Original Research Paper

Speed of Sound and Apparent Molal Volume Approach to Study the Ion-Solvent Interactions in Pharmaceutically Important Liquid Systems

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Abstract: Presence of zinc ion and lactose in different pharmaceutical compositions have been inspired to investigate the ion-solvation and related interactions among the components in solution media. This study has been carried out by the measurements of ultrasonic velocity, viscosity and density for the binary solutions of zinc sulphate (ZnSO₄) in lactose-water mixed solvent systems at 303.15, 308.15, 313.15 K temperature and at atmospheric pressure. Different thermo-acoustic parameters such as isentropic compressibility, apparent molal volume, solvation number, free volume, internal pressure etc., have been evaluated from the measured values. All these parameters have been analyzed in the light of molecular interactions from their variations against concentration as well as temperature. Presence of ion-solvation and structure promoting nature of solute are the major findings in the present investigation. Besides, it also reveals that the ion-solvation decreases as the temperature increases.

Keywords: Solute-Solvent Interaction, Ion-Solvation, Thermo-Acoustic Parameters, Apparent Molal Compressibility

Introduction

Certain metal ions are essential for different types of critical functions in human organs. Scarcity of such metal ions can lead to many complicated diseases. Few alkali metals including some transition metals are currently known to be required for normal biological functions in humans and even other living organisms (Lane and Morel, 2006; Staiger and Pietak, 2006). Zinc is an essential and most important trace element in biological systems (Coleman, 1967). It is the second most abundant transition metal in organisms after iron and it is the only metal which appears in all enzyme classes (Wapnir, 1990; Broadley et al., 2007). Zinc metal is mostly present in the brain, muscle, bones, kidney and liver (Pfeiffer and Braverman, 1982). Deficiency of zinc produces growth retardation, skin lesions, poor appetite and loss of body hair etc. Even the deficiency of this metalion affects adversely chronic diseases like neurological disorders, Alzheimer’s disease and other age-related diseases (Evans, 1986). The unique properties of zinc may have significant therapeutic benefits in these diseases. Besides, zinc ions along with other metal ions such as magnesium, potassium, sodium etc., have their importance in pharmaceutics for the preparations of various drugs. Especially, zinc sulfate is used to treat and to prevent zinc deficiency and also it is used as an alternative to, or in a rotation with, copper sulphate for controlling digital dermatitis. It is supposed to be a better supplement for chronic diarrhea (Khan and Sellen, 2011).

In continuation of our earlier works on ion solvation (Kamila et al., 2017; Dash and Kamila, 2017), presently the inter-molecular interactions of zinc sulphate are studied with a saccharide like lactose in water systems. Generally, carbohydrates are supposed to be the major component of the entire living organisms in energy production and other protein synthesis processes. Various saccharides are known to have their functions as stabilizing agents for the native state of proteins and enzymes (Dash and Kamila, 2015; Kannappan and Vinayagam, 2006). They also show their importance in the field of chemicals, bio-chemicals, foods and pharmaceutical industries. Besides, it is exclusively present in milk apart from medicines and culture media. Absorption of lactose is dependent upon the enzyme
lactase that enhances the absorption of calcium, magnesium and zinc. It also promotes the growth of lactobacilli and provides galactose, which is essential for the formation of cerebral galactolipids and hence development of the brain. Review of literature shows that zinc sulphate mixed with lactose of different potencies is used in homeopathy for the biological activity (Chauhan et al., 2013).

Number of studies has been reported for various electrolytes with mixed solvent systems for the intermolecular association studies (Kamila et al., 2017; Dash and Kamila, 2017; 2015; Kannappan and Vinayagam, 2006; Jones and Dole, 1929; Nain et al., 2013a). Besides, interaction studies have also been reported using different carbohydrates as major reacting components in the binary systems (Gupta, 1991; Timasheff and Arakawa, 1989; Nithyanantham and Palaniappan, 2013; Kannappan and Palani, 2007). But, however, studies involving transition metal ion with a disaccharide in mixed solvent system is scarce in literature. So an attempt has been made to study the solvation of zinc sulphate in lactose-water mixed solvent system at three different temperatures.

Material and Methods

Analytical grade zinc sulphate heptahydrate and lactose were procured from Qualigen Chemicals (more than 99.9% purity). Stock solutions of lactose were prepared by taking accurate weight of solute in freshly prepared double distilled water (w/v ratio). The water-lactose mixed solvent system varies from 0% to 10% (w/v). Similarly, different ZnSO₄ solutions in lactose-water mixed solvents were prepared by taking exact amount of ZnSO₄ in mixed solvents and the concentration of zinc sulphate varies from 0.01 to 0.1 mole dm⁻³. The solutions were kept for half an hour in a thermostat to acquire different temperature with an accuracy of 0.01K. The densities of all solutions were measured by a bicapillary pyknometer with deionized double distilled water with 0.9960×10³ kg m⁻³ as its density at different temperatures. The precision of density measurements was within ±0.0003 kg m⁻³. The viscosity measurements of the solutions were carried out by using a calibrated Ostwald viscometer. The constant temperature was maintained by immersing the viscometer in a water bath maintained within ±0.01K. The ultrasonic velocity of all the solutions were measured at 303.15K, 308.15K, 313.15K temperature and atmospheric pressure by a Mittal make (India) single-crystal variable-path ultrasonic interferometer operating at 3 MHz by circulating water from a thermostatically regulated bath maintained within ±0.01K around the sample holder for constant temperature. The velocity measurements were précised to ± 0.5 ms⁻¹.

Results

These measured values of ultrasonic velocity, density and viscosity were used to evaluate different acoustic parameters such as isentropic compressibility, β, the intermolecular free length, Lᵢ, using standard formulae (Franks et al., 1972; Kaulgud, 1976; Kamila et al., 2005). In addition, parameters like free volume, Vᵢ, internal pressure, πᵢ, relaxation time, τ and relative association, R₄ were calculated using following relations (Kamila et al., 2017):

\[ Vᵢ = \left( \frac{M_{eff}U}{K} \right)^{\frac{1}{2}} \]  

(1)

\[ πᵢ = bRT \left( \frac{K}{U} \right)^{\frac{1}{2}} \frac{\rho^{2/3}}{M_{eff}^{3/4}} \]  

(2)

\[ τ = 4/3pU^{2} \]  

(3)

\[ RA = \left( \frac{ρ}{ρ₀} \right) \left( \frac{U_{i}}{U} \right)^{\frac{3}{2}} \]  

(4)

where, b is the space packing factor generally 2 for liquids, R is the gas constant, T is absolute temperature and K is a constant equal to 4.28×10⁹, independent of temperature for all types of liquids. M_{eff} is the effective molecular mass. Similarly, Parameters like apparent molal volume, \( \phi_{v} \) and apparent molal compressibility, \( \phi_{c} \) can be determined by using the following formulæ (Kamila and Dash, 2012; Kamila et al., 2004; Nain et al., 2013b; Wadi and Ramasami, 1997):

\[ \phi_{v} = \frac{1000(ρ₀ - ρ)}{cρ₀} + \frac{M}{ρ} \]  

(5)

\[ \phi_{c} = \frac{1000(β₀ν₀ - βν₀ρ)}{cρ₀} + \frac{βM}{ρ} \]  

(6)

where, ρ₀ and β₀ν₀ are the density and isentropic compressibility of the solvent (aqueous-lactose), ρ and β are those of solution, respectively. c is the molarity of the solution, M is the molar mass of the solute (zinc sulphate), n₀ and n are the moles of solvent and solute, respectively.

The limiting apparent molal volume \( \phi_{v} \) was obtained using the method of linear regression from Masson’s equation (Masson, 1929) based on Debye- Hückel theory as follows (Debye and Hückel, 1923):

\[ φ_v = φ_v^0 + S \cdot c^{1/2} \]  

(7)

where, \( φ_v^0 \) and S, are the intercept and slope in the plot of \( φ_v \) against \( c^{1/2} \). Similarly, the limiting apparent molal
compressibility, $\phi^0_k$, is obtained from Gucker’s limiting law (Gucker Jr., 1933), which states $\phi_k$ as:

$$\phi_k = \phi^0_k + S_k e^{\frac{k}{2}}$$ (8)

where, $S_k$ is the slope related to ion-ion interaction and $\phi^0_k$ is the intercept related to ion-solvent interaction. The slope and intercept are obtained from the plot of $\phi_k$ against $e^{\frac{k}{2}}$. Solvation number, $S_n$, suggested by Passynski (1938) was calculated to assess the mode of association:

$$S_n = \frac{n_0}{n_1} \left( 1 - \frac{\beta}{\beta^0} \right)$$ (9)

where, $n_0$ and $n_1$ are the moles of solvent and solute, respectively. The limiting solvation number, $S_n^0$, is determined from the variation of the solvation number with molar concentration of solute. It can be calculated from the following relation:

$$\lim_{c \to 0} \phi^0_k = -S^0_n V^0_i \beta^0$$ (10)

where, $V^0_i$ is the molar volume of the solvent having moles of solvent as $n_1$.

The measured values of density, viscosity, ultrasonic velocity and computed values of other relevant acoustic parameters of zinc sulphate in water and different proportions of lactose-water systems at 303.15 K, 308.15 K and 313.15 K have been summarized in Table 1 to 5 whereas some parameters are graphically represented as figures.

**Discussion**

From the observations obtained in the present study, it reveals that the sound velocity, density and viscosity increase with the increase in the concentration of both zinc sulphate and lactose. As the concentration increases, the number of molecules in the medium increases. This makes the medium denser and reduces compressibility resulting in the increment of the sound velocity. The velocity was also found to increase with temperature indicating the structural rearrangement due to solvation (Singh and Banipal, 2008; Palani and Jayachitra, 2008). According to Thirumaran and Kannappan (2009), the increase in ultrasonic velocity with solute concentration and temperature is due to the cohesion brought about by ionic hydration. The increase in components increases the frictional resistance between the layers of the liquids and hence there is enhancement of coefficient of viscosity (Table 1). This decreases with temperature due to reduction in frictional forces among the particles.

![Fig. 1: Variation of isentropic compressibility, $\beta$, vs. Concentration of ZnSO$_4$ in water and Lactose-water mixed solvent at 303.15K](image-url)
This behaviour increases in volumetric concentration of the solution. Moreover, there is breakage in the molecular structure of water with the addition of solute and making a more compact structure with the water molecules surrounded by the solute in mixed solvent. Santosh et al. (2011) also have reported similar type of observations and which was depicted as the existence of strong solute–solvent interactions through dipole–dipole and acceptor-donor interactions (Rao and Verrall, 1987; Nikam et al., 2000). This behaviour increases the intermolecular association and decreases $\beta_s$ (Savaroglu and Ozdemir, 2008; Fort and Moore, 1965). There is also decrease in compressibility with temperature due to thermal expansion of the liquid systems (Fig. 2).

This compactness among the particles also reduces the intermolecular free length. According to literature, such type of behaviour is indicative of structure-promoting tendency of added solute as well as presence of water mixed solvent at 303.15, 308.15 and 313.15K temperature

Table 1: Experimentally determined density, $\rho$, viscosity, $\eta$ and ultrasonic velocity, $U$ of ZnSO$_4$ in water, 2.5%, 5.0%, 7.5% and 10% lactose-water mixed solvent at 303.15, 308.15 and 313.15K temperature

| C mol.kg$^{-1}$ | $\rho \times 10^3$ kg.m$^{-3}$ | $\eta \times 10^3$ kg.m$^{-1}$s$^{-1}$ | $U$ m.s$^{-1}$ |
|-----------------|-------------------------------|--------------------------------------|--------------|
|                 | 303.15K                       | 308.15K                              | 313.15K      |
|                 | ZnSO$_4$ in Water              | ZnSO$_4$ in 2.5% Lactose-Water        | ZnSO$_4$ in 5% Lactose-Water        |
|                 | ZnSO$_4$ in 7.5% Lactose-Water | ZnSO$_4$ in 10% Lactose-Water        |              |
| 0.00            | 0.9964                        | 0.9950                               | 0.9937       |
| 0.01            | 0.9987                        | 0.9973                               | 0.9959       |
| 0.02            | 1.0008                        | 0.9995                               | 0.9976       |
| 0.04            | 1.0044                        | 1.0024                               | 1.0009       |
| 0.06            | 1.0073                        | 1.0045                               | 1.0040       |
| 0.08            | 1.0107                        | 1.0070                               | 1.0062       |
| 0.10            | 1.0136                        | 1.0096                               | 1.0089       |
| 0.00            | 1.0060                        | 1.0046                               | 1.0030       |
| 0.01            | 1.0079                        | 1.0066                               | 1.0050       |
| 0.02            | 1.0096                        | 1.0085                               | 1.0065       |
| 0.04            | 1.0129                        | 1.0117                               | 1.0096       |
| 0.06            | 1.0162                        | 1.0151                               | 1.0123       |
| 0.08            | 1.0191                        | 1.0184                               | 1.0152       |
| 0.10            | 1.0222                        | 1.0214                               | 1.0181       |
| 0.00            | 1.0151                        | 1.0143                               | 1.0125       |
| 0.01            | 1.0172                        | 1.0164                               | 1.0145       |
| 0.02            | 1.0192                        | 1.0181                               | 1.0163       |
| 0.04            | 1.0224                        | 1.0215                               | 1.0199       |
| 0.06            | 1.0259                        | 1.0249                               | 1.0234       |
| 0.08            | 1.0286                        | 1.0278                               | 1.0266       |
| 0.10            | 1.0309                        | 1.0293                               | 1.0281       |
| 0.00            | 1.0238                        | 1.0218                               | 1.0197       |
| 0.01            | 1.0262                        | 1.0241                               | 1.0220       |
| 0.02            | 1.0284                        | 1.0262                               | 1.0242       |
| 0.04            | 1.0323                        | 1.0302                               | 1.0284       |
| 0.06            | 1.0353                        | 1.0341                               | 1.0322       |
| 0.08            | 1.0385                        | 1.0369                               | 1.0352       |
| 0.10            | 1.0416                        | 1.0391                               | 1.0376       |
| 0.00            | 1.0327                        | 1.0311                               | 1.0302       |
| 0.01            | 1.0356                        | 1.0334                               | 1.0325       |
| 0.02            | 1.0370                        | 1.0356                               | 1.0345       |
| 0.04            | 1.0404                        | 1.0395                               | 1.0383       |
| 0.06            | 1.0435                        | 1.0421                               | 1.0413       |
| 0.08            | 1.0468                        | 1.0455                               | 1.0446       |
| 0.10            | 1.0495                        | 1.0477                               | 1.0467       |

Isentropic compressibility, $\beta_s$, an acoustic parameter, derived from the velocity data is known to be a sensitive indicator of the elasticity as well as of the molecular interactions of the system (Katrinak et al., 2012). In the present study, the compressibility decreases as the concentration of both zinc sulphate and lactose increases (Fig. 1). When the solute ion enters into the bulk of the solvent, the solvent molecules are attracted towards this ion because of electrostrictive force resulting in the decrease of solvent molecules for the incoming ions. This condition of the system is compression. Therefore, compressibility decreases with the increase in volumetric concentration of the solution. Moreover, there is breakage in the molecular structure of water with the addition of solute and making a more
Table 2: Calculated values of isentropic compressibility, $\beta_s$, intermolecular free length, $L_r$, free volume, $V_f$, of ZnSO$_4$ in water, 2.5%, 5.0%, 7.5% and 10% lactose-water mixed solvent at 303.15, 308.15 and 313.15K temperature

| C mol.kg$^{-1}$ | $\beta_s \times 10^{10}$ N$^{-1}$m$^2$ | $L_r \times 10^{11}$ M | $V_f \times 10^3$ m$^3$.mol$^{-1}$ |
|-----------------|--------------------------------------|-------------------------|----------------------------------|
|                 | ZnSO$_4$ in Water                     |                         |                                  |
| 0.00            | 4.4262                                | 4.3676                  | 4.3249                           |
| 0.01            | 4.4061                                | 4.3554                  | 4.3058                           |
| 0.02            | 4.3892                                | 4.3378                  | 4.2838                           |
| 0.04            | 4.3567                                | 4.3066                  | 4.2419                           |
| 0.06            | 4.3276                                | 4.2801                  | 4.2118                           |
| 0.08            | 4.3011                                | 4.2488                  | 4.1922                           |
| 0.10            | 4.2707                                | 4.2197                  | 4.1685                           |
|                 | ZnSO$_4$ in 2.5% Lactose-Water         |                         |                                  |
| 0.00            | 4.3326                                | 4.2904                  | 4.2419                           |
| 0.01            | 4.3125                                | 4.2706                  | 4.2241                           |
| 0.02            | 4.2978                                | 4.2525                  | 4.2084                           |
| 0.04            | 4.2765                                | 4.2197                  | 4.1862                           |
| 0.06            | 4.2537                                | 4.1968                  | 4.1594                           |
| 0.08            | 4.2299                                | 4.1728                  | 4.1394                           |
| 0.10            | 4.2071                                | 4.1497                  | 4.1159                           |
|                 | ZnSO$_4$ in 5% Lactose-Water          |                         |                                  |
| 0.00            | 4.2560                                | 4.1952                  | 4.1596                           |
| 0.01            | 4.2372                                | 4.1778                  | 4.1418                           |
| 0.02            | 4.2228                                | 4.1610                  | 4.1259                           |
| 0.04            | 4.1991                                | 4.1353                  | 4.0959                           |
| 0.06            | 4.1744                                | 4.1141                  | 4.0714                           |
| 0.08            | 4.1498                                | 4.0908                  | 4.0472                           |
| 0.10            | 4.1276                                | 4.0722                  | 4.0298                           |
|                 | ZnSO$_4$ in 7.5% Lactose-Water        |                         |                                  |
| 0.00            | 4.1780                                | 4.1266                  | 4.0978                           |
| 0.01            | 4.1552                                | 4.1067                  | 4.0790                           |
| 0.02            | 4.1360                                | 4.0887                  | 4.0629                           |
| 0.04            | 4.1107                                | 4.0670                  | 4.0318                           |
| 0.06            | 4.0850                                | 4.0397                  | 4.0081                           |
| 0.08            | 4.0602                                | 4.0184                  | 3.9817                           |
| 0.10            | 4.0335                                | 3.9933                  | 3.9602                           |
|                 | ZnSO$_4$ in 10% Lactose-Water         |                         |                                  |
| 0.00            | 4.0894                                | 4.0572                  | 4.0097                           |
| 0.01            | 4.0695                                | 4.0372                  | 3.9921                           |
| 0.02            | 4.0540                                | 4.0208                  | 3.9767                           |
| 0.04            | 4.0308                                | 3.9882                  | 3.9474                           |
| 0.06            | 4.0095                                | 3.9670                  | 3.9270                           |
| 0.08            | 3.9860                                | 3.9434                  | 3.9056                           |
| 0.10            | 3.9609                                | 3.9271                  | 3.8809                           |
Table 3: Calculated values of Internal pressure, \( \pi \), viscous relaxation time, \( \tau \), relative association, \( R_A \) of ZnSO\(_4\) in water, 2.5\%, 5.0\%, 7.5\% and 10% lactose-water mixed solvent at 303.15, 308.15 and 313.15K temperature

| C mol.kg\(^{-1}\) | 303.15K | 308.15K | 313.15K | 303.15K | 308.15K | 313.15K | 303.15K | 308.15K | 313.15K |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| \( \pi \times 10^9 \text{Pa} \) | 2.5955  | 2.5010  | 2.4208  | 4.7065  | 4.2118  | 3.8117  | 1.0019  | 1.0018  | 1.0016  |
| \( \tau \times 10^3 \text{s} \) | 0.01    | 2.6027  | 2.5094  | 2.4250  | 4.7315  | 4.2434  | 3.8252  | 1.0037  | 1.0037  | 1.0027  |
| \( R_A \) | 0.02    | 2.6029  | 2.5182  | 2.4264  | 4.7351  | 4.2742  | 3.8320  | 1.0067  | 1.0059  | 1.0049  |
| \( \text{ZnSO}_4 \text{ in Water} \) | 0.04    | 2.6053  | 2.5187  | 2.4290  | 4.7547  | 4.2916  | 3.8466  | 1.0090  | 1.0073  | 1.0074  |
| \( \text{ZnSO}_4 \text{ in 2.5\% Lactose-Water} \) | 0.06    | 2.6073  | 2.5163  | 2.4320  | 4.7805  | 4.3081  | 3.8692  | 1.0119  | 1.0090  | 1.0091  |
| \( \text{ZnSO}_4 \text{ in 5\% Lactose-Water} \) | 0.08    | 2.6128  | 2.5178  | 2.4303  | 4.8166  | 4.3321  | 3.8881  | 1.0141  | 1.0109  | 1.0114  |
| \( \text{ZnSO}_4 \text{ in 7.5\% Lactose-Water} \) | 0.10    | 2.6131  | 2.5173  | 2.4314  | 4.8345  | 4.3485  | 3.9095  | 1.0141  | 1.0109  | 1.0114  |
| \( \text{ZnSO}_4 \text{ in 10\% Lactose-Water} \) | 0.00    | 2.6121  | 2.5158  | 2.4290  | 4.8999  | 4.3887  | 3.9512  | 1.0014  | 1.0016  | 1.0016  |
| 0.01 | 2.6169  | 2.5218  | 2.4356  | 4.9202  | 4.4113  | 3.9746  | 1.0014  | 1.0016  | 1.0016  |
| 0.02 | 2.6207  | 2.5269  | 2.4409  | 4.9419  | 4.4323  | 3.9991  | 1.0028  | 1.0030  | 1.0027  |
| 0.04 | 2.6326  | 2.5279  | 2.4440  | 5.0075  | 4.4487  | 4.0266  | 1.0058  | 1.0055  | 1.0055  |
| 0.06 | 2.6355  | 2.5311  | 2.4468  | 5.0386  | 4.4766  | 4.0546  | 1.0087  | 1.0085  | 1.0075  |
| 0.08 | 2.6363  | 2.5331  | 2.4488  | 5.0646  | 4.5005  | 4.0815  | 1.0112  | 1.0114  | 1.0101  |
| 0.10 | 2.6462  | 2.5361  | 2.4521  | 5.1231  | 4.5299  | 4.1099  | 1.0138  | 1.0139  | 1.0125  |

The apparent molal volume, \( \phi \), shows positive value and increasing trends with lactose content in the solution (Fig. 6 and 7). Similarly, the limiting apparent molal volume, \( \phi^\infty \), provides information about ion-solvent interactions, which shows positive variation. Positive variations for both \( \phi \) and \( \phi^\infty \) (Table 4 and 5) are indicative of strong solute-solvent interactions in the systems (Parmar and Thakur, 2006; Rathore and Singh, 2006; Ali et al., 2002). Pinto et al. (2015) and Naseem and Ashraf (2016) have also reported similar type of observation for their systems. The constant \( S_\infty \) is indicative of ion-ion interaction and the values are positive but smaller in comparison to \( \phi^\infty \). According to Ali and Shahjahan (2016) such type of variations are due to weak ion-ion interactions.

The parameter, internal pressure is the cohesive force, which is due to the attractive and repulsive forces between the molecules (Kannappan et al., 2009). In the present systems, there is increase in internal pressure with the concentration of both ZnSO\(_4\) as well as lactose (Fig 8). This can be explained due to the strengthening of cohesive forces obtained during the structure making of solvents in presence of solute (Suryanarayanan and Kuppu Samy, 1981). This force, however decreases with the increase in temperature because of dispersion of solute molecules (Table. 3).
In the present study, the relaxation time, \( \tau \), is in the order of \( 10^{-13} \) and according to Kinsler and Ray (1989) this is due to structural relaxation process, which again suggests these molecules to be rearranged due to supportive process (Sawhney et al., 2014) (Fig. 9). The relative association, \( R_4 \), is the parameter that depends on the structure breaking behaviour of solute when it is added to solvent and the solvation of ions by the free solvent molecules (Palani and Geeta, 2007). However, the increase in \( R_4 \) is associated with the later effect as per the literature (Ali et al., 2001). Therefore in the present investigation, the solvation of solute predominates over the breaking of the solvent.
aggregates. Jahagirdar and Shankarwar (2000) have also reported similar kind of observations.

Fig. 2: Variation of isentropic compressibility, $\beta_s$ of ZnSO$_4$ in 2.5% Lactose-water vs. temperature

Fig. 3: Variation of apparent molal compressibility, $\phi_k$ of ZnSO$_4$ in 2.5% Lactose-water vs. Concentration of ZnSO$_4$ in water and Lactose-water mixed solvent at 303.15K

Fig. 4: Variation of apparent molal compressibility, $\phi_k$ of ZnSO$_4$ in 2.5% Lactose-water vs. Temperature

Fig. 5: Variation of free volume, $V_f$ vs. Concentration of ZnSO$_4$ in water and Lactose-water mixed solvent at 303.15K
Solvation number explains the interaction of solute with the solvent molecules present in the solutions. The positive values of solvation number in the present study indicate appreciable solvation of solutes (Mehraand and Sajnami, 2000). This is indicative of structure-promoting nature of solute and the positive values also suggest the compressibility to be less in solution in comparison to solvent. This increases the ion mobility and so also the probability to interact with the solvent molecules. The solvent molecules are attached to the ions by strong covalent bonds in the primary sheath of solvation and in the secondary sheath, there are weak forces of attraction between solute and solvent species (Dash and Kamila, 2017). In the present investigation, the solvation number decreases as the concentration of solute increases (Fig. 10). This is attributed to the decrease in the size of the secondary sheath of solvation. More over, $S_n$ decreases with increase in temperature, which shows weakening of solute-solvent interaction (Fig. 11). According to Marcus (2005), this number depends on both the ion and solvent involved as well as on the concentration through the interactions of this ion with other ions. However, the non-linear variation of solvation number with $\text{ZnSO}_4$ indicates the increase in ion-solvent interactions (Palani et al., 2001).
Conclusion

Acoustic studies involving ultrasonic velocity measurement are non-destructive techniques to access the molecular association among the components through ion-solvation. Besides, different other supporting parameters such as isentropic compressibility, internal pressure and apparent molal volume etc., have been evaluated at three different temperatures. The present study reports the existence of solute-solvent and solute-solute interaction between ZnSO₄ and aqueous lactose solution. From the Results and discussion, it reveals the structure-promoting tendency of added solute. The electrostrictive solvation of ions is supported by partial molal volume. The breaking of solvent structure was also confirmed from internal pressure as well as relative association, where the solvation of solute predominates over the breaking of the solvent aggregates. Sᵥ and Sₖ values show weak ion-ion interaction in the systems. The solvation number indicates appreciable ion solvation along with structure promoting nature of solute. However, the ion solvation decreases as the temperature increases. So overall, it can be concluded that the strength of interaction increases with increase in lactose as well as ZnSO₄ concentration. The decrease in solvation number with the increase in lactose concentration is indicative of the dehydrating effect of co-solute on ZnSO₄. This result would be of great importance to pharmaceutical industries for the
drugs related to lactose and ZnSO₄ for designing and delivery systems.

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Author’s Contributions

Ganesh Durgachalam Natraj: Ganesh is the first author and did all the experimental work along with data collection.

Vinay Sathyanarayan Bhat: Vinay’s contributions involve the evaluation and calculation part of different parameters.

Susmita Kamila: Susmita is the supervisor and the corresponding author. Her contribution includes Research planning, organizational designing and framework of the manuscript.

Conflict of Interest

The authors declares that they have no conflict of interest.

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