Study of Molecular Interaction of PEG-200 and PEG-600 in Aqueous D-Mannitol Solutions at Different Temperatures

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Abstract: The density and speed of sound for polyethylene glycols (PEG-200 and PEG-600) in an aqueous solution of D-Mannitol have been measured by Anton Paar DSA 5000M at different temperatures and concentrations. Experimentally obtained data of density and speed of sound are employed to calculate various theoretical parameters such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant, which gave the better insight into molecular interactions between the polyethylene glycols and D-mannitol solutions.

Keywords: density; the speed of sound; polyethylene glycols.

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1. Introduction

In the medical field, the use of chemicals attains attention in every sector, including ultrasonic behavior. When combined with other water resources, ultrasonic techniques are important to investigate molecular interactions. Ultrasonic techniques are widely used to learn about the different types of interaction present in the mixtures' molecules [1-4]. In the present years, ultrasonic techniques play a crucial role in finding physicochemical behavior. Ultrasonic techniques are an effective source of information about the structural and molecular changes in the mixture of liquid [5,6]. It is an interesting technique to study the properties of liquid-liquid mixtures, electrolytic solutions, and polymeric solutions. These mixtures have many applications in the pharmaceutical, leather, textiles, food, and chemical industries [7-9].

Volumetric and acoustical properties play an important role in examining structural properties. Polyethylene glycols are polyether compounds with numerous applications from modern manufacturing to medication. Polyethylene glycols belong to the polymer family, H-(O-CH2+CH2)-H-OH. The liquid form of the polymer plays a very important role in everyday life due to its extraordinary properties. Polyethylene is formed by various methods in addition to the polymerization of ethane. Polyethylene is commonly used in plastic, and its essential use is to make plastic bags, plastic films, containers including bottles, etc. [10].

D-Mannitol is a sugar alcohol and also has an acoustic property. D-Mannitol is a kind of sugar alcohol (polyol) used in medication due to its beneficial activity on the brain, kidneys, and heart. D-Mannitol is found in nature, especially in exudates from trees, and in marine green...
growth and crisp mushrooms. D-Mannitol is economically accessible in an assortment of powder and granular structures [11,12]. In the present work, the physicochemical behavior of polyethylene glycols in an aqueous D-Mannitol solution has been investigated by using the density and speed of sound data at different temperatures. The density and velocity data were utilized to calculate the ultrasonic parameters such as adiabatic compressibility, acoustic impedance, intermolecular free length, Wada's constant, Rao's constant, and Vander Waal's constant.

2. Materials and Methods

For the present investigation, polyethylene glycols with molar mass 200 g·mol⁻¹, and 600 g·mol⁻¹, respectively, and D-Mannitol with molar mass 182.17 g·mol⁻¹ are utilized. Chemicals have a purity of the order of ≥0.99. These chemicals were purchased from Loba Chemie Pvt. Ltd., India. All the solutions used in the measurement have been prepared in distilled water, and weighing was done by Sartorius CPA 225D balance with accuracy (±0.00001g). The Anton Paar density sound analyzer (DSA) 5000M is used to measure the density and speed of sound at different temperatures (293.15, 298.15, 303.15, and 308.15) K and constant frequency, i.e., 3 MHz. It is a two-in-one device that measures the density and speed of sound simultaneously and works on the piezoelectric effect. Fresh samples were made on the same day of measurement to prevent any aging effects. The syringe was used for inserting the samples into the device DSA (Density sound analyzer) very carefully (avoid air bubbles). After insert, the sample set the required temperature value, and the value of density and speed of sound was noticed from DSA. After obtaining, the syringe is taken out then the syringe and tube are washed with ether. The same further procedure has been used for other samples.

2.1. Theoretical considerations

The following equations are used to evaluate theoretical parameter intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant.

Acoustic impedance

\[ Z = \rho \times c \] (1)

Adiabatic compressibility

\[ \beta = \frac{1}{\rho (c^2)} \] (2)

Wada's constant

\[ W = \left( \beta \right)^{\frac{1}{3}} \left( \frac{M}{\rho} \right) \] (3)

Rao’s Constant

\[ R = \left( \frac{c^3}{M} \right) / \rho \] (4)

Intermolecular free length

\[ L_F = K_f (\beta)^{\frac{1}{2}} \] (5)

Vander Waal’s constant

\[ b = \left( \frac{M}{\rho} \right) [1 - (RT/Mc^2) \sqrt{1 + (Mc^2/3RT)} - 1] \] (6)

3. Results and Discussion

The density and ultrasonic speed for PEG-200 and PEG-600 in (0.01, 0.03, and 0.05) mol.kg⁻¹ D-Mannitol at different temperatures is obtained experimentally [13-15].
Experimental data utilized for calculated ultrasonic parameters are reported in Tables 1-6. Table 1 indicates the acoustic impedance values, and acoustic impedance values increase with the increase in molality and temperatures. The acoustic impedance value varies linearly with molality, which indicates the presence of strong interaction between the liquid mixtures and the acoustic impedance graphically represented in Figure 1. In Table 2, the decrease in the adiabatic compressibility with an increase in molality indicates the bond strength among molecules [16], and variation is shown in Figure 2. The variation of the Wada constant depicts the space between the solute and solvent molecules [17-19]. Table 3 and Figure 3. Represent the values and variation of Wada constant with molality and concentration. The Wada's constant decrease with an increase in molality and increase in temperatures [20]. The values of Rao's constant, intermolecular free length and Vander Waal constant also increase with the increase in temperature and decrease with increase in molality. Values are given in Table 4, 5, 6 and graphically represented in Figures 4, 5, and 6, respectively. Intermolecular free length depicts the strong solute-solvent interactions. The strong binding force is confirmed by the variation of the Vander Waal constant [21,22].

### Table 1. Values of Acoustic impedance of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

| m_A (mol.kg⁻¹) | Z/ (kg m⁻²S⁻¹) |
|------------------|-----------------|
|                  | T= 293.15 K     | T=298.15 K     | T= 303.15 K | T= 308.15 K |
|                  |                 |                 |             |             |
| PEG 200 + 0.01 m D-Mannitol |                 |                 |             |             |
| 0.00000          | 1480.618        | 1493.437        | 1504.088    | 1512.642    |
| 0.10160          | 1494.933        | 1507.628        | 1518.250    | 1525.673    |
| 0.20371          | 1509.396        | 1522.502        | 1532.734    | 1538.699    |
| 0.30012          | 1522.468        | 1536.284        | 1546.039    | 1551.231    |
| 0.40211          | 1537.168        | 1551.070        | 1560.619    | 1564.555    |
| 0.49810          | 1550.394        | 1564.726        | 1573.914    | 1576.946    |
| PEG 200 + 0.03 m D-Mannitol |                 |                 |             |             |
| 0.00000          | 1484.871        | 1497.442        | 1507.683    | 1516.365    |
| 0.10516          | 1498.830        | 1512.234        | 1522.308    | 1529.952    |
| 0.20753          | 1513.161        | 1527.091        | 1536.545    | 1543.323    |
| 0.30249          | 1526.425        | 1540.757        | 1549.572    | 1555.394    |
| 0.41702          | 1542.728        | 1557.410        | 1565.588    | 1570.449    |
| 0.49987          | 1554.180        | 1569.797        | 1577.411    | 1581.125    |
| PEG 200 + 0.05 m D-Mannitol |                 |                 |             |             |
| 0.00000          | 1489.131        | 1501.452        | 1511.283    | 1520.093    |
| 0.11021          | 1504.190        | 1517.130        | 1525.941    | 1534.542    |
| 0.20923          | 1518.035        | 1531.429        | 1539.012    | 1547.518    |
| 0.30703          | 1531.417        | 1545.879        | 1551.840    | 1560.508    |
| 0.39832          | 1544.394        | 1559.327        | 1564.075    | 1572.636    |
| 0.50431          | 1559.304        | 1575.217        | 1577.634    | 1586.716    |
| PEG 600 + 0.01 m D-Mannitol |                 |                 |             |             |
| 0.00000          | 1483.188        | 1496.909        | 1507.067    | 1516.588    |
| 0.10007          | 1526.090        | 1536.92         | 1547.997    | 1555.153    |
| 0.19940          | 1567.976        | 1579.567        | 1588.054    | 1593.849    |
| 0.30387          | 1612.554        | 1623.605        | 1630.708    | 1635.345    |
| 0.40836          | 1658.095        | 1667.935        | 1673.539    | 1677.163    |
| 0.51045          | 1702.070        | 1712.505        | 1716.259    | 1718.419    |
| PEG 600 + 0.03 m D-Mannitol |                 |                 |             |             |
| 0.00000          | 1487.812        | 1502.009        | 1510.652    | 1520.922    |
| 0.10164          | 1531.645        | 1543.818        | 1551.132    | 1559.823    |
| 0.19998          | 1573.766        | 1584.491        | 1590.872    | 1598.548    |
| 0.29836          | 1616.368        | 1626.210        | 1631.909    | 1638.256    |
| 0.40338          | 1662.135        | 1671.077        | 1675.085    | 1680.580    |
| 0.50796          | 1707.447        | 1716.593        | 1719.346    | 1723.080    |
Table 2. Values of adiabatic compressibility of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

| $^{a}m_{A}$ (mol.kg$^{-1}$) | $T= 293.15$ K | $T=298.15$ K | $T= 303.15$ K | $T= 308.15$ K |
|-----------------------------|---------------|---------------|---------------|---------------|
| PEG 600 + 0.05 m D-Mannitol |               |               |               |               |
| 0.00000                     | 1496.011      | 1508.060      | 1514.624      | 1524.413      |
| 0.10321                     | 1540.350      | 1550.584      | 1556.248      | 1564.556      |
| 0.20127                     | 1581.846      | 1591.407      | 1596.178      | 1603.461      |
| 0.29925                     | 1624.357      | 1633.087      | 1637.158      | 1643.354      |
| 0.40027                     | 1669.417      | 1676.852      | 1679.071      | 1684.514      |
| 0.50798                     | 1717.265      | 1723.932      | 1725.504      | 1728.478      |

$^{a}m_{A}$ is the molality of polyethylene glycols in the aqueous solution D-Mannitol.
### Table 3. Values of Wada constant $W$, of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

| $^\circ m_A$ / (mol.kg$^{-1}$) | $W$ / (m$^3$/mol) (Pa)$^{1/2}$ |
|-----------------------------|--------------------------------|
|                             | T= 293.15 K   | T=298.15 K   | T= 303.15 K   |
|                             | T= 298.15 K   | T= 303.15 K   | T= 308.15 K   |
| 0.00000                     | 161.2145      | 161.8319      | 162.4123      | 162.9805    |
| 0.10160                     | 161.1338      | 161.7440      | 162.3183      | 162.8503    |
| 0.20371                     | 161.0523      | 161.6703      | 162.2288      | 162.7108    |
| 0.30012                     | 160.9551      | 161.5893      | 162.1304      | 162.5877    |
| 0.40211                     | 160.8763      | 161.5090      | 162.0395      | 162.4574    |
| 0.49810                     | 160.7816      | 161.4208      | 161.9391      | 162.3294    |
| PEG 200 + 0.01 m D-Mannitol  |                             |               |               |
| 0.00000                     | 161.0828      | 161.7007      | 162.2525      | 162.8271    |
| 0.10516                     | 160.9839      | 161.6251      | 162.1728      | 162.7148    |
| 0.20753                     | 160.9080      | 161.5611      | 162.0907      | 162.6041    |
| 0.30249                     | 160.8343      | 161.4960      | 162.0344      | 162.4892    |
| 0.41702                     | 160.7515      | 161.4193      | 161.9074      | 162.3596    |
| 0.49987                     | 160.6795      | 161.3711      | 161.8401      | 162.2612    |
| PEG 200 + 0.03 m D-Mannitol  |                             |               |               |
| 0.00000                     | 160.9513      | 161.5697      | 162.0931      | 162.6741    |
| 0.11021                     | 160.8604      | 161.4953      | 161.9876      | 162.5591    |
| 0.20923                     | 160.7858      | 161.4293      | 161.8849      | 162.4513    |
| 0.30703                     | 160.7009      | 161.3718      | 161.7776      | 162.3472    |
| 0.39832                     | 160.6342      | 161.3149      | 161.6836      | 162.2469    |
| 0.50431                     | 160.5495      | 161.2545      | 161.5525      | 162.1288    |
| PEG 600 + 0.01 m D-Mannitol  |                             |               |               |
| 0.00000                     | 483.4839      | 485.1736      | 487.1212      | 488.6151    |
| 0.10007                     | 482.5350      | 484.6360      | 485.8603      | 487.6403    |
| 0.19940                     | 481.5343      | 483.2360      | 484.8670      | 486.6031    |
| 0.30387                     | 480.5094      | 482.1931      | 483.7585      | 485.4070    |
| 0.40836                     | 479.3750      | 481.1466      | 482.6754      | 484.2943    |
| 0.51045                     | 478.2738      | 480.0514      | 481.6794      | 483.1773    |
| PEG 600 + 0.03 m D-Mannitol  |                             |               |               |
| 0.00000                     | 483.1132      | 485.0304      | 486.6671      | 488.2225    |
| 0.10164                     | 482.2519      | 484.0767      | 485.6453      | 487.1172    |
| 0.19998                     | 481.3111      | 483.0752      | 484.6289      | 486.0706    |
| 0.29836                     | 480.3502      | 482.0904      | 483.5856      | 485.0069    |
| 0.40338                     | 479.1822      | 481.0245      | 482.3887      | 483.7214    |
| 0.50796                     | 478.0062      | 479.9114      | 481.3445      | 482.5426    |
| PEG 600 + 0.05 m D-Mannitol  |                             |               |               |
| 0.00000                     | 481.7265      | 484.1563      | 486.1964      | 487.6477    |
| 0.10321                     | 480.9929      | 483.2198      | 485.2036      | 486.6380    |
| 0.20127                     | 480.0821      | 482.2393      | 484.1254      | 485.5957    |
| 0.29925                     | 479.1966      | 481.2222      | 483.0790      | 484.4483    |
| 0.40027                     | 478.2612      | 480.1810      | 481.8512      | 483.2571    |
| 0.50798                     | 477.1648      | 479.0271      | 480.6956      | 481.8546    |

### Table 4. Values of Rao constant, of polyethylene glycols 200,600 in aqueous D-Mannitol solution at different temperatures.

| $^\circ m_A$ / (mol.kg$^{-1}$) | $R$ / (m$^3$/mol) (m/s)$^{1/4}$ |
|-----------------------------|--------------------------------|
|                             | T= 293.15 K   | T=298.15 K   | T= 303.15 K   |
|                             | T= 303.15 K   | T= 308.15 K   |
| 0.00000                     | 2282.793      | 2292.996      | 2302.592      | 2311.993    |
| 0.10160                     | 2281.459      | 2291.543      | 2301.038      | 2309.838    |
| 0.20371                     | 2280.113      | 2290.324      | 2299.558      | 2307.531    |
| 0.30012                     | 2278.509      | 2288.986      | 2297.931      | 2305.494    |
| 0.40211                     | 2277.207      | 2287.659      | 2296.428      | 2303.338    |
| 0.49810                     | 2275.643      | 2286.202      | 2294.768      | 2301.222    |

PEG 200 + 0.01 m D-Mannitol

PEG 200 + 0.03 m D-Mannitol
### Table 5. Values of the intermolecular free length of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

| $^a$m_A (mol·kg$^{-1}$) | \( T = 293.15\) K | \( T = 298.15\) K | \( T = 303.15\) K | \( T = 308.15\) K |
|-------------------------|------------------|------------------|------------------|------------------|
| 0.00000                 | 2280.617         | 2290.827         | 2299.949         | 2309.455         |
| 0.10516                 | 2278.984         | 2289.577         | 2298.631         | 2307.597         |
| 0.20753                 | 2277.730         | 2288.52          | 2297.274         | 2305.765         |
| 0.30249                 | 2276.512         | 2287.443         | 2295.831         | 2303.865         |
| 0.41702                 | 2275.146         | 2286.175         | 2294.244         | 2301.720         |
| 0.49987                 | 2273.956         | 2285.379         | 2293.130         | 2300.094         |
| **PEG 200 + 0.05 m D-Mannitol** |                  |                  |                  |                  |
| 0.00000                 | 2278.446         | 2288.662         | 2297.314         | 2306.923         |
| 0.11021                 | 2276.945         | 2287.433         | 2295.570         | 2305.022         |
| 0.20923                 | 2275.712         | 2286.342         | 2293.872         | 2303.238         |
| 0.30703                 | 2274.311         | 2285.391         | 2292.098         | 2301.516         |
| 0.39832                 | 2273.209         | 2284.451         | 2290.544         | 2299.857         |
| 0.50431                 | 2271.810         | 2283.454         | 2288.377         | 2297.904         |
| **PEG 600 + 0.01 m D-Mannitol** |                  |                  |                  |                  |
| 0.00000                 | 6845.741         | 6873.662         | 6905.864         | 6930.578         |
| 0.10007                 | 6830.069         | 6864.776         | 6885.014         | 6914.450         |
| 0.19940                 | 6813.547         | 6841.647         | 6868.594         | 6897.294         |
| 0.30387                 | 6796.630         | 6824.424         | 6850.283         | 6878.903         |
| 0.40836                 | 6777.915         | 6807.146         | 6832.388         | 6859.130         |
| 0.51045                 | 6759.752         | 6789.073         | 6815.942         | 6840.677         |
| **PEG 600+ 0.03 m D-Mannitol** |                  |                  |                  |                  |
| 0.00000                 | 6839.617         | 6871.295         | 6898.353         | 6924.083         |
| 0.09998                 | 6825.394         | 6855.534         | 6881.459         | 6905.797         |
| 0.09998                 | 6809.862         | 6838.991         | 6864.659         | 6888.490         |
| 0.20127                 | 6789.580         | 6825.186         | 6856.340         | 6880.044         |
| 0.30703                 | 6755.340         | 6786.764         | 6810.413         | 6830.194         |
| **PEG 600+ 0.05 m D-Mannitol** |                  |                  |                  |                  |
| 0.00000                 | 6816.719         | 6856.849         | 6890.570         | 6914.573         |
| 0.10164                 | 6804.610         | 6841.378         | 6874.158         | 6897.873         |
| 0.20127                 | 6789.580         | 6825.186         | 6856.340         | 6880.044         |
| 0.30925                 | 6774.971         | 6808.394         | 6839.054         | 6861.674         |
| 0.40247                 | 6759.545         | 6791.212         | 6818.779         | 6841.995         |
| 0.50798                 | 6741.469         | 6772.175         | 6799.703         | 6818.834         |

**Table 5.** Values of the intermolecular free length of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.
| *m_A* / (mol.kg⁻¹) | \( L_d / \text{Å} \) | T= 293.15 K | T=298.15 K | T= 303.15 K | T= 308.15 K |
|-------------------|----------------------|-------------|-------------|-------------|-------------|
| 0.30703           | 4.216716             | 4.224968   | 4.244493   | 4.255476   |
| 0.39832           | 4.180071             | 4.193715   | 4.216482   | 4.227889   |
| 0.50431           | 4.144185             | 4.157355   | 4.180258   | 4.19638    |
| **PEG 600 + 0.01 m D-Mannitol** | | | | |
| 0.00000           | 4.323352             | 4.341514   | 4.376247   | 4.356963   |
| 0.10007           | 4.229964             | 4.244510   | 4.251691   | 4.260001   |
| 0.19940           | 4.134455             | 4.149317   | 4.161427   | 4.179130   |
| 0.30387           | 4.037801             | 4.054502   | 4.070097   | 4.090286   |
| 0.40836           | 3.954440             | 3.963820   | 3.982710   | 4.004522   |
| 0.51045           | 3.868789             | 3.877267   | 3.899353   | 3.924925   |
| **PEG 600 + 0.03 m D-Mannitol** | | | | |
| 0.00000           | 4.312992             | 4.329170   | 4.340367   | 4.347625   |
| 0.10164           | 4.217592             | 4.230051   | 4.244992   | 4.256822   |
| 0.19998           | 4.121949             | 4.138634   | 4.155868   | 4.170374   |
| 0.29836           | 4.040029             | 4.049197   | 4.068115   | 4.085706   |
| 0.40338           | 3.946724             | 3.957738   | 3.980528   | 4.000173   |
| 0.50796           | 3.859071             | 3.869802   | 3.894415   | 3.917887   |
| **PEG 600 + 0.05 m D-Mannitol** | | | | |
| 0.00000           | 4.291631             | 4.317327   | 4.332293   | 4.341150   |
| 0.10321           | 4.191493             | 4.217163   | 4.234469   | 4.247381   |
| 0.20127           | 4.108078             | 4.126018   | 4.145628   | 4.161105   |
| 0.29925           | 4.016871             | 4.037453   | 4.058502   | 4.076669   |
| 0.40027           | 3.924967             | 3.948839   | 3.974169   | 3.993674   |
| 0.50798           | 3.842719             | 3.858375   | 3.884540   | 3.909618   |

**Table 6.** Values of Vander Waal's constant of polyethylene glycols 200, 600 in aqueous D-Mannitol solution at different temperatures.

| *m_A* / (mol.kg⁻¹) | \( b / (\text{m}^3/\text{mol}) \) | T= 293.15 K | T=298.15 K | T= 303.15 K | T= 308.15 K |
|-------------------|----------------------|-------------|-------------|-------------|-------------|
| PEG 200 + 0.01 m D-Mannitol | | | | |
| 0.00000           | 395.9098             | 396.3769   | 396.9057   | 397.5432   |
| 0.10160           | 394.8174             | 395.2842   | 395.8076   | 396.4425   |
| 0.20371           | 393.7253             | 394.1904   | 394.7100   | 395.3320   |
| 0.30012           | 392.6981             | 393.1603   | 393.6770   | 394.2962   |
| 0.40211           | 391.6189             | 392.0803   | 392.5919   | 393.2055   |
| 0.49810           | 390.6069             | 391.0629   | 391.5748   | 392.1853   |
| PEG 200 + 0.03 m D-Mannitol | | | | |
| 0.00000           | 395.3517             | 395.8386   | 396.3342   | 396.9789   |
| 0.10516           | 394.2470             | 394.7381   | 395.2411   | 395.8850   |
| 0.20753           | 393.1789             | 393.6703   | 394.1783   | 394.8181   |
| 0.30249           | 392.1930             | 392.6848   | 393.1894   | 393.8314   |
| 0.41702           | 391.0107             | 391.5028   | 392.0096   | 392.6407   |
| 0.49987           | 390.1588             | 390.6514   | 391.1546   | 391.7900   |
| PEG 200 + 0.05 m D-Mannitol | | | | |
| 0.00000           | 394.7952             | 395.3017   | 395.7644   | 396.4162   |
| 0.11021           | 393.6418             | 394.1520   | 394.6175   | 395.2664   |
| 0.20923           | 392.6116             | 393.1188   | 393.5862   | 394.2377   |
| 0.30703           | 391.5984             | 392.1051   | 392.5693   | 393.2171   |
| 0.39382           | 390.6582             | 391.1642   | 391.6251   | 392.2695   |
| 0.50431           | 389.5716             | 390.0785   | 390.5308   | 391.1753   |
| PEG 600 + 0.01 m D-Mannitol | | | | |
| 0.00000           | 1186.888             | 1187.772   | 1189.901   | 1191.181   |
| 0.10007           | 1176.710             | 1179.081   | 1179.538   | 1181.906   |
| 0.19940           | 1166.906             | 1168.336   | 1170.174   | 1172.713   |
| 0.30387           | 1156.855             | 1158.392   | 1160.364   | 1163.109   |
| 0.40836           | 1146.701             | 1148.672   | 1150.840   | 1153.524   |
| 0.51045           | 1137.157             | 1139.079   | 1141.766   | 1144.436   |
| m_A (mol.kg\(^{-1}\)) | h (m\(^3\)/mol) |
|----------------------|------------------|
|                     | T= 293.15 K | T=298.15 K | T= 303.15 K | T= 308.15 K |
| 0.00000             | 1185.197     | 1186.489   | 1188.244   | 1189.521   |
| 0.10164             | 1175.072     | 1176.612   | 1178.503   | 1179.937   |
| 0.19998             | 1165.392     | 1167.116   | 1169.178   | 1170.753   |
| 0.29836             | 1155.857     | 1157.727   | 1159.793   | 1161.592   |
| 0.40338             | 1145.621     | 1147.893   | 1149.983   | 1151.759   |
| 0.50796             | 1135.730     | 1138.13    | 1140.572   | 1142.366   |

**PEG 600 + 0.03 m D-Mannitol**

| m_A (mol.kg\(^{-1}\)) | h (m\(^3\)/mol) |
|----------------------|------------------|
| 0.00000             | 1180.641     | 1183.461   | 1186.483   | 1187.633   |
| 0.10321             | 1170.773     | 1173.542   | 1176.636   | 1178.056   |
| 0.20127             | 1161.339     | 1164.116   | 1167.161   | 1168.805   |
| 0.29925             | 1152.044     | 1154.716   | 1157.836   | 1159.545   |
| 0.40027             | 1142.478     | 1145.169   | 1148.197   | 1150.137   |
| 0.50798             | 1132.4       | 1135.115   | 1138.246   | 1140.072   |

**Figure 1.** Variation of Acoustic Impedance, Z, of, PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.
Figure 2. Variation of Adiabatic compressibility, $\beta$, of PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.
Figure 3. Variation of Wada constant, W, of, PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.
Figure 4. Variation of Rao constant of, PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.

Figure 5. Variation intermolecular free length of, PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.
Figure 6. Variation of Vander Waal constant of PEG 200 (a) 0.01 D-Mannitol, (b) 0.03 D-Mannitol and (c) 0.05 D-Mannitol, and PEG 600 (d) 0.01 D-Mannitol, (e) 0.03 D-Mannitol and (f) 0.05 D-Mannitol at different temperature.

4. Conclusions

The experimentally obtained and derived parameters indicate the presence of molecular interaction between the polyethylene glycols and D-Mannitol solution. Additionally, it is concluded that molecular interactions increase with the increase in molar mass. So, polyethylene glycol with molar mass 600 shows stronger interaction than polyethylene glycol with molar mass 200. The derived parameters, such as intermolecular free length, acoustic impedance, adiabatic compressibility, Wada's constant, Rao's Constant, and Vander Waal's constant, show a linear trend. The linear trend of the parameters indicates the absence of
complex formation. Acoustic impedance shows the increasing linear trend with concentration and temperature. The values of adiabatic compressibility decrease with the increase in temperature and the concentration of D-Mannitol. Furthermore, values of Wada constant, Rao constant, intermolecular free length, and Vander Waal constant increase with the increase in temperature and decrease with increase in the concentration of D-mannitol.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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