# Exploring Thermodynamic Interactions in Carbohydrate-Aqueous Polymeric Systems: A Comprehensive Study of Volumetric, Acoustical, and UV Properties

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## Abstract

This study investigates the nature of interactions between carbohydrates (ribose and lactose) and the polymer PEG8000 in an aqueous medium. The examination is conducted at various temperatures (T = 293.15, 298.15, 303.15, 308.15, and 313.15 K) and at polymer concentrations of 0% w/w, 2% w/w, and 4% w/w. The analysis employs density (ρ) and sound speed (u) data to compute apparent molar volumes and apparent molar isentropic compressibility values. These parameters are crucial for understanding the molecular interactions between the carbohydrate and polymer. Additionally, UV spectroscopy is employed to confirm the presence of interactions involving carbohydrates. The comprehensive approach utilized in this work provides valuable insights into the complex intermolecular relationships within the studied system, shedding light on the behavior of carbohydrates and polymers in aqueous solutions across different temperatures and concentrations.

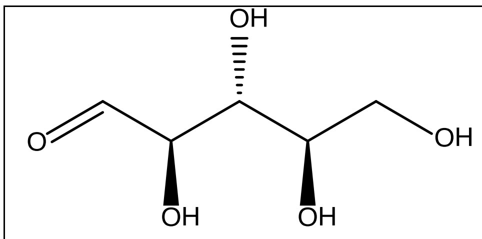
**Keywords**: Polymer, carbohydrates, intermolecular interactions

## 1. Introduction

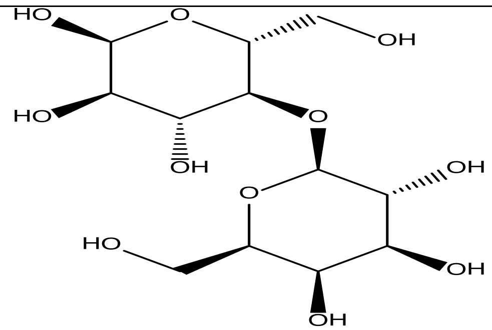
Carbohydrates, vital biomolecules, serve as the primary energy source for both animals and plants. As fundamental building blocks of cells, they play a crucial role in various physiological processes across organisms and find applications in the food, pharmaceutical, and cosmetic industries. Carbohydrates exhibit two enantiomeric forms, namely dextrorotatory (D) and levorotatory (L), showcasing their biological versatility. While the D-form is naturally occurring, the L-form is synthesized in laboratories. The interaction of carbohydrates with other biomolecules such as lipids, proteins, and polymers has gained significant attention due to the ease of availability, renewable nature, and structural diversity of carbohydrates [1-3].

Polymers, encompassing a vast array of materials with diverse properties, form stable two-phase liquid systems when mixed with aqueous solutions of polymers or polymers and electrolytes [2-4]. These systems are widely employed in biotechnology as they provide a biocompatible medium for the separation of different biomolecules. Carbohydrates can participate in the formation of aqueous biphasic systems (ABS) in polymeric solutions, resulting in carbohydrate-rich and polymer-rich aqueous phases [5-9]. Such ABS, particularly involving carbohydrates, offer additional advantages in various industries. Therefore, a comprehensive study of the thermodynamic properties of polymer-carbohydrate aqueous mixtures is essential to understand their phase-forming behavior [10-15].

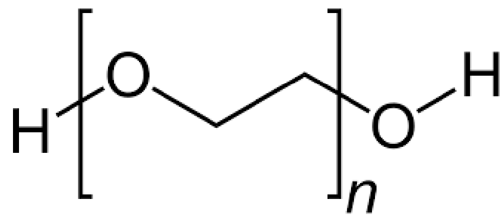
Volumetric and acoustical properties stand out as crucial thermodynamic parameters for investigating the interactions within polymer-carbohydrate systems [16-18]. While some literature exists on the volumetric and acoustic properties of carbohydrates in water and other solutions, there is ongoing interest among researchers to systematically understand the behavior of carbohydrates in aqueous polymeric systems [19,20]. In this study, we aim to contribute further insights into the diverse interactions within carbohydrate-aqueous polymeric systems. A comprehensive investigation of volumetric and acoustical properties, along with UV studies, was conducted at various temperatures (T = 293.15, 298.15, 303.15, 308.15, and 313.15 K) for binary and ternary aqueous systems containing ribose and lactose in polymer PEG8000 solutions at concentrations of 0% w/w, 2% w/w, and 4% w/w.




Ribose




Lactose



Polyethylene Glycol

Molecular structures of chemicals used.

## 2.1 Materials

Polyethylene Glycol (PEG): The study utilized Polyethylene Glycol (PEG) with a molecular weight of 8000 (L.R grade) sourced from s.d.fine – Chem Private Limited.

Saccharides: High-purity Ribose and Lactose (>99%) were procured from LOBA CHEMIE PVT. LTD. (INDIA) and were used without additional purification.

Solvent: Water served as the primary solvent in this investigation, and the apparatus calibration required purified water. Approximately 1000 ml of pure water was collected from the Millipore distillation unit. This water sample underwent further distillation over a ~750 mm long fractionating column with acidified $KMnO_4$. Various fractions of the distilled water were collected, and their conductivity ($\kappa$, $S\cdot cm^{-1}$) and pH were determined. The sample with a $\kappa$ value 2-3 $\times 10^{-6}$ $S\cdot cm^{-1}$ was selected for use. The pH value of the collected sample remained in the range of 6.50–6.95, measured at room temperature. It's important to note that the purified water obtained was not used beyond two days.

## 2.2 Experimental Details

### 2.2.1 Density and Speed of Sound Measurements

Density and speed of sound measurements were performed with a high–precision digital Density and Sound Analyzer–5000 (DSA–5000). It was supplied by Anton Paar Gmbh, Graz, Austria. The instrument was calibrated periodically with distilled water over a temperature range 293–318 K. The precision in the density data was found to be better than $\pm 2 \times 10^{-6}$ $g\cdot cm^{-3}$ and that of speed of sound data it was better than $\pm$ 0.20 $m\cdot s^{-1}$. The precision in the temperature of the DSA–5000 is $\pm$ 0.01 K.

#### 2.2.2 UV–Visible Measurements

Genesys 10S UV-Vis spectrophotometer (190-900 nm) supplied by Thermo Scientific USA has been used for obtaining absorption spectra of Polyethylene Glycol (PEG) 8000 in aqueous solutions of (0.00, 2.00 and 4.00) % (w/v) Ribose and Lactose, with the help of 10 mm path length quartz cuvette. The spectra were recorded in the wavelength range 200-400 nm. All the measurements were taken at room temperature i.e. 298.15 ± 0.1 K.

## 3. Results and Discussion

In this manuscript, an attempt has been made to explore the volumetric, compressibility and acoustical parameters of carbohydrates, namely ribose and lactose in aqueous solutions of Polyethylene glycol 8000 (0.00, 2.00 and 4.00 %) from density, speed of sound and UV-Visible studies. It is very useful for a better understanding the physico-chemical behavior of solution where the structural rearrangements are influenced by the shape of molecules as well as their mutual interactions.

### 3.1 Volumetric Calculations

In order to study the effect of water soluble polymer on the volumetric and compressibility properties of saccharides in aqueous solutions, the density and speed of sound of ribose and lactose in aqueous solutions of 0.00, 2.00 and 4.00 % w/w PEG 8000 were measured over a wide temperature range 293.15 – 313.15 K at an interval of 5 K. The studies were taken in the concentration range (0.02 – 0.20 mmol.kg$^{-1}$) of ribose and lactose. The measured density and sound velocity data have been reported in **TablesS1 and S2 of the supplementary Data**. These values reveal that there is a regular increase in density values with increase in concentrations of studied carbohydrates as shown in the **Figures S1 and S3 .** On the other hand, these values of density decrease with rise in the temperature may be attributed to the fact that thermal energy is greater than the interaction energy at higher temperature due to destruction of water structure. However, the temperature increment favors the increase of kinetic energy and volume expansion and hence, results in decrease of density. Also, the speed of sound values increases with increase in the concentration of saccharides, as well as with temperature also (Fig S2 and S4). This trend can be explained in terms of cohesion brought about by ionic hydration, which may also be due to overall increase of cohesion brought about by solute-solvent interactions present in solution that results into decrease in volume due to presence of solute [21].

The density and speed of sound values have been used to derive the parameters such as isentropic compressibility ($\kappa_s$), apparent molar volume ($V_\phi$) and apparent molar compression, ($\kappa_{s,\phi}$). The $\kappa_s$, $V_\phi$ and $\phi_\kappa$ values for ribose and lactose in aqueous polymer in varying concentrations have been calculated from the following equations [22-24]:

$$\kappa_s = 1/u^2 d \quad (3.1)$$

$$V_\phi = \frac{M}{d} + \frac{(d_o - d)}{mdd_o} \quad (3.2)$$

$$\kappa_{s,\phi} = V_\phi \kappa_s + \frac{(\kappa_s - \kappa_o)}{m\rho_o} \quad (3.3)$$

where, m is the molality of the solution, $d$, $\kappa_s$ and $d_o$, $\kappa_o$ are the densities and isentropic compressibility of the solution and pure solvent respectively. The isentropic compressibility values have been reported in **Table 1** and plots have been shown in **Figures 1** and **2**. The graphical representation reveals that $\kappa_s$ decreases with increase in concentration of saccharides as well as polymer, and with temperature also for both the saccharides. The decrease in $\kappa_s$ may be resulted due to increase in the number of incompressible ions and molecules [25]. The $\kappa_s$ values are higher for lactose as compare to ribose thus, shows stronger polymer-saccharide interactions in case of lactose.

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-9, Issue-12, December 2023
ISSN: 2395-3470
www.ijseas.com

**Table. 1 Isentropic compressibility, $\kappa_S$ (TPa$^{-1}$) for Ribose and Lactose in pure water and aqueous solutions of Polyethylene glycol 8000 at different temperatures (K).**

| Conc. (mol·kg$^{-1}$) | $\kappa_S$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| | [ PEG 8000 ] = 0.00 % w/w | | | | | | | | | |
| 0.02 | 454.64 | 446.68 | 440.10 | 434.93 | 430.27 | 455.54 | 447.79 | 440.63 | 435.63 | 431.18 |
| 0.04 | 454.27 | 446.34 | 439.75 | 434.35 | 430.04 | 453.47 | 445.54 | 438.93 | 433.54 | 429.25 |
| 0.06 | 453.28 | 445.40 | 438.84 | 433.48 | 429.21 | 451.40 | 443.57 | 437.06 | 431.74 | 427.50 |
| 0.08 | 452.25 | 444.34 | 437.94 | 432.63 | 428.38 | 449.17 | 441.43 | 435.02 | 429.75 | 425.57 |
| 0.10 | 450.75 | 443.00 | 436.57 | 431.29 | 427.08 | 446.92 | 439.23 | 432.82 | 427.61 | 423.59 |
| 0.12 | 449.86 | 442.14 | 435.76 | 430.53 | 426.33 | 444.63 | 437.04 | 430.81 | 425.75 | 421.77 |
| 0.14 | 448.45 | 441.28 | 434.95 | 429.78 | 425.69 | 442.23 | 434.73 | 428.58 | 423.58 | 419.74 |
| 0.16 | 447.36 | 439.80 | 433.55 | 428.45 | 424.39 | 440.03 | 432.69 | 426.60 | 421.34 | 418.06 |
| 0.18 | 445.52 | 438.92 | 432.44 | 427.66 | 423.65 | 437.72 | 430.50 | 424.55 | 419.12 | 415.86 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.20 | 444.43 | 438.20 | 432.04 | 427.01 | 423.04 | 435.43 | 428.11 | 422.51 | 416.88 | 413.67 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **[ PEG8000 ] = 2.00 % w/w** | | | | | | | | | | |
| 0.02 | 446.57 | 439.31 | 433.57 | 428.67 | 424.78 | 446.67 | 439.56 | 434.35 | 429.74 | 425.56 |
| 0.04 | 446.00 | 438.78 | 432.82 | 427.99 | 424.18 | 445.22 | 437.97 | 432.04 | 427.25 | 423.43 |
| 0.06 | 445.00 | 437.84 | 431.93 | 427.12 | 423.34 | 442.87 | 435.74 | 429.91 | 425.16 | 421.41 |
| 0.08 | 444.10 | 436.99 | 431.11 | 426.36 | 422.64 | 440.29 | 433.31 | 427.53 | 422.85 | 419.19 |
| 0.10 | 443.09 | 436.04 | 430.23 | 425.52 | 421.84 | 438.01 | 431.10 | 425.43 | 420.87 | 417.26 |
| 0.12 | 442.53 | 435.49 | 429.70 | 425.01 | 421.20 | 435.65 | 428.89 | 423.28 | 418.79 | 415.29 |
| 0.14 | 441.29 | 434.34 | 428.61 | 423.97 | 420.33 | 433.57 | 426.88 | 421.37 | 416.94 | 413.44 |
| 0.16 | 440.43 | 433.49 | 427.81 | 423.23 | 419.60 | 430.84 | 424.28 | 418.87 | 414.50 | 411.14 |
| 0.18 | 439.02 | 432.22 | 426.61 | 422.08 | 418.55 | 428.40 | 422.21 | 416.70 | 412.40 | 409.10 |
| 0.20 | 438.31 | 431.35 | 425.93 | 421.39 | 417.78 | 426.14 | 419.77 | 414.54 | 410.32 | 407.05 |
| **[ PEG 8000 ] = 4.00 % w/w** | | | | | | | | | | |
| 0.02 | 448.68 | 441.15 | 434.92 | 429.85 | 425.73 | 440.33 | 433.34 | 427.31 | 422.77 | 418.44 |
| 0.04 | 447.39 | 439.93 | 433.74 | 428.70 | 424.62 | 438.35 | 431.23 | 425.85 | 421.52 | 417.43 |
| 0.06 | 446.05 | 438.60 | 432.48 | 427.46 | 423.43 | 436.31 | 429.80 | 424.44 | 420.15 | 416.50 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.08 | 444.60 | 437.24 | 431.19 | 426.18 | 422.21 | 434.07 | 427.66 | 423.03 | 418.79 | 415.31 |
| 0.10 | 443.19 | 435.82 | 429.85 | 424.84 | 420.93 | 431.75 | 425.53 | 421.45 | 417.44 | 413.87 |
| 0.12 | 441.70 | 434.36 | 428.43 | 423.48 | 419.65 | 429.47 | 423.42 | 420.06 | 416.09 | 412.53 |
| 0.14 | 440.19 | 432.89 | 426.99 | 422.07 | 418.33 | 427.21 | 421.32 | 418.67 | 414.75 | 411.54 |
| 0.16 | 438.63 | 431.35 | 425.47 | 420.67 | 416.91 | 424.96 | 419.24 | 417.03 | 413.41 | 410.15 |
| 0.18 | 437.00 | 429.75 | 423.95 | 419.09 | 415.39 | 422.73 | 417.17 | 415.31 | 412.08 | 408.67 |
| 0.20 | 435.28 | 428.04 | 422.32 | 417.54 | 413.91 | 420.52 | 415.11 | 413.55 | 410.76 | 407.13 |

Standard uncertainties, u are u (T) = ±0.01 K, u (P) =0.002 MPa, u ([Ribose]/[Lactose]]) = ± 0.002 mol·kg$^{-1}$.

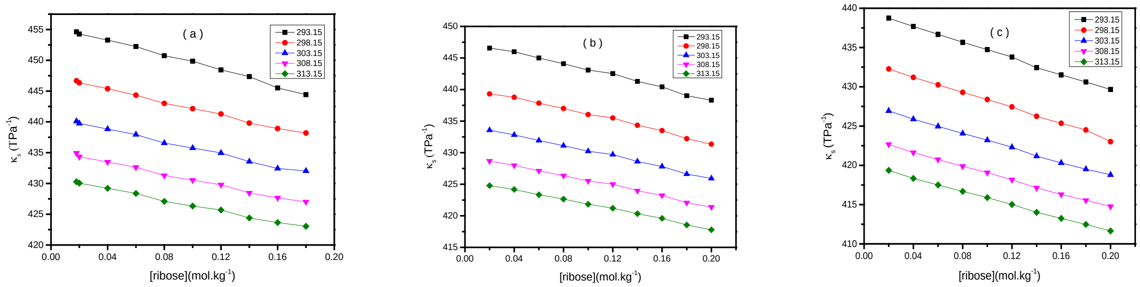



**Figure 1:** Plots of $\kappa_S$ vs. [Ribose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

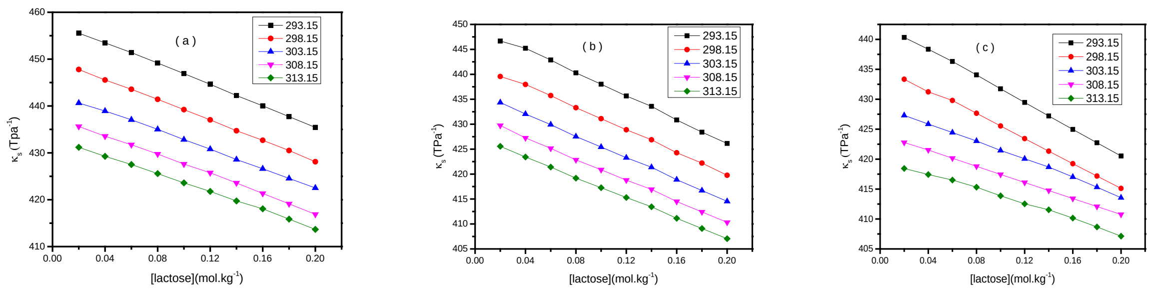



**Figure 2:** Plots of $\kappa_S$ vs. [Lactose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

The apparent molar volume, $V_\phi$ values (**Table 2**) are positive at all studied concentrations of carbohydrates and polymer. **Figures (3-4)** which illustrate that these values vary linearly at all concentrations of carbohydrates. Increase in value of $V_\phi$ by increasing the temperature because of increase in thermal kinetic energy of water molecules and then their interactions with carbohydrate molecules are weakened, this phenomenon leads to irregular carbohydrate hydration layer and finally, the release of a number of water molecules around the carbohydrate molecules which reduces the pressure on these molecules and increasing the volume of the carbohydrate. The values of $V_\phi$ for all the investigated carbohydrates (ribose and lactose) in aqueous solutions increase in the presence of polymer. Because of the polymer−water hydrogen bond interactions, hydrogen bond interactions between water and carbohydrate molecules are weakened which results in the reduction of water molecules around the carbohydrate molecules and therefore increasing $V_\phi$ .Lactose which is a disaccharide has a larger apparent molar volume than monosaccharide ribose [20].

**Table 2. Apparent molar volume, $V_\phi$ ($m^3 \cdot mol^{-1}$) for Ribose and Lactose in pure water and aqueous solutions of Polyethylene glycol 8000 at different temperatures (K).**

| Conc. ($mol \cdot kg^{-1}$) | $V_\phi$, $10^{-6}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ribose | | | | | | Lactose | | | | |
| | | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0 % w/w | | | | | | | | | | | | |
| 0.02 | | 291.18 | 291.47 | 292.08 | 292.49 | 292.74 | | 297.34 | 297.98 | 298.45 | 299.05 | 300.01 |
| 0.04 | | 291.10 | 291.35 | 291.94 | 292.41 | 292.69 | | 296.78 | 297.55 | 297.85 | 298.54 | 299.38 |
| 0.06 | | 290.94 | 291.23 | 291.72 | 292.19 | 292.47 | | 296.58 | 297.01 | 297.24 | 298.05 | 298.89 |
| 0.08 | | 290.80 | 291.10 | 291.58 | 292.02 | 292.32 | | 296.11 | 296.35 | 296.8 | 297.45 | 298.33 |
| 0.10 | | 290.65 | 290.95 | 291.44 | 291.83 | 292.14 | | 295.14 | 295.48 | 296.11 | 296.92 | 297.28 |
| 0.12 | | 290.51 | 290.84 | 291.33 | 291.67 | 291.98 | | 294.77 | 294.97 | 295.88 | 296.62 | 296.88 |
| 0.14 | | 290.38 | 290.70 | 291.16 | 291.55 | 291.84 | | 294.46 | 294.68 | 295.38 | 295.93 | 296.50 |
| 0.16 | | 290.29 | 290.56 | 291.04 | 291.41 | 291.61 | | 294.16 | 294.61 | 295.36 | 295.59 | 296.11 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.18 | | 290.13 | 290.41 | 290.83 | 291.24 | 291.47 | | 293.77 | 293.96 | 294.35 | 294.83 | 295.47 |
| 0.20 | | 290.06 | 290.27 | 290.72 | 291.01 | 291.28 | | 293.44 | 293.74 | 294.29 | 294.45 | 295.25 |

| **[ PEG 8000 ] = 2 % w/w** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | | 296.97 | 297.58 | 298.51 | 299.35 | 299.80 | | 301.62 | 302.98 | 304.72 | 306.48 | 307.70 |
| 0.04 | | 296.45 | 297.11 | 297.76 | 298.52 | 299.38 | | 301.24 | 302.62 | 304.31 | 305.74 | 306.99 |
| 0.06 | | 295.96 | 296.54 | 297.36 | 298.05 | 298.77 | | 300.78 | 302.28 | 303.80 | 305.14 | 306.34 |
| 0.08 | | 295.47 | 296.06 | 296.85 | 297.39 | 298.08 | | 300.40 | 301.65 | 303.38 | 304.54 | 305.91 |
| 0.10 | | 294.94 | 295.52 | 296.25 | 296.79 | 297.67 | | 299.83 | 300.98 | 302.80 | 304.03 | 305.30 |
| 0.12 | | 294.39 | 294.96 | 295.65 | 296.36 | 297.08 | | 299.45 | 300.47 | 302.42 | 303.40 | 304.59 |
| 0.14 | | 293.79 | 294.33 | 295.00 | 295.79 | 296.43 | | 299.04 | 299.85 | 301.90 | 302.96 | 304.04 |
| 0.16 | | 293.23 | 293.82 | 94.53 | 295.21 | 295.97 | | 298.50 | 299.38 | 301.40 | 302.30 | 303.15 |
| 0.18 | | 292.80 | 293.22 | 293.91 | 294.53 | 295.02 | | 298.05 | 298.73 | 300.74 | 301.87 | 302.38 |
| 0.20 | | 292.29 | 292.57 | 293.17 | 293.77 | 294.28 | | 297.53 | 298.29 | 300.14 | 301.15 | 301.64 |

| [ PEG 8000 ] = 4 % w/w | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | | 298.46 | 298.88 | 299.75 | 300.40 | 300.65 | | 331.32 | 334.40 | 337.34 | 339.65 | 341.53 |
| 0.04 | | 297.97 | 298.33 | 299.06 | 299.45 | 299.85 | | 328.34 | 331.46 | 334.46 | 337.56 | 339.81 |
| 0.06 | | 297.46 | 297.80 | 298.36 | 298.88 | 299.13 | | 325.46 | 328.36 | 332.46 | 335.16 | 337.76 |
| 0.08 | | 296.86 | 297.25 | 297.79 | 298.25 | 298.34 | | 321.46 | 325.46 | 328.46 | 332.06 | 335.96 |
| 0.10 | | 296.32 | 296.78 | 297.21 | 297.50 | 297.77 | | 318.36 | 322.46 | 326.46 | 329.46 | 333.46 |
| 0.12 | | 295.82 | 296.22 | 296.60 | 296.92 | 297.19 | | 315.36 | 319.26 | 323.76 | 326.96 | 331.36 |
| 0.14 | | 295.23 | 295.62 | 296.01 | 296.37 | 296.61 | | 311.36 | 315.86 | 319.66 | 322.76 | 329.46 |
| 0.16 | | 294.73 | 295.03 | 295.47 | 295.77 | 295.97 | | 307.46 | 313.56 | 316.26 | 320.26 | 327.36 |
| 0.18 | | 294.15 | 294.51 | 294.95 | 295.19 | 295.37 | | 305.66 | 309.56 | 313.46 | 318.16 | 324.36 |
| 0.20 | | 293.68 | 293.93 | 294.38 | 294.50 | 294.68 | | 302.37 | 306.46 | 311.46 | 314.36 | 321.86 |

Standard uncertainties, u are u (T) = ±0.01 K, u (P) =0.002 MPa, u ([Ribose]/Lactose]]) = ± 0.002 mol·kg$^{-1}$, u 10$^{-6}$ $V_\phi$ ± 0.04 m$^3$.mol$^{-1}$

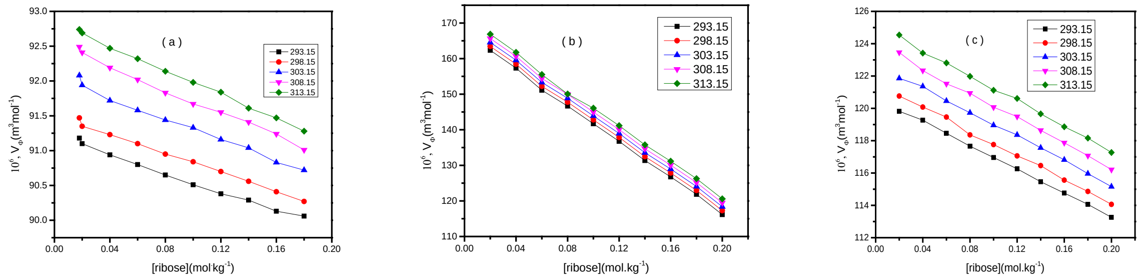



**Figure 3:** Plots of $V_{\phi}$ vs. [Ribose] in (a) 0% w/w, (b) 2.00 w/w and (c) 4.00 w/w aqueous solutions of PEG 8000 at different temperatures.

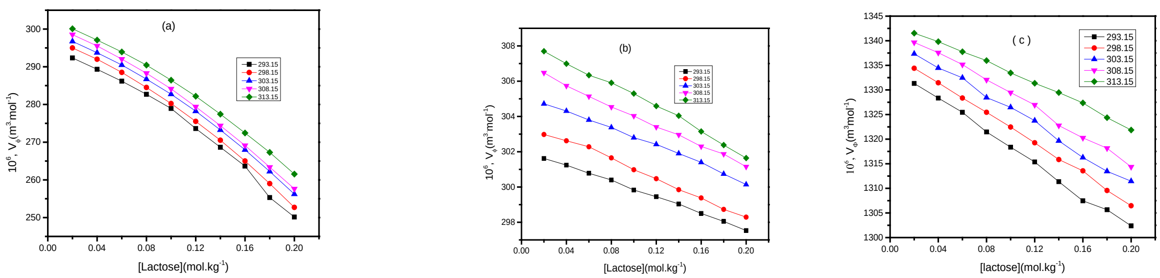



**Figure 4:** Plots of $V_{\phi}$ vs. [Lactose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

The value of apparent molar isentropic compressibility ($\kappa_{s,\phi}$) has been calculated by using the relation indicate by equation 3.3. The $\kappa_{s,\phi}$ values of ribose and lactose in aqueous solutions of PEG8000 have been reported in **Table 3**. From these tables, it is seen that the trends in the variation of $\kappa_{s,\phi}$ value with carbohydrates concentration are almost similar at all different temperatures. The apparent molar isentropic compressibility values of ribose and lactose are negative. The negative values of apparent molar isentropic compressibility indicate that the water molecules in the hydration layer of the solutes i.e. (ribose and lactose) are more compact than bulk water molecules. $\kappa_{s,\phi}$ values become less negative with rise in the temperature because the carbohydrate-water interactions are weakened (decreasing the electrostriction), and therefore, the water molecules in the hydration layer of the solutes become more compressible. The lesser negative values of apparent molar isentropic compression for solutes (i.e. ribose and lactose) in aqueous PEG solution as compared to aqueous solution because at higher polymeric concentration, the water molecules surrounding carbohydrates are more compressible than water molecule at lower polymeric concentration. These results show that hydrophilic-hydrophilic interactions exceed hydrophilic-hydrophobic/hydrophobic interactions.

**Table 3. Apparent molar isentropic compressibility, $\kappa_{s,\phi}$ ($m^3 \cdot mol^{-1} \cdot TPa^{-1}$) for Ribose and Lactose in pure water and aqueous solutions of PEG 8000 at different temperatures (K).**

| Conc. ($mol \cdot kg^{-1}$) | $\kappa_{s,\phi}$ , $10^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0 % w/w | | | | | | | | | | |
| 0.02 | –21.24 | –18.79 | –16.63 | –14.65 | –13.78 | –34.80 | –31.65 | –27.64 | –24.66 | –21.76 |
| 0.04 | –21.41 | –19.02 | –16.86 | –15.11 | –14.37 | –35.03 | –31.81 | –27.74 | –24.90 | –21.89 |
| 0.06 | –23.09 | –20.63 | –18.49 | –16.58 | –15.14 | –35.19 | –31.99 | –27.90 | –24.98 | –22.05 |
| 0.08 | –24.33 | –21.83 | –19.71 | –17.88 | –16.67 | –35.46 | –32.19 | –27.98 | –25.25 | –22.24 |
| 0.10 | –25.66 | –23.26 | –21.01 | –19.22 | –18.02 | –35.61 | –32.32 | –28.29 | –25.31 | –22.39 |
| 0.12 | –26.81 | –24.19 | –22.12 | –20.15 | –19.21 | –35.82 | –32.52 | –28.47 | –25.49 | –22.61 |
| 0.14 | –27.91 | –25.44 | –23.15 | –21.52 | –20.07 | –36.01 | –32.65 | –28.64 | –25.63 | –22.76 |
| 0.16 | –28.65 | –26.21 | –24.01 | –22.26 | –21.03 | –36.23 | –33.01 | –28.78 | –25.76 | –22.91 |
| 0.18 | –29.81 | –26.98 | –24.73 | –23.29 | –22.02 | –36.53 | –33.10 | –28.94 | –27.91 | –23.08 |
| 0.20 | –31.12 | –28.07 | –25.59 | –24.19 | –22.88 | –36.80 | –33.31 | –29.21 | –26.03 | –23.24 |

| [ PEG 8000 ] = 2 % w/w | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | | –19.87 | –16.95 | –14.27 | –13.58 | –11.63 | | –34.15 | –30.80 | –25.36 | –21.38 | –18.09 |
| 0.04 | | –21.68 | –19.57 | –17.09 | –15.57 | –14.23 | | –34.27 | –30.90 | –25.67 | –21.98 | –18.81 |
| 0.06 | | –23.66 | –21.78 | –19.50 | –17.90 | –16.42 | | –34.56 | –31.00 | –26.07 | –22.56 | –19.47 |
| 0.08 | | –25.68 | –24.14 | –22.04 | –19.20 | –19.09 | | –34.72 | –31.34 | –26.45 | –23.22 | –19.72 |
| 0.10 | | –28.23 | –25.94 | –23.51 | –21.33 | –21.17 | | –35.04 | –31.66 | –26.83 | –23.72 | –20.56 |
| 0.12 | | –30.54 | –28.17 | –25.51 | –24.14 | –22.82 | | –35.22 | –32.00 | –2720 | –24.10 | –21.03 |
| 0.14 | | –32.43 | –29.82 | –27.14 | –25.93 | –24.00 | | –35.45 | –32.24 | –27.54 | –24.43 | –21.35 |
| 0.16 | | –34.60 | –32.31 | –29.28 | –28.13 | –26.31 | | –35.78 | –32.54 | –27.88 | –24.84 | –22.08 |
| 0.18 | | –36.02 | –34.01 | –30.87 | –29.95 | –27.63 | | –36.06 | –32.89 | –28.19 | –25.48 | –22.58 |
| 0.20 | | –37.94 | –36.25 | –32.82 | –31.60 | –29.54 | | –36.24 | –33.22 | –28.55 | –25.87 | –23.18 |
| [ PEG 8000 ] = 4 % w/w | | | | | | | | | | | |
| 0.02 | | –19.19 | –16.54 | –14.56 | –11.24 | –10.48 | | –31.04 | –25.91 | –20.45 | –16.34 | –12.57 |
| 0.04 | | –23.10 | –18.31 | –16.58 | –14.58 | –13.54 | | –32.19 | –27.12 | –21.74 | –17.62 | –13.52 |
| 0.06 | | –22.72 | –21.03 | –18.78 | –17.29 | –15.98 | | –33.52 | –28.21 | –22.58 | –18.80 | –14.46 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.08 | | –24.34 | –22.91 | –20.55 | –19.35 | –17.75 | | –34.42 | –28.09 | –23.15 | –19.05 | –15.36 |
| 0.10 | | –26.40 | –24.78 | –22.14 | –21.39 | –19.55 | | –35.46 | –28.93 | –24.31 | –20.49 | –16.22 |
| 0.12 | | –28.03 | –26.52 | –24.09 | –22.98 | –20.89 | | –36.91 | –30.19 | –25.10 | –21.08 | –16.58 |
| 0.14 | | –29.45 | –27.95 | –25.75 | –24.61 | –22.21 | | –38.32 | –31.36 | –26.32 | –22.27 | –17.20 |
| 0.16 | | –30.85 | –29.59 | –27.53 | –25.88 | –23.94 | | –39.94 | –33.18 | –27.77 | –23.60 | –18.09 |
| 0.18 | | –32.48 | –31.23 | –29.04 | –27.95 | –25.94 | | –41.50 | –33.95 | –28.72 | –24.10 | –18.64 |
| 0.20 | | –34.30 | –33.23 | –30.86 | –29.57 | –27.48 | | –42.86 | –34.83 | –29.60 | –25.18 | –20.04 |

Standard uncertainties, u are u (T) = ±0.01 K, u (P) =0.002 MPa, u ([Ribos]/[Lactose]) = ± 0.002 mol·$kg^{-1}$.

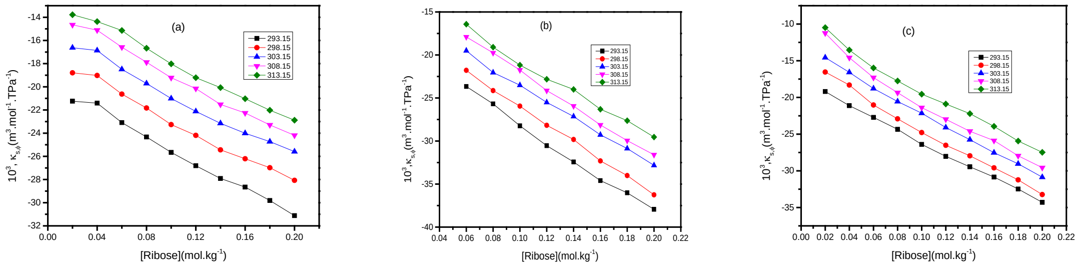



**Figure 5:** Plots of $\kappa_{s,\phi}$ vs. [Ribose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

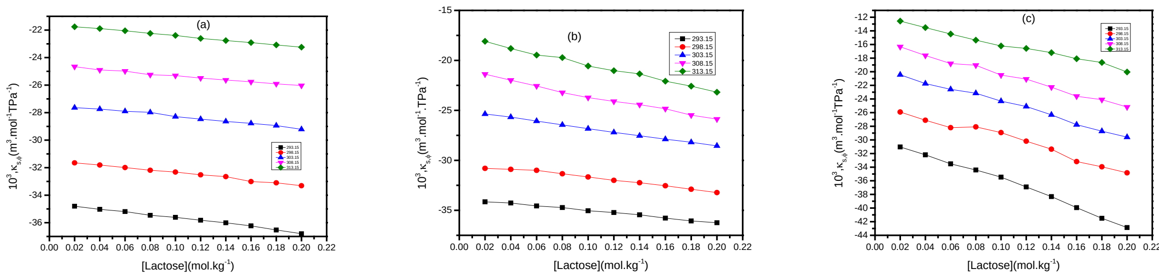



**Figure 6:** Plots of $\kappa_{s,\phi}$ vs. [Lactose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

### 3.1.2 Acoustical Parameters of Polyethylene glycol 8000 in Aqueous Solutions of Ribose and Lactose

In this section, we have used the experimentally determined densities and speeds of sound of ribose and lactose in pure water as well as in aqueous solutions of polyethylene glycol 8000 under different experimental conditions to derive some relevant acoustical parameters, such as intermolecular free length, $L_f$, relative association, $RA$, specific acoustic impedance, $Z$ and molar sound number, $[U]$ since they were also expected to yield reliable information regarding the solute–solvent interactions [26-31].

$$L_f = K\sqrt{\kappa_s} \qquad (3.4)$$

$$RA = (d/d_o)(u_o/u)^{1/3} \qquad (3.5)$$

$$Z = u \times d \qquad (3.6)$$

$$[U] = (u - u_o)/u_o \times c \qquad (3.7)$$

where, $K$ = [ (93.875+0.375 T) × $10^{-8}$] and $c$ is the concentration of solution.

The experimental data for the parameters intermolecular free length *($L_f$)*, relative association *(RA)*, specific acoustic impedance *(Z)* and molar sound number, $[U]$ for polyethylene glycol in aqueous solutions of ribose and lactose ( 0.00, 2.00 and 4.00% w/v ) have been reported in **Tables 4-7** and represented in **Figures 7-14** as follows:

A perusal of **Figures 7-8** inferred that $L_f$, which depends on intermolecular interactions existing between components of the mixture, decreases linearly with [polyethylene glycol] and increases with temperature in all the studied solvent systems. It has been observed that, intermolecular free length (**Table 4**) decreases linearly with increase in concentration of carbohydrates indicating that there are significant interactions between solute and solvent suggesting the structure promoting behavior of solutes which is strengthen by addition of polyethylene glycol as shown by smaller $L_f$ values as compared to pure water (**Figures 7-8)**. The intermolecular forces present in the solution become stronger giving rise to closed packed structure which provides the cohesion between carbohydrates and solvent molecules on rise in concentration of solutes.

However, it is apparent from **Figures 7-8** that intermolecular free length increases with rise in temperature. Increment in temperature increases thermal energy of the system, leading to disruption of co-sphere and disordering of the molecules. This results into more spacing between components of the system and hence $L_f$ values increase. Such an increase in $L_f$ values has also been cited in literature for polymer-carbohydrate system.

RA values (**Table 5**) show concentration dependence (**Figures 9-10)** as they increase with concentration of carbohydrates, suggesting that the solvation of carbohydrates in aqueous polymer predominates over breaking-up the solvent structures. RA values increase with increase in concentrations of polyethylene glycol which is attributed to the increase in electrostatic attraction or hydrogen bonding.

The specific Acoustic impedance ( $Z$ ) is the ratio of the effective sound pressure at a point to the effective particle velocity at that point. As it is the parameter related to the elastic properties of medium, therefore, it is important to examine it in relation to concentration and temperature. It is defined as the resistance offered to the sound wave by the component of mixture and is found to be almost inversely proportional to the isentropic compressibility ( $\kappa_s$ ) and directly proportional to speed of sound. The pattern of $Z$ at all concentrations is similar to density and sound velocity which increases with increase in the concentration of carbohydrates as well as polymer (**Table 6**) and represented in (Figure 11-12). This indicates the possibility of strong molecular interaction between the components present in the mixture. However, the increase in speed of sound values is a dominating factor for the observed increase in $Z$ values with temperature. The increase in $Z$ with the increase in concentration of solutes can be explained in terms of inter and intra- molecular interactions between the molecules of mixtures.

Molar sound number [U] affords another evidence to explain intermolecular interaction or structural changes taking place in solution system and the calculated values have been summarized in **Table 7**. A non-linear variation in $[U]$ **(Figures 13-14)** indicates that various interactions are occurring among species present in the solution. However, with rise in temperature, a decreasing trend in the values of $[U]$ for all cases has been observed which has been expected on the basis of role played by intermolecular hydrophobic interactions between carbohydrates polymer system. The higher values of $[U]$ at higher carbohydrates concentration can be associated to stronger electrostatic interactions and almost decreasing trend in $[U]$ values with concentration may be the result of intramolecular hydrophobic interactions. The non-linear behavior of these acoustical parameters confirms the presence of complex formation, association between species and solute-solvent interactions in the system.

**Table 4: Intermolecular free length, $L_f$ (m) for Ribose and Lactose in aqueous solutions of PEG 8000 at different temperatures (K).**

| Conc. (mol·kg$^{-1}$) | $L_f$, $10^{11}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0% w/w | | | | | | | | | | |
| 0.02 | 4.340 | 4.347 | 4.354 | 4.368 | 4.383 | 4.343 | 4.352 | 4.358 | 4.371 | 4.388 |
| 0.04 | 4.338 | 4.345 | 4.352 | 4.365 | 4.382 | 4.330 | 4.342 | 4.348 | 4.361 | 4.378 |
| 0.06 | 4.334 | 4.341 | 4.348 | 4.360 | 4.378 | 4.324 | 4.332 | 4.339 | 4.352 | 4.369 |
| 0.08 | 4.329 | 4.336 | 4.344 | 4.356 | 4.373 | 4.313 | 4.321 | 4.329 | 4.342 | 4.359 |
| 0.10 | 4.325 | 4.329 | 4.337 | 4.349 | 4.367 | 4.302 | 4.311 | 4.318 | 4.331 | 4.349 |
| 0.12 | 4.319 | 4.325 | 4.333 | 4.346 | 4.363 | 4.291 | 4.300 | 4.308 | 4.321 | 4.340 |
| 0.14 | 4.315 | 4.321 | 4.329 | 4.342 | 4.357 | 4.281 | 4.288 | 4.297 | 4.310 | 4.329 |
| 0.16 | 4.309 | 4.313 | 4.322 | 4.335 | 4.353 | 4.271 | 4.278 | 4.287 | 4.299 | 4.319 |
| 0.18 | 4.304 | 4.309 | 4.318 | 4.332 | 4.346 | 4.261 | 4.268 | 4.277 | 4.288 | 4.309 |
| 0.20 | 4.301 | 4.306 | 4.314 | 4.328 | 4.341 | 4.250 | 4.257 | 4.266 | 4.276 | 4.298 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[ PEG 8000 ] = 2% w/w** | | | | | | | | | | | | |
| 0.02 | | 4.308 | 4.313 | 4.322 | 4.338 | 4.357 | | 4.304 | 4.316 | 4.328 | 4.341 | 4.359 |
| 0.04 | | 4.304 | 4.308 | 4.318 | 4.333 | 4.352 | | 4.294 | 4.304 | 4.314 | 4.329 | 4.348 |
| 0.06 | | 4.299 | 4.304 | 4.314 | 4.328 | 4.348 | | 4.283 | 4.293 | 4.304 | 4.318 | 4.338 |
| 0.08 | | 4.295 | 4.300 | 4.310 | 4.324 | 4.344 | | 4.271 | 4.281 | 4.292 | 4.307 | 4.326 |
| 0.10 | | 4.290 | 4.295 | 4.305 | 4.320 | 4.340 | | 4.261 | 4.271 | 4.281 | 4.297 | 4.316 |
| 0.12 | | 4.287 | 4.292 | 4.302 | 4.316 | 4.335 | | 4.249 | 4.260 | 4.270 | 4.286 | 4.306 |
| 0.14 | | 4.281 | 4.287 | 4.297 | 4.312 | 4.330 | | 4.237 | 4.250 | 4.261 | 4.276 | 4.297 |
| 0.16 | | 4.277 | 4.282 | 4.293 | 4.307 | 4.326 | | 4.226 | 4.237 | 4.248 | 4.264 | 4.285 |
| 0.18 | | 4.270 | 4.276 | 4.287 | 4.303 | 4.323 | | 4.213 | 4.226 | 4.237 | 4.253 | 4.274 |
| 0.20 | | 4.267 | 4.273 | 4.284 | 4.299 | 4.219 | | 4.202 | 4.214 | 4.226 | 4.242 | 4.263 |
| **[ PEG 8000 ] = 4% w/w** | | | | | | | | | | | | |
| 0.02 | | 4.295 | 4.299 | 4.308 | 4.322 | 4.341 | | 4.271 | 4.281 | 4.293 | 4.308 | 4.322 |
| 0.04 | | 4.289 | 4.293 | 4.302 | 4.316 | 4.335 | | 4.261 | 4.271 | 4.283 | 4.300 | 4.317 |
| 0.06 | | 4.282 | 4.287 | 4.296 | 4.311 | 4.330 | | 4.253 | 4.264 | 4.276 | 4.293 | 4.310 |
| 0.08 | | 4.276 | 4.280 | 4.290 | 4.305 | 4.324 | | 4.243 | 4.253 | 4.269 | 4.286 | 4.301 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | | 4.269 | 4.273 | 4.283 | 4.298 | 4.318 | | 4.235 | 4.243 | 4.261 | 4.279 | 4.296 |
| 0.12 | | 4.262 | 4.266 | 4.277 | 4.292 | 4.311 | | 4.224 | 4.232 | 4.254 | 4.272 | 4.289 |
| 0.14 | | 4.254 | 4.259 | 4.270 | 4.285 | 4.305 | | 4.212 | 4.222 | 4.247 | 4.265 | 4.285 |
| 0.16 | | 4.247 | 4.252 | 4.263 | 4.278 | 4.298 | | 4.201 | 4.211 | 4.240 | 4.258 | 4.278 |
| 0.18 | | 4.240 | 4.245 | 4.255 | 4.271 | 4.291 | | 4.190 | 4.201 | 4.233 | 4.251 | 4.271 |
| 0.20 | | 4.232 | 4.237 | 4.247 | 4.263 | 4.283 | | 4.179 | 4.191 | 4.226 | 4.245 | 4.261 |

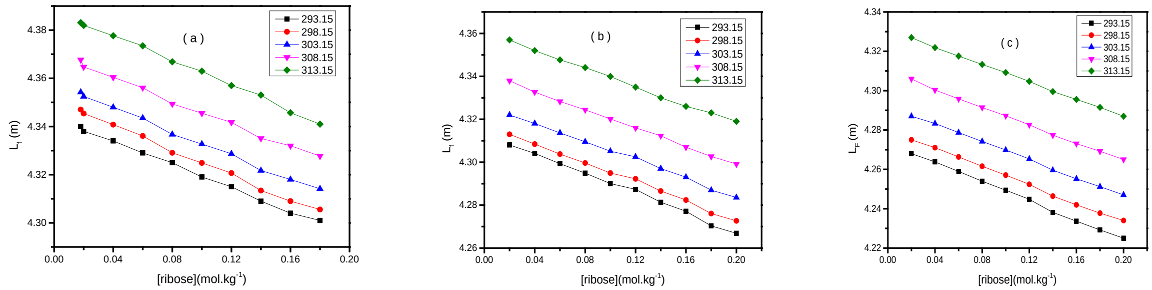



**Figure 7:** Plots of $L_f$ vs. [Ribose] in (a) 0 % w/w, (b) 2 % w/w and (c) 4 % w/w aqueous solutions of PEG 8000 at different temperatures.

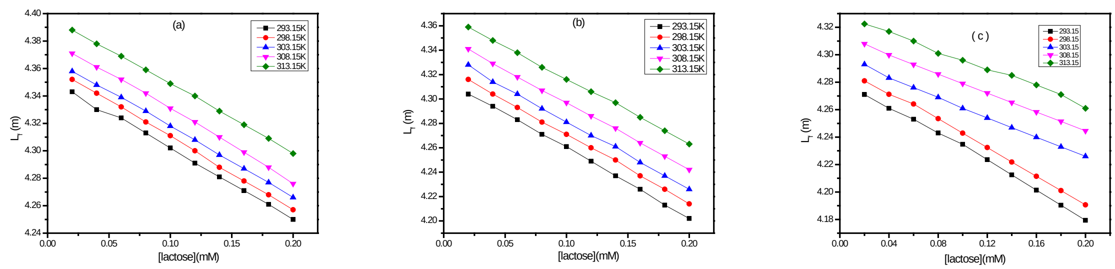



**Figure 8.** Plots of $L_f$ vs. [Lactose] in (a) 0% w/w, (b) 2 % w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-9, Issue-12, December 2023
ISSN: 2395-3470
www.ijseas.com

**Table 5: Relative association, *RA*, for Ribose and Lactose in aqueous solutions of PEG 8000 at different temperatures (K).**

| Conc. (mol·kg⁻¹) | RA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0% w/w | | | | | | | | | | |
| 0.02 | 1.00130 | 1.00128 | 1.00112 | 1.00158 | 1.00151 | 1.00112 | 1.00116 | 1.00 120 | 1.00124 | 1.00128 |
| 0.04 | 1.00174 | 1.00171 | 1.00169 | 1.00167 | 1.00164 | 1.00281 | 1.00284 | 1.00284 | 1.00282 | 1.00278 |
| 0.06 | 1.00292 | 1.00288 | 1.00285 | 1.00281 | 1.00277 | 1.00499 | 1.00539 | 1.00530 | 1.00529 | 1.00523 |
| 0.08 | 1.00412 | 1.00406 | 1.00400 | 1.00394 | 1.00389 | 1.00775 | 1.00813 | 1.00803 | 1.00799 | 1.00793 |
| 0.10 | 1.00560 | 1.00540 | 1.00563 | 1.00548 | 1.00534 | 1.01068 | 1.01104 | 1.01098 | 1.01090 | 1.01077 |
| 0.12 | 1.00701 | 1.00691 | 1.00680 | 1.00671 | 1.00665 | 1.01341 | 1.01376 | 1.01361 | 1.01348 | 1.01330 |
| 0.14 | 1.00818 | 1.00811 | 1.00805 | 1.00815 | 1.00812 | 1.01639 | 1.01670 | 1.01653 | 1.01638 | 1.01619 |
| 0.16 | 1.00987 | 1.00971 | 1.00955 | 1.00941 | 1.00929 | 1.01924 | 1.01948 | 1.01931 | 1.02746 | 1.01891 |
| 0.18 | 1.01201 | 1.01178 | 1.01159 | 1.01142 | 1.01126 | 1.02220 | 1.02241 | 1.02217 | 1.03663 | 1.02178 |
| 0.20 | 1.01478 | 1.01371 | 1.01352 | 1.01335 | 1.01345 | 1.02516 | 1.02286 | 1.02503 | 1.04423 | 1.02465 |

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**Table10. cntd./….**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **[ PEG 8000 ] = 2% w/w** | | | | | |
| 0.02 | 0.99837 | 0.99846 | 0.99854 | 0.99861 | 0.99868 | 1.00016 | 1.00023 | 1.00038 | 1.00042 | 1.00047 |
| 0.04 | 0.99924 | 0.99932 | 0.99939 | 0.99945 | 0.99951 | 1.00158 | 1.00163 | 1.00171 | 1.00178 | 1.00187 |
| 0.06 | 1.00040 | 1.00045 | 1.00049 | 1.00055 | 1.00060 | 1.00378 | 1.00385 | 1.00393 | 1.00399 | 1.00408 |
| 0.08 | 1.00151 | 1.00154 | 1.00161 | 1.00161 | 1.00163 | 1.00669 | 1.00670 | 1.00671 | 1.00673 | 1.00675 |
| 0.10 | 1.00269 | 1.00270 | 1.00271 | 1.00272 | 1.00273 | 1.00962 | 1.00959 | 1.00958 | 1.00954 | 1.00954 |
| 0.12 | 1.00350 | 1.00374 | 1.00386 | 1.00384 | 1.00381 | 1.01261 | 1.00254 | 1.01249 | 1.01244 | 1.01239 |
| 0.14 | 1.00498 | 1.00495 | 1.00493 | 1.00482 | 1.00489 | 1.01537 | 1.01526 | 1.01519 | 1.01509 | 1.01507 |
| 0.16 | 1.00590 | 1.00586 | 1.00583 | 1.00579 | 1.00577 | 1.01881 | 1.01866 | 1.01855 | 1.01846 | 1.01836 |
| 0.18 | 1.00742 | 1.00734 | 1.00727 | 1.00720 | 1.00715 | 1.02189 | 1.02118 | 1.02154 | 1.02141 | 1.02130 |
| 0.20 | 1.00844 | 1.00835 | 1.00828 | 1.00821 | 1.00841 | 1.02495 | 1.02474 | 1.00245<br>6 | 1.02441 | 1.02428 |

**[ PEG 8000 ] = 4% w/w**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | 1.00064 | 1.00064 | 1.00063 | 1.00063 | 1.00063 | 1.00057 | 1.00056 | 1.00055 | 1.00054 | 1.00054 |
| 0.04 | 1.00128 | 1.00128 | 1.00127 | 1.00126 | 1.00127 | 1.00125 | 1.00123 | 1.00122 | 1.00120 | 1.00119 |
| 0.06 | 1.00192 | 1.00191 | 1.00190 | 1.00190 | 1.00189 | 1.00195 | 1.00191 | 1.00190 | 1.00188 | 1.00187 |
| 0.08 | 1.00258 | 1.00252 | 1.00253 | 1.00253 | 1.00255 | 1.00266 | 1.00262 | 1.00259 | 1.00258 | 1.00255 |
| 0.10 | 1.00324 | 1.00315 | 1.00318 | 1.00316 | 1.00316 | 1.00339 | 1.00336 | 1.00331 | 1.00328 | 1.00325 |
| 0.12 | 1.00387 | 1.00377 | 1.00381 | 1.00379 | 1.00380 | 1.00413 | 1.00411 | 1.00411 | 1.00402 | 1.00400 |
| 0.14 | 1.00457 | 1.00445 | 1.00442 | 1.00444 | 1.00449 | 1.00488 | 1.00489 | 1.00476 | 1.00475 | 1.00475 |
| 0.16 | 1.00534 | 1.00510 | 1.00513 | 1.00503 | 1.00519 | 1.00566 | 1.00566 | 1.00552 | 1.00554 | 1.00556 |
| 0.18 | 1.00609 | 1.00584 | 1.00572 | 1.00566 | 1.00585 | 1.00644 | 1.00648 | 1.00634 | 1.00628 | 1.00639 |
| 0.20 | 1.00687 | 1.00656 | 1.00637 | 1.00632 | 1.00644 | 1.00726 | 1.00728 | 1.00716 | 1.00712 | 1.00723 |

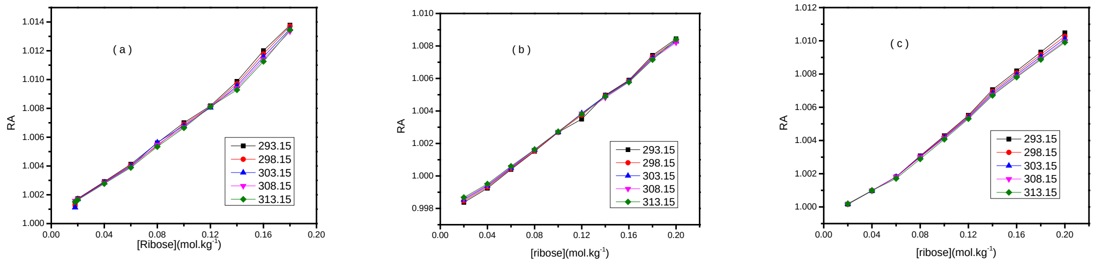


**Figure 9.** Plots of *RA* vs. [Ribose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

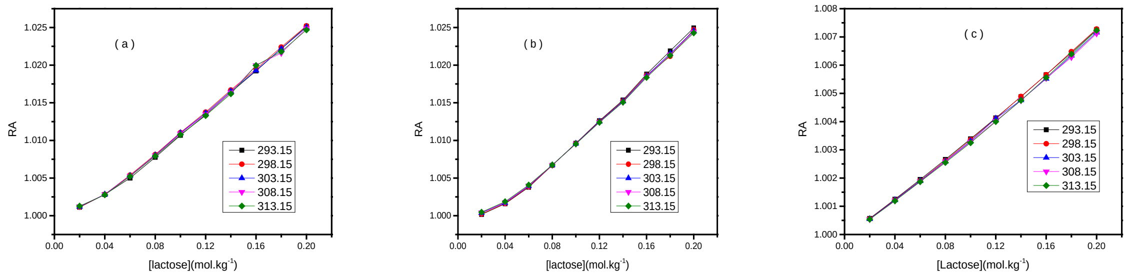


**Figure 10.** Plots of RA vs. [Lactose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

**Table 6: Specific acoustic impedance, $Z$ (kg·m$^{-2}$·s$^{-1}$), for Ribose and Lactose in aqueous solutions of PEG 8000 at different temperatures (K).**

| Conc. (mol·kg$^{-1}$) | $Z$, $10^{-5}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0% w/w | | | | | | | | | | |
| 0.02 | 14.83 | 14.95 | 15.05 | 15.12 | 15.19 | 14.81 | 14.93 | 15.04 | 15.12 | 15.28 |
| 0.04 | 14.84 | 14.96 | 15.06 | 15.14 | 15.20 | 14.85 | 14.98 | 15.08 | 15.16 | 15.22 |
| 0.06 | 14.86 | 14.98 | 15.08 | 15.16 | 15.22 | 14.90 | 15.03 | 15.13 | 15.21 | 15.27 |
| 0.08 | 14.88 | 15.00 | 15.10 | 15.18 | 15.24 | 14.96 | 15.08 | 15.18 | 15.26 | 15.32 |
| 0.10 | 14.92 | 15.04 | 15.14 | 15.21 | 15.27 | 15.02 | 15.14 | 15.24 | 15.32 | 15.38 |
| 0.12 | 14.94 | 15.06 | 15.16 | 15.24 | 15.30 | 15.07 | 15.19 | 15.29 | 15.37 | 15.43 |
| 0.14 | 14.96 | 15.08 | 15.18 | 15.26 | 15.33 | 15.13 | 15.25 | 15.35 | 15.43 | 15.48 |
| 0.16 | 15.00 | 15.12 | 15.21 | 15.29 | 15.36 | 15.19 | 15.30 | 15.40 | 15.47 | 15.53 |
| 0.18 | 15.04 | 15.16 | 15.26 | 15.33 | 15.40 | 15.24 | 15.36 | 15.46 | 15.52 | 15.59 |

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-9, Issue-12, December 2023
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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.20 | 15.08 | 15.19 | 15.29 | 15.37 | 15.44 | 15.30 | 15.42 | 15.51 | 15.58 | 15.65 |
| **[ PEG 8000 ] = 2% w/w** | | | | | | | | | | |
| 0.02 | 14.98 | 15.09 | 15.18 | 15.25 | 15.31 | 14.96 | 15.07 | 15.17 | 15.24 | 15.30 |
| 0.04 | 15.00 | 15.11 | 15.20 | 15.27 | 15.33 | 15.02 | 15.13 | 15.22 | 15.30 | 15.35 |
| 0.06 | 15.02 | 15.13 | 15.22 | 15.30 | 15.35 | 15.08 | 15.19 | 15.28 | 15.35 | 15.41 |
| 0.08 | 15.04 | 15.15 | 15.25 | 15.32 | 15.37 | 15.14 | 15.25 | 15.34 | 15.41 | 15.47 |
| 0.10 | 15.07 | 15.18 | 15.27 | 15.34 | 15.39 | 15.20 | 15.31 | 15.40 | 15.47 | 15.52 |
| 0.12 | 15.08 | 15.19 | 15.28 | 15.36 | 15.41 | 15.26 | 15.37 | 15.46 | 15.53 | 15.58 |
| 0.14 | 15.11 | 15.22 | 15.31 | 15.38 | 15.41 | 15.31 | 15.42 | 15.51 | 15.58 | 15.63 |
| 0.16 | 15.13 | 15.24 | 15.33 | 15.40 | 15.43 | 15.38 | 15.49 | 15.58 | 15.65 | 15.70 |
| 0.18 | 15.16 | 15.27 | 15.36 | 15.43 | 15.45 | 15.44 | 15.54 | 15.64 | 15.71 | 15.75 |
| 0.20 | 15.18 | 15.29 | 15.38 | 15.45 | 15.48 | 15.51 | 15.61 | 15.70 | 15.77 | 15.81 |
| **[PEG 8000 ] = 4% w/w** | | | | | | | | | | |
| 0.02 | 15.04 | 15.15 | 15.25 | 15.32 | 15.38 | 15.12 | 15.23 | 15.31 | 15.37 | 15.41 |
| 0.04 | 15.07 | 15.18 | 15.27 | 15.35 | 15.40 | 15.16 | 15.27 | 15.35 | 15.42 | 15.45 |
| 0.06 | 15.10 | 15.21 | 15.30 | 15.38 | 15.43 | 15.20 | 15.31 | 15.39 | 15.46 | 15.49 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.08 | 15.13 | 15.24 | 15.33 | 15.40 | 15.46 | 15.26 | 15.36 | 15.43 | 15.50 | 15.52 |
| 0.10 | 15.16 | 15.27 | 15.36 | 15.43 | 15.49 | 15.32 | 15.42 | 15.48 | 15.54 | 15.57 |
| 0.12 | 15.19 | 15.30 | 15.39 | 15.47 | 15.52 | 15.38 | 15.46 | 15.52 | 15.58 | 15.61 |
| 0.14 | 15.23 | 15.34 | 15.43 | 15.50 | 15.55 | 15.44 | 15.51 | 15.56 | 15.62 | 15.65 |
| 0.16 | 15.26 | 15.37 | 15.46 | 15.53 | 15.58 | 15.49 | 15.56 | 15.60 | 15.66 | 15.70 |
| 0.18 | 15.30 | 15.41 | 15.50 | 15.57 | 15.61 | 15.55 | 15.61 | 15.64 | 15.70 | 15.74 |
| 0.20 | 15.33 | 15.44 | 15.53 | 15.60 | 15.65 | 15.60 | 15.64 | 15.68 | 15.74 | 15.78 |

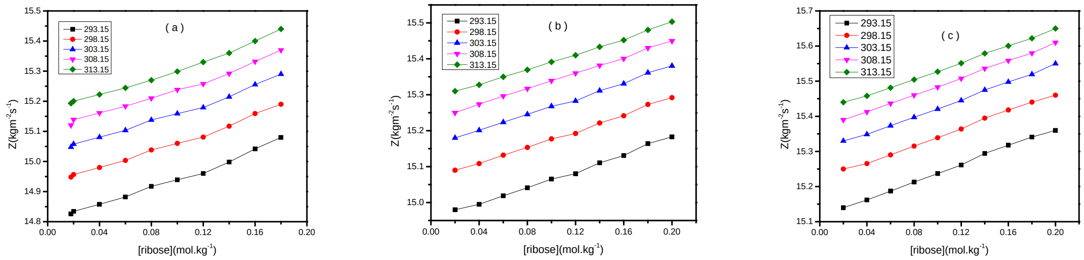


**Figure 11.** Plots of *Z* vs. [Ribose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

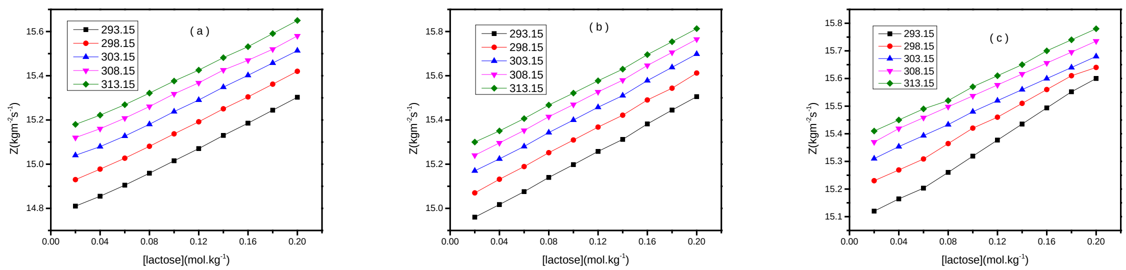


**Figure 12.** Plots of Z vs. [Lactose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-9, Issue-12, December 2023
ISSN: 2395-3470
www.ijseas.com

**Table 7: Molar sound number, $[U]$ for Ribose and Lactose in aqueous solutions of PEG 8000 at different temperatures (K).**

| Conc. (mol·kg$^{-1}$) | $[U]$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ribose | | | | | Lactose | | | | |
| | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| [ PEG 8000 ] = 0% w/w | | | | | | | | | | |
| 0.02 | 0.0378 | 0.0362 | 0.0354 | 0.0338 | 0.0323 | 0.0201 | 0.0192 | 0.0181 | 0.0170 | 0.0161 |
| 0.04 | 0.0382 | 0.0365 | 0.0358 | 0.0352 | 0.0337 | 0.0225 | 0.0219 | 0.0213 | 0.0207 | 0.0202 |
| 0.06 | 0.0398 | 0.0379 | 0.0373 | 0.0365 | 0.0352 | 0.0252 | 0.0247 | 0.0242 | 0.0236 | 0.0230 |
| 0.08 | 0.0412 | 0.0396 | 0.0388 | 0.0376 | 0.0364 | 0.0276 | 0.0269 | 0.0263 | 0.0257 | 0.0251 |
| 0.10 | 0.0428 | 0.0412 | 0.0403 | 0.0387 | 0.0374 | 0.0301 | 0.0296 | 0.0289 | 0.0284 | 0.0278 |
| 0.12 | 0.0441 | 0.0423 | 0.0416 | 0.0399 | 0.0389 | 0.0327 | 0.0321 | 0.0314 | 0.0308 | 0.0301 |
| 0.14 | 0.0457 | 0.0436 | 0.0427 | 0.0411 | 0.0402 | 0.0352 | 0.0345 | 0.0340 | 0.0333 | 0.0327 |
| 0.16 | 0.0472 | 0.0448 | 0.0443 | 0.0426 | 0.0419 | 0.0376 | 0.0371 | 0.0368 | 0.0362 | 0.0356 |
| 0.18 | 0.0486 | 0.0463 | 0.0458 | 0.0441 | 0.0433 | 0.0403 | 0.0397 | 0.0392 | 0.0386 | 0.0381 |

*International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-9, Issue-12, December 2023*
*ISSN: 2395-3470*
*www.ijseas.com*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.20 | | 0.0499 | 0.0475 | 0.0470 | 0.0455 | 0.0446 | | 0.0426 | 0.0420 | 0.0413 | 0.0408 | 0.0402 |
| **[ PEG 8000 ] = 2% w/w** | | | | | | | | | | | |
| 0.02 | | -0.0268 | -0.0288 | -0.0318 | -0.0338 | -0.0358 | | -0.0987 | -0.0897 | -0.0778 | -0.0708 | -0.0623 |
| 0.04 | | -0.0202 | -0.0222 | -0.0242 | -0.0262 | -0.0282 | | -0.0756 | -0.0666 | -0.0560 | -0.0470 | -0.0382 |
| 0.06 | | -0.0165 | -0.0185 | -0.0205 | -0.0225 | -0.0245 | | -0.0552 | -0.0457 | -0.0362 | -0.0275 | -0.0180 |
| 0.08 | | -0.0102 | -0.0122 | -0.0142 | -0.0162 | -0.0182 | | -0.0389 | -0.0296 | -0.0188 | -0.0094 | -0.0012 |
| 0.10 | | -0.0058 | -0.0078 | -0.0098 | -0.0118 | -0.0138 | | -0.0235 | -0.0136 | -0.0032 | 0.0059 | 0.0151 |
| 0.12 | | 0.0007 | -0.0.12 | -0.0032 | -0.0052 | -0.0072 | | -0.0078 | 0.0041 | 0.0148 | 0.0238 | 0.0330 |
| 0.14 | | 0.0063 | 0.0043 | 0.0023 | 0.0003 | -0.0021 | | 0.0037 | 0.0143 | 0.0250 | 0.0351 | 0.0448 |
| 0.16 | | 0.0094 | 0.0074 | 0.0054 | 0.0034 | 0.0013 | | 0.0165 | 0.0269 | 0.0375 | 0.0489 | 0.0579 |
| 0.18 | | 0.0140 | 0.0120 | 0.0100 | 0.0080 | 0.0060 | | 0.0312 | 0.0410 | 0.0514 | 0.0619 | 0.0712 |
| 0.20 | | 0.0194 | 0.0165 | 0.0145 | 0.0116 | 0.0097 | | 0.0505 | 0.0601 | 0.0709 | 0.0814 | 0.0919 |
| **[ PEG 8000 ] = 4% w/w** | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | | 0.0448 | 0.0421 | 0.0411 | 0.0398 | 0.0383 | | -0.2111 | -0.2085 | -0.2063 | -0.2039 | -0.2021 |
| 0.04 | | 0.0458 | 0.0436 | 0.0417 | 0.0410 | 0.0391 | | -0.1887 | -0.1857 | -0.1827 | -0.1805 | -0.1793 |
| 0.06 | | 0.0469 | 0.0452 | 0.0436 | 0.0418 | 0.0409 | | -0.1652 | -0.1625 | -0.1603 | -0.1591 | -0.1580 |
| 0.08 | | 0.0478 | 0.0470 | 0.0449 | 0.0431 | 0.0419 | | -0.1419 | -0.1393 | -0.1378 | -0.1358 | -0.1345 |
| 0.10 | | 0.0489 | 0.0488 | 0.0461 | 0.0443 | 0.0432 | | -0.1186 | -0.1162 | -0.1141 | -0.1127 | -0.1108 |
| 0.12 | | 0.0507 | 0.0503 | 0.0472 | 0.0457 | 0.0441 | | -0.0962 | -0.0943 | -0.0914 | -0.0893 | -0.0878 |
| 0.14 | | 0.0520 | 0.0512 | 0.0488 | 0.0468 | 0.0448 | | -0.0714 | -0.0685 | -0.0665 | -0.0639 | -0.0621 |
| 0.16 | | 0.0527 | 0.0524 | 0.0495 | 0.0487 | 0.0457 | | -0.0485 | -0.0459 | -0.0434 | -0.0413 | -0.0401 |
| 0.18 | | 0.0535 | 0.0527 | 0.0513 | 0.0499 | 0.0467 | | -0.0275 | -0.0251 | -0.0225 | -0.0204 | -0.0185 |
| 0.20 | | 0.0543 | 0.0541 | 0.0527 | 0.0511 | 0.0488 | | -0.0075 | -0.0053 | -0.0027 | -0.0013 | -0.0008 |

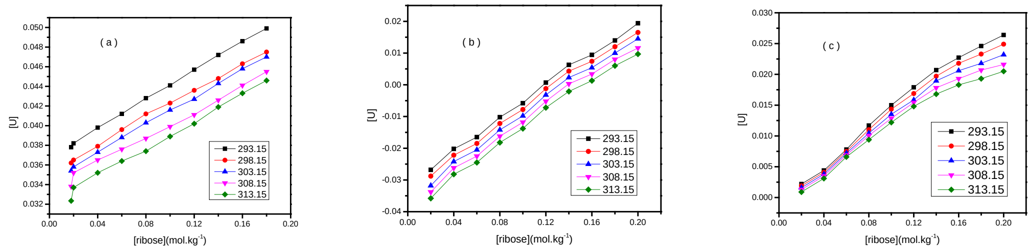


**Figure 13.** Plots of [U] vs. [Ribose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperatures.

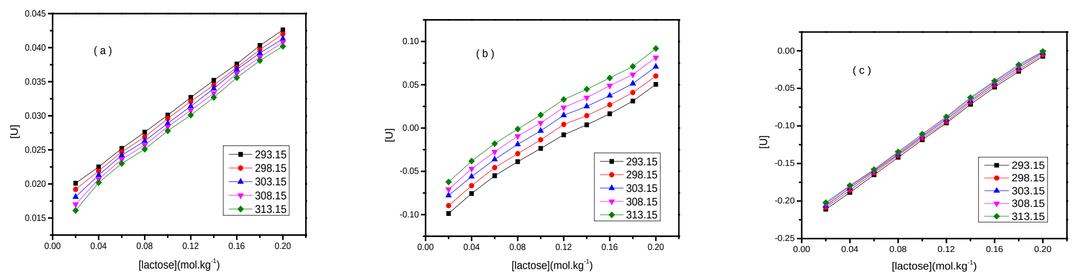


**Figure 14.** Plots of [U] vs. [Lactose] in (a) 0% w/w, (b) 2% w/w and (c) 4% w/w aqueous solutions of PEG 8000 at different temperature.

### 3.2 UV-Visible Probe Studies

UV-Visible studies have been employed to explore the interactions among the various component of a system. The solution of carbohydrates and polymer exhibits characteristic absorption spectra in UV-region [32-35]. The alteration of absorption maximum for carbohydrates (0.02-0.20 mol.kg$^{-1}$) in aqueous solutions of PEG 8000 (0.00, 2.00 and 4.00 % w/w) depends upon the nature and concentration of the solute (carbohydrates)/solvent (PEG8000). A detailed examination of **Figure 15** reveals that absorbance maximum increases with augment in content of carbohydrates (ribose and lactose) and PEG80000 at 298.15K. The absorbance value pursue the order given as: **Lactose > Ribose** and 4.00 > 2.00 > 0.00 % w/w of PEG8000. This effect may accredited to increase in physico-chemical interactions i.e. hydrophilic-hydrophilic and ion-hydrophilic interactions in the ternary systems. These outcomes are in compliance with that of results accessed from acoustical studies.

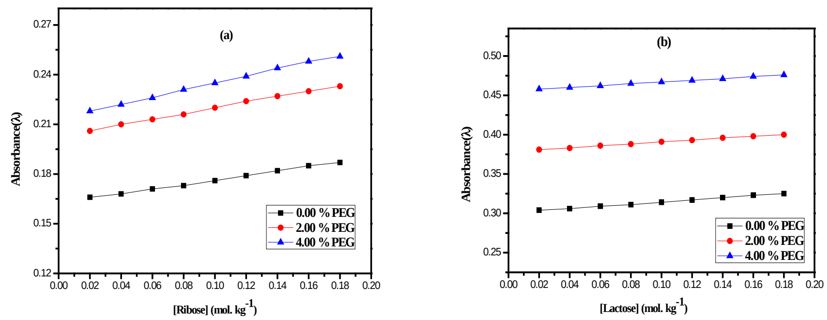


**Figure 15.** Plots of λ vs. [conc.] of (a) ribose(b) Lactose in (■) 0.00 %, (●) 2.00 %, and 4.00 % (▲) aqueous solutions of PEG.

## CONCLUSION

In this study, we investigate the intermolecular interactions of saccharides, specifically ribose and lactose, in aqueous solutions of Polyethylene glycol 8000. Through experimental techniques including density, speed of sound, and UV-Visible spectroscopy measurements, our primary goal is to gain a comprehensive understanding of these interactions. Our analysis of volumetric ($V_{\phi,}$), compressibility ($\kappa_{\phi,s}$, $k_{s,\phi}^{0}$), and thermo-acoustical parameters ($L_f$, U, Z, RA) as functions of concentration and temperature reveals substantial interactions between solvent and solute molecules. Notably, these interactions exhibit a pronounced dependence on both polymer concentration and temperature. A key observation is the comparison between ribose and lactose in the ternary system, highlighting the dominance of intermolecular interactions, particularly in the case of lactose. Our UV-Vis spectral studies complement and reinforce the results obtained from acoustical and volumetric analyses, providing additional insights into the various modes of interaction, such as ion-hydrophilic and hydrophilic-hydrophilic interactions.

In summary, our research significantly contributes to the understanding of how polymers interact with carbohydrates, shedding light on the intricate dynamics of these systems and offering valuable insights for applications in diverse fields.

### Acknowledgements

Kiran Negi expresses gratitude to the University Grants Commission (UGC) in New Delhi for bestowing upon them the Junior Research Fellowship and Senior Research Fellowship, with reference to Ref. No. 33/ (CSIR-UGC NET DEC. 2017). The generous financial assistance provided to the Department of Chemistry at HPU Shimla by UGC-SAP (DRS-I, II, and III) (No.F.540/3DRS/2010 and F.540/2/DRS-II/2018(SAP-1)) is also sincerely acknowledged.

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