of these bubbles might lead to an increase in the internal pressure of the material. The influence of cavitation is most evident in liquids and polymer solutions, where it can enhance the process of mixing, promote chemical reactions, or facilitate the dispersion of particles. At higher frequencies, ultrasonic waves have shorter wavelengths, which leads to less joint cavitation. This, in turn, causes localized pressure fluctuations owing to the fluid motion induced by the waves. Despite being less in magnitude compared to cavitation-induced pressure changes at low frequencies [45-49], these pressure fluctuations can still occur.

The absorption coefficient at lower frequencies (1 and 5 MHz) is parallel to the temperature axis, showing no effect from temperature, and it steadily declines at higher temperatures, suggesting that the molecules are arranged so that more void space is available, indicating an increase in free volume. The absorption coefficient proliferates as frequency rises since it is inversely related to the square of frequency [50-53].

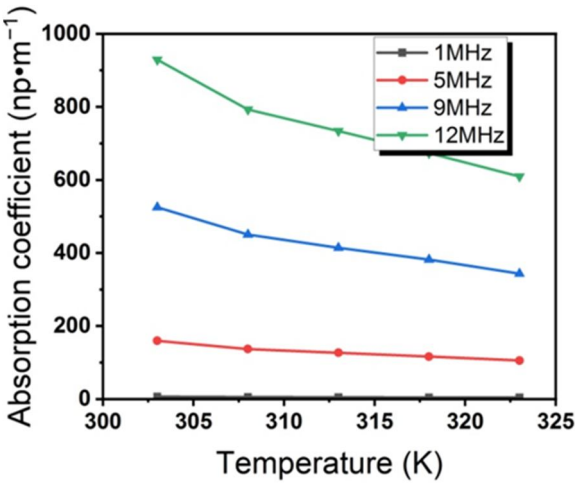

FIG. 7. Absorption coefficient vs temperature.

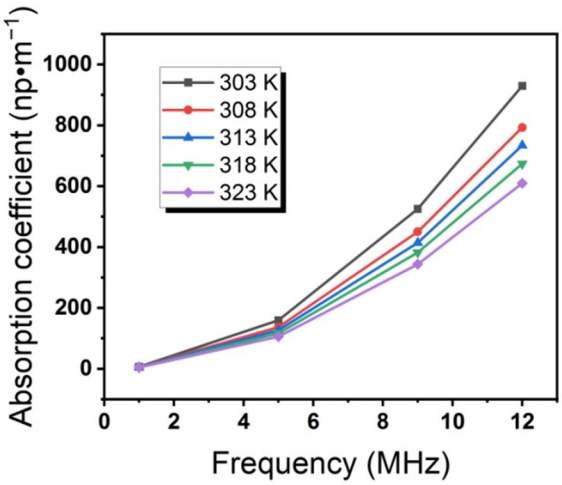

FIG. 8. Absorption coefficient vs frequency.

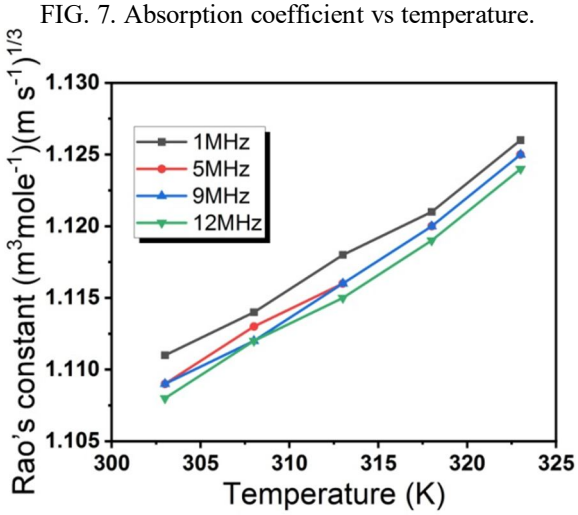

FIG. 9. Rao's constant vs temperature.

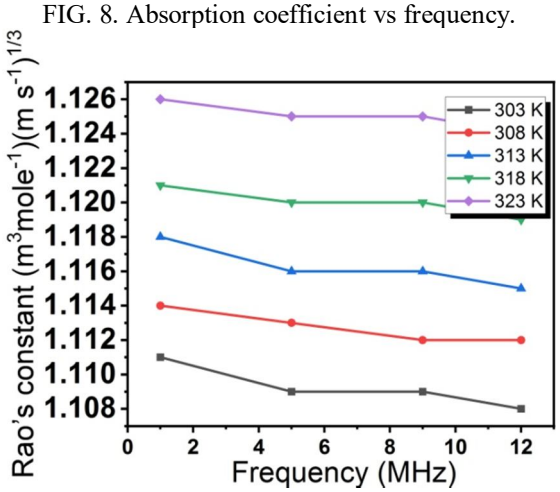

FIG. 10. Rao's constant vs frequency.

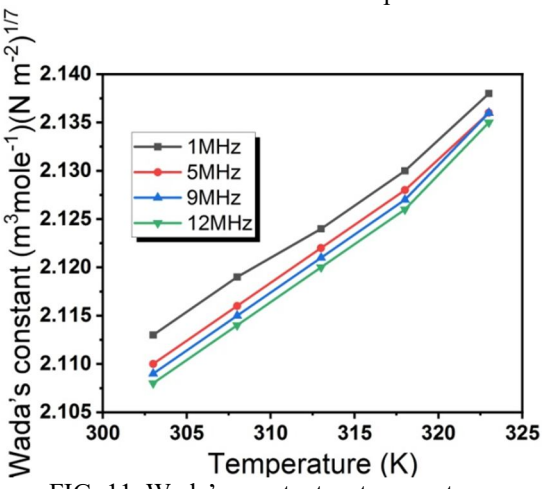

FIG. 11. Wada's constant vs temperature.

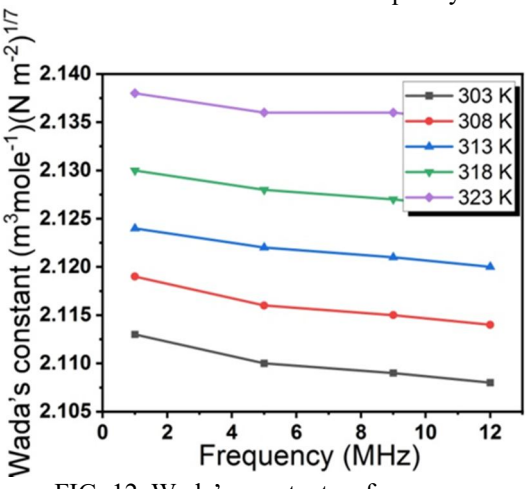

FIG. 12. Wada's constant vs frequency.

Rao's constant (R) and Wada's constant (W) increase with increasing temperature (Figs. 9 and 11), demonstrating the interaction between the molecules of the solvent and the solute. Figures 10 and 12 show that the variation of "R" and "W" with frequency is practically parallel to the frequency axis, showing a relatively tiny change in "R" and "W" with increasing frequency [54-62].

5. Conclusion

The acoustic properties of dextran in 2M glycine solution were examined at varying temperatures and frequencies. The molecules travel quickly and have little time to communicate as the frequency rises, so there is little change in the auditory characteristics. The findings demonstrate that the particular solute-

solvent interactions are crucial in explaining how acoustic characteristics change with temperature.

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