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Study of excess acoustical parameters of dimethyl sulphoxide in 2-Propanol as binary liquid mixture at various temperatures

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Abstract- Ultrasonic velocity, density and viscosity of binary liquid mixtures of Dimethyl sulphoxide (DMSO) (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 volume percent) in 2-Propanol have been measured at various temperatures. The acoustical parameters such as adiabatic compressibility (β), acoustic impedance (Z), free length (L_f), relaxation time (τ), free volume (V_f), available volume (V_a), internal pressure (π_i), Gibbs free energy (ΔG), Molar sound velocity or Rao's constant (R), absorption coefficient (α/f^2) and enthalpy (H) have been obtained from the experimental data of the liquid mixtures with a view to investigate the exact nature of the molecular interactions. The Excess values of adiabatic compressibility (β^E), acoustic impedance (Z^E), free length (L_f^E), free volume (V_f^E), available volume (V_a^E) and internal pressure (π_i^E) have also been calculated and found to be useful in estimating the strength of molecular interactions in the mixture.

Index Terms- Ultrasonic velocity, density, viscosity, molecular interaction, excess acoustical parameters.

I. Introduction

Ultrasonic methods find extensive applications for characterizing aspects of physicochemical behavior such as the nature of molecular interactions in pure liquids as well as liquid mixtures [1-4]. Extensive investigations in binary liquid mixtures have been carried out by different techniques [5-15]. The thermodynamic functions of binary liquid mixtures provide insight into the structure breaking and making effect of the component liquids. In the present study, derived parameters such as adiabatic compressibility (β), acoustic impedance (Z), free length (L_f), relaxation time (τ), free volume (V_f), available volume (V_a), internal pressure (π_i), Gibbs free energy (ΔG), Molar sound velocity or Rao's constant (R), absorption coefficient (α/f^2) and enthalpy (H) will be useful to know the molecular interactions of the systems. A deeper knowledge of mixing properties of binary liquid system is essential in many industrial applications such as design calculation, mass transfer, and fluid flow etc. [16].

Molecular interactions in different liquid mixtures changes depending upon the nature of solvent, the structure of molecules and the extent of solution [17].

II. Experimental

All the chemicals used in the present work were analytical reagent (AR) grade (99.9% pure) and were supplied by Loba chemicals, Mumbai. The liquids were thoroughly distilled to remove dissolved impurities using standard chemical procedures [18]. The chemicals were analyzed for the density measurements and the results were compared with the literature values. Ultrasonic velocities were measured with ultrasonic interferometer (model F80) supplied by Mittal enterprises, New Delhi, operating at a frequency of 2 MHz. It has an accuracy of ±0.1%. Viscosities of pure compounds and their mixtures were determined using Ostwald's viscometer with an accuracy of ±0.002%, calibrated with double distilled water. The densities of pure compounds and their solutions were measured accurately using 25 mL specific gravity bottles and Citizen electronic balance (the accuracy in weighing is ±0.001 g).

III. Results and discussion

The values of ultrasonic velocity, density and viscosity of DMSO (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 volume percent) in 2-Propanol have been measured at various temperatures and are reported in table-1. A close perusal of table-1 shows decrease in the values of ultrasonic velocity (U), density (ρ) and viscosity (η) with increase in temperature at all compositions of DMSO in 2-Propanol. The values of ultrasonic velocities and densities show increasing trend with composition of DMSO in 2-Propanol. This trend suggests that the dipole-dipole interactions are more at higher volume percent of DMSO in the binary mixture. While the viscosities decrease up to 20% of DMSO in 2-Propanol and further increases up to 100% of DMSO at all temperatures. When the temperature is increased, the ultrasonic velocity, density and viscosity decrease. This trend reveals that at higher temperature the molecular interactions between the components are low. The similar trends have been observed for DMSO in 1-Butanol by Bhosale et al. [19].

Density is measure of liquid-liquid interaction. Increase in densities with increase in composition of one of the components indicates solvent-solvent interaction while decrease in density indicates lesser solvent interactions. This may be also be assumed that solvent-solvent interaction bring about a bonding between them. So the sizes of the molecules increase and hence there will be decrease in density.

The properties such as adiabatic compressibility (β), acoustic impedance (Z), free length (L_f), relaxation time (τ), free volume (V_f), available volume (V_a), internal pressure (π_i), Gibbs free energy (ΔG), Molar sound velocity or Rao's constant (R), absorption coefficient (α/f^2) and enthalpy (H) were determined by using ultrasound velocity, density and viscosity in similar way as by Arul et al.[20].

1) Adiabatic Compressibility (β): The Adiabatic Compressibility is related to density and ultrasonic velocity by the relation.

$$\beta = \frac{1}{U^2\rho}$$

2) Intermolecular free length (L_f) has been calculated from the relation:

$$L_f = \frac{K_T}{\sqrt{\rho U^2}}$$

Where, K_T is the temperature dependent constant having a value of 199.53×10^{-8} in MKS system.

3) Free volume (V_f) has been calculated from relation:

$$V_f = \left[\frac{M_{eff}\ U}{K\eta}\right]^{3/2}$$

Where, M_{eff} is the effective molecular weight ($M_{eff} = \sum m_i x_i$, in which m_i, x_i is the molecular weight and mole fraction of the individual constituents, respectively). K is a temperature independent constant which is equal to 4.281×10^9 in MKS system for all liquids.

4) The internal pressure (π_i) has been evaluated by:

$$\pi_i = bRT\left(\frac{K\eta}{U}\right)^{1/2}\left(\frac{\rho^{2/3}}{M_{eff}^{7/6}}\right)$$

Where, K is a constant, b is a factor depending on packing pattern which is 1.78, R is gas constant, T is the absolute temperature, η is the viscosity in $Nm^{-2}s$, U is the ultrasonic velocity in m sec^{-1}, ρ is the density in kg m^{-3} and M_{eff} is the effective molecular weight.

5) Acoustic impedance (Z): The specific acoustic impedance is related to density and ultrasonic velocity by the relation.

$$Z = \rho U$$

6) Relaxation time (τ): Relaxation time has been calculated from viscosity coefficient, density and ultrasonic velocity of binary mixtures using the equation,

$$\tau = \frac{4\eta}{3\rho U^2}$$

7) Molar sound velocity or Rao's constant (R): 'R' has been evaluated by

$$R = \left[\frac{M_{eff}}{\rho}\right] U^{1/3} m^3 \left[\frac{m}{S}\right]^{1/3}$$

8) Available volume (V_a): Available volume has been evaluated by

$$V_a = V\left[1 - \frac{U}{U_\infty}\right]$$

Where, U_∞ =Schaff's limiting value taken as 1600 m/s for liquids [21].

9) Gibbs free energy has been calculated from acoustic relaxation time (τ) following Eyring rate processing theory [22].

$$\Delta G = RT \ln\left(\frac{kT\tau}{h}\right)$$

Where, R is the gas constant, k is the Boltzmann's constant ($1.23\ \times10^{-23}$J.K^{-1}), T is absolute temperature, h is Plank's constant (6.62×10^{-34}J.s) and τ is the relaxation time.

10) Absorption coefficient (α/f^2) is calculated from the following equation:

$$\alpha/f^2 = \frac{8\pi^2\eta}{3\rho U^3}$$

Where, τ is the acoustical relaxation time, f is frequency and U is ultrasonic velocity.

11) Enthalpy (H) has been calculated from the following equation:

$$H = \pi_i \times V_m$$

Where, $V_m = \frac{M_{eff}}{\rho}$

12) Excess parameters (A^E) have been calculated by using relation

$$A^E = A_{exp} - A_{id}$$

Where $A_{id} = \sum_{i=0}^{n} A_i X_i$, A_i is any acoustical parameters and X_i is mole fraction of the liquid component.

The ultrasonic velocity, density and viscosity variations with respect to volume percentage of DMSO are shown in Figure-1, Figure-2 and Figure-3 respectively at various temperatures.

Table 2 shows the values of adiabatic compressibility (β), acoustic impedance (Z), free length (L_f), relaxation time (τ), free volume (V_f), available volume (V_a), internal pressure (π_i), Gibbs free energy (ΔG), Rao's constant (R), absorption coefficient (α/f^2) and enthalpy (H) of DMSO in 2-Propanol at various temperatures.

It may be noted that in the five different temperature, the adiabatic compressibility (β) decreases with increase in composition of DMSO in 2-Propanol indicating the possibility of stronger interaction at higher composition. It is also observed that, the interactions are more at lower temperature as compared to at higher.

Acoustic impedance (Z) increases while relaxation time (τ) decreases with increase in volume percent of DMSO in 2-Propanol. The dispersion of the ultrasonic velocity in the system should contain information about the characteristic time (τ) of relaxation processes that causes dispersion. The relaxation time which is in the order of 10^{-12}sec is due to structural relaxation process [23] and in such a situation it is suggested that the molecules get rearranged due to co-operative process [24]. The ultrasonic velocity increases with increase in composition of DMSO in 2-Propanol. This is in accordance with the view that the ultrasonic velocities increases with decrease in free length (L_f) and vice versa [25].

Rao's constant or molar sound velocity (R) is an important factor in deciding the molecular association in liquid mixtures. In the present work, Rao's constant values were found to increase with increase in volume percent of DMSO in 2-Propanol up to 50% at all temperatures and further decreases which suggest molecular association up to 50% and further depolymerization of aggregates of 2-Propanol molecules.

Internal pressure (π_i) values deceases when the composition of DMSO in 2-Propanol increases which shows the strong interaction present at lower composition. It is also interesting to observe that the free volume (V_f) of the system increases as internal pressure decreases [26]. The Gibb's free energy (ΔG) reveals closer packing of the molecules due to the hydrogen bonding of unlike molecules in the solutions. The Gibb's free energy decreases with temperature rise suggest that less time is required for the cooperative process or the rearrangement of molecules in the solution. The values of absorption coefficient (α/f^2) decreases with rise in composition and temperature indicate that interaction decreases within the liquid molecules in the solution [27]. The variation in acoustical parameters is shown graphically by Figure-4 to Figure-14.

Table 3 shows the excess values of adiabatic compressibility (β^E), acoustic impedance (Z^E), free length (L_f^E), free volume (V_f^E), available volume and internal pressure (π_i^E).

Excess adiabatic compressibility (β^E) values are negative, it may be attributed to the existence of dispersion and dipolar interactions between the unlike molecules indicating that mixing structure are less compressible than the ideal mixture. The additional rigidity may be the reason for the negative values of excess adiabatic compressibility [28].

Excess acoustic impedance (Z^E) values are throughout negative. Negative values of Z^E in all compositions and temperatures results the possibility of the presence of weak attractive forces between the components of binary liquid mixture.

The negative values of the excess intermolecular free length (L_f^E) are observed. Similarly, excess internal pressure (π_i^E) are found to be negative suggest that weak interaction are operating in this system [29].

Excess free volume (V_f^E) values are positive indicating the existence of weak molecular interactions in the liquid mixture [30]. The variation in excess parameters is shown graphically by Figure-15 to Figure-20.

Excess adiabatic compressibility, excess acoustic impedance, excess free length and excess internal pressure showing minimum at 50% DMSO in 2-Propanol. It implies that at 50% of DMSO in 2-Propanol the molecular interaction is very weak.

Excess free volume shows maximum at around 20% and 50% DMSO and excess available volume shows maximum at 20% of DMSO and minimum at 80% of DMSO.

IV. Conclusion

The values of ultrasonic velocity, density, viscosity, acoustical parameters and the excess values of DMSO (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 volume percent) in 2-Propanol at various temperatures supports for the existence of very weak interactions in the present system.

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Table 1: Ultrasonic velocity, density and viscosity of DMSO with 2-Propanol at various temperatures

Volume %of DMSO	**Ultrasonic Velocity U (ms^{-1})**	**Density □□ ($kg\ m^{-3}$)**	**Viscosity □□ 10^3 ($Nm^{-2}s$)**	**Ultrasonic Velocity U (ms^{-1})**	**Density □□ ($kg\ m^{-3}$)**	**Viscosity □□ 10^3 ($Nm^{-2}s$)**
	298.15K			**303.15K**		
0	1143.16	786.00	0.1892	1124.21	782.40	0.1605
10	1172.63	816.00	0.1665	1155.79	814.00	0.1353
20	1202.11	846.80	0.1492	1187.37	843.60	0.1260
30	1235.79	882.00	0.1520	1221.05	878.80	0.1325
40	1267.37	913.20	0.1571	1252.63	909.20	0.1385
50	1303.16	943.60	0.1536	1286.32	939.60	0.1335
60	1341.05	978.00	0.1620	1324.21	972.80	0.1447
70	1376.84	1008.40	0.1766	1360.00	1004.80	0.1553
80	1418.95	1045.20	0.1908	1402.11	1040.00	0.1657
90	1456.84	1073.20	0.1921	1437.89	1069.20	0.1661
100	1492.63	1101.20	0.1946	1473.68	1095.60	0.1693
	308.15K			**313.15K**		
0	1109.47	778.40	0.1307	1094.74	774.40	0.1026
10	1136.84	809.60	0.1133	1120.00	804.00	0.0876
20	1170.53	838.80	0.1039	1151.58	834.40	0.0839
30	1204.21	874.00	0.1110	1187.37	870.40	0.0929
40	1235.79	904.40	0.1159	1218.95	899.60	0.0938
50	1271.58	934.00	0.1113	1256.84	930.40	0.0911
60	1307.37	968.00	0.1234	1292.63	963.20	0.1006
70	1343.16	1000.40	0.1315	1328.42	996.40	0.1071
80	1387.37	1034.80	0.1396	1370.53	1029.60	0.1139
90	1423.16	1064.40	0.1402	1408.92	1060.00	0.1144
100	1456.84	1093.20	0.1415	1442.11	1089.20	0.1154

	318.15K		
0	1075.79	770.00	0.0740
10	1107.37	800.00	0.0653
20	1136.84	830.00	0.0620
30	1170.53	865.60	0.0691
40	1202.11	894.80	0.0716
50	1240.00	925.20	0.0683
60	1275.79	957.20	0.0740
70	1311.58	992.40	0.0800
80	1353.68	1024.80	0.0859
90	1391.58	1056.00	0.0866
100	1427.37	1083.60	0.0878

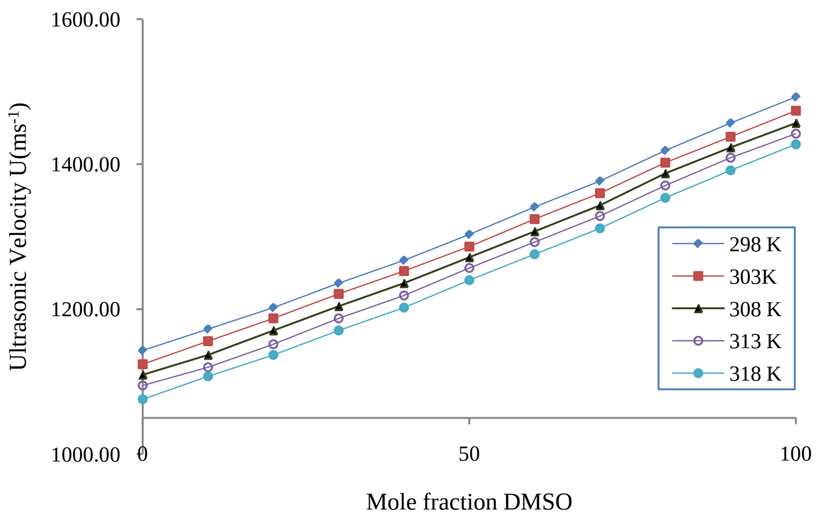

Figure-1: Ultrasonic velocity against volume % of DMSO

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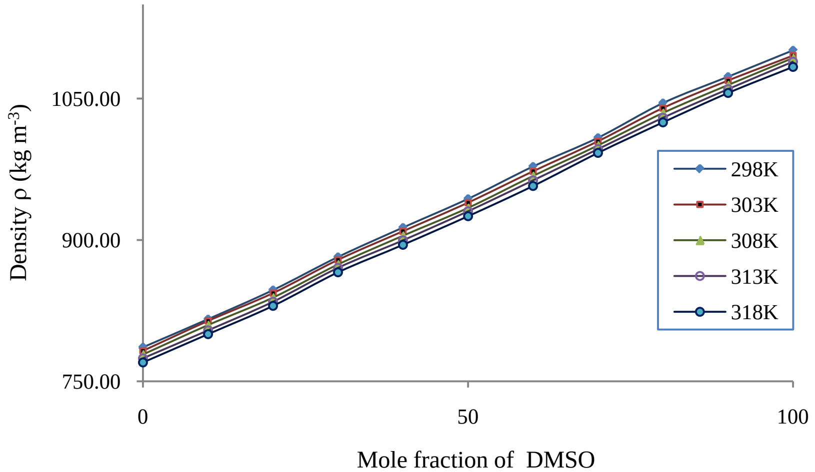

Figure-2: Density against volume % of DMSO

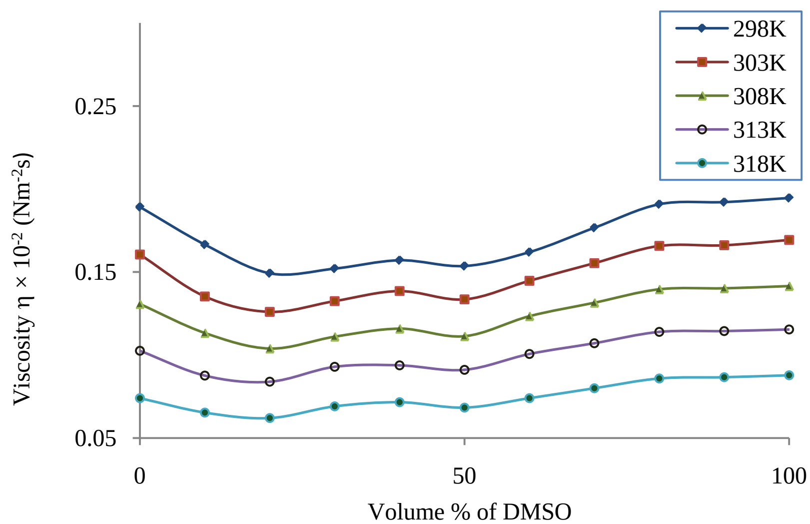

Figure-3: Viscosity against volume % of DMSO

Table 2: The values of adiabatic compressibility (β), acoustic impedance (Z), free length (L_f), relaxation time (τ), free volume (V_f), available volume (V_a), internal pressure (π_i), Gibbs free energy (ΔG), Molar sound velocity or Rao's constant (R), absorption coefficient (α/f^2) and enthalpy (H) of DMSO in 2-Propanol at various temperatures.

Volume % of DMSO	□ $\times10^{10}$ $ms^2\ kg^{-1}$	$Z\times10^{6}$ $kg\ m^{-2}s^{-1}$	L_f $\times10^{-9}$ m	□$\times10^{12}$ sec	V_f $\times10^{-6}$ ml	V_a $\times10^{-5}$ m^3mol^{-1}	π_i $\times10^{3}$ Nm^{-2}	□G$\times10^{21}$ $Jmol^{-1}$	Rao's Const 'R'	□□ /f²) $\times 10^{-10}$ $Npm^{-1}s^2$	H $\times10^{-3}$ $kJ\ mol^{-1}$
298.15K											
0	9.736	0.899	0.642	245.60	2.4704	2.183	9.449	1.7886	799.50	4.236	722.49
10	8.912	0.957	0.614	197.85	3.3725	2.077	8.423	1.7350	819.96	3.327	654.95
20	8.172	1.018	0.588	162.57	4.4324	1.954	7.635	1.6863	835.59	2.667	600.04

30	7.424	1.090	0.560	150.46	4.7813	1.790	7.441	1.6672	843.96	2.401	585.22
40	6.818	1.157	0.537	142.80	4.9846	1.636	7.335	1.6542	851.74	2.222	577.30
50	6.240	1.230	0.514	127.80	5.6208	1.456	7.061	1.6267	857.07	1.934	554.08
60	5.686	1.312	0.490	122.81	5.6144	1.255	7.121	1.6168	854.99	1.806	552.08
70	5.231	1.388	0.470	123.18	5.2701	1.068	7.335	1.6176	851.52	1.764	561.44
80	4.752	1.483	0.448	120.89	4.9940	0.845	7.591	1.6129	839.30	1.680	566.95
90	4.390	1.563	0.431	112.45	5.1764	0.654	7.612	1.5950	828.20	1.522	556.10
100	4.076	1.644	0.415	105.76	5.2375	0.476	7.732	1.5798	810.84	1.397	548.55
303.15K											
0	10.113	0.880	0.660	216.42	3.0836	2.284	8.896	1.7909	798.72	3.796	683.33
10	9.196	0.941	0.629	165.90	4.5026	2.163	7.767	1.7239	817.73	2.831	605.19
20	8.408	1.002	0.602	141.25	5.6013	2.033	7.166	1.6834	834.79	2.346	564.90
30	7.632	1.073	0.573	134.83	5.7628	1.868	7.096	1.6717	842.95	2.177	559.65
40	7.010	1.139	0.550	129.44	5.9086	1.715	7.031	1.6614	851.35	2.038	555.27
50	6.432	1.209	0.526	114.49	6.7926	1.543	6.726	1.6305	856.14	1.755	529.48
60	5.862	1.288	0.503	113.10	6.5163	1.342	6.869	1.6274	855.10	1.684	534.92
70	5.381	1.367	0.481	111.42	6.2654	1.151	7.028	1.6236	850.31	1.615	539.35
80	4.891	1.458	0.459	108.06	6.0547	0.928	7.218	1.6159	839.54	1.520	541.38
90	4.524	1.537	0.441	100.18	6.3089	0.743	7.230	1.5968	827.32	1.374	529.92
100	4.203	1.615	0.426	94.87	6.3318	0.563	7.354	1.5831	811.52	1.269	524.46
308.15K											
0	10.437	0.864	0.677	181.88	4.1139	2.367	8.186	1.7801	799.30	3.233	632.04
10	9.557	0.920	0.647	144.38	5.7300	2.267	7.260	1.7210	817.47	2.504	568.66
20	8.701	0.982	0.618	120.54	7.3176	2.127	6.639	1.6747	835.27	2.031	526.21
30	7.890	1.052	0.588	116.77	7.3556	1.961	6.628	1.6666	843.27	1.912	525.31
40	7.240	1.118	0.564	111.89	7.5574	1.806	6.563	1.6556	851.57	1.785	520.80
50	6.622	1.188	0.539	98.27	8.7631	1.625	6.258	1.6224	857.50	1.524	495.30
60	6.044	1.266	0.515	99.44	8.1107	1.431	6.472	1.6254	855.24	1.500	506.23

70	5.541	1.344	0.493	97.15	7.8869	1.237	6.599	1.6195	850.12	1.426	508.42
80	5.021	1.436	0.469	93.45	7.7025	1.001	6.750	1.6095	840.49	1.328	508.67
90	4.639	1.515	0.451	86.71	8.0084	0.814	6.768	1.5903	828.03	1.201	498.21
100	4.310	1.593	0.435	81.32	8.1450	0.639	6.864	1.5739	810.19	1.101	490.54

Table 2: continued….

Volume % of DMSO	□ $\times 10^{10}$ $\mathbf{ms^2\ kg^{-1}}$	$\mathbf{Z \times 10^6}$ $\mathbf{kg\ m^{-2}s^{-1}}$	$\mathbf{L_f \times 10^{-9}}$ **m**	□$\times 10^{12}$ **sec**	$\mathbf{V_f \times 10^{-6}}$ **ml**	$\mathbf{V_a \times 10^{-5}}$ $\mathbf{m^3mol^{-1}}$	$\mathbf{\pi_i \times 10^3}$ $\mathbf{Nm^{-2}}$	□$G \times 10^{21}$ $\mathbf{Jmol^{-1}}$	**Rao's Const 'R'**	□□ $/f^2)$ $\mathbf{\times 10^{-10}}$ $\mathbf{Npm^{-1}s^2}$	$\mathbf{H \times 10^{-3}}$ $\mathbf{kJ\ mol^{-1}}$
313.15K											
0	10.775	0.848	0.694	147.400	5.7975	2.451	7.394	1.7585	799.86	2.655	573.87
10	9.915	0.900	0.665	115.811	8.2381	2.365	6.508	1.6957	818.84	2.039	513.15
20	9.037	0.961	0.635	101.097	9.8329	2.232	6.095	1.6603	834.69	1.731	485.36
30	8.149	1.033	0.603	100.940	9.3966	2.051	6.193	1.6599	842.23	1.676	492.56
40	7.481	1.097	0.578	93.566	10.1570	1.899	6.025	1.6401	851.57	1.514	480.31
50	6.804	1.169	0.551	82.647	11.6149	1.703	5.777	1.6078	856.81	1.297	458.69
60	6.213	1.245	0.527	83.344	10.8205	1.509	5.958	1.6100	855.61	1.271	467.97
70	5.687	1.324	0.504	81.213	10.5433	1.312	6.074	1.6033	849.82	1.206	469.54
80	5.171	1.411	0.480	78.527	10.2534	1.086	6.217	1.5945	840.85	1.130	470.62
90	4.752	1.493	0.461	73.125	10.6972	0.883	6.229	1.5760	828.43	1.023	460.30
100	4.415	1.571	0.444	67.927	10.8918	0.708	6.316	1.5568	810.42	0.929	453.03
318.15K											
0	11.222	0.828	0.714	110.72	9.2201	2.5572	6.412	1.7150	799.76	2.029	500.44
10	10.194	0.886	0.681	88.75	12.5767	2.4389	5.725	1.6565	819.51	1.580	453.47
20	9.322	0.944	0.651	77.06	15.1671	2.3158	5.343	1.6192	834.95	1.337	427.43
30	8.432	1.013	0.619	77.68	14.3185	2.1449	5.451	1.6213	842.14	1.309	435.55
40	7.734	1.076	0.593	73.83	14.8930	1.9911	5.373	1.6079	851.32	1.211	430.16
50	7.029	1.147	0.565	64.01	17.5060	1.7945	5.104	1.5701	856.85	1.018	407.07
60	6.419	1.221	0.540	63.33	16.7913	1.5999	5.210	1.5673	856.33	0.979	411.38

70	5.858	1.302	0.516	62.48	15.9996	1.3979	5.359	1.5637	848.84	0.939	415.55
80	5.325	1.387	0.492	60.99	15.3507	1.1700	5.507	1.5573	840.70	0.888	418.50
90	4.890	1.470	0.471	56.46	15.9324	0.9658	5.529	1.5369	827.78	0.800	409.96
100	4.530	1.547	0.454	53.03	16.1611	0.7779	5.606	1.5203	811.82	0.733	404.23

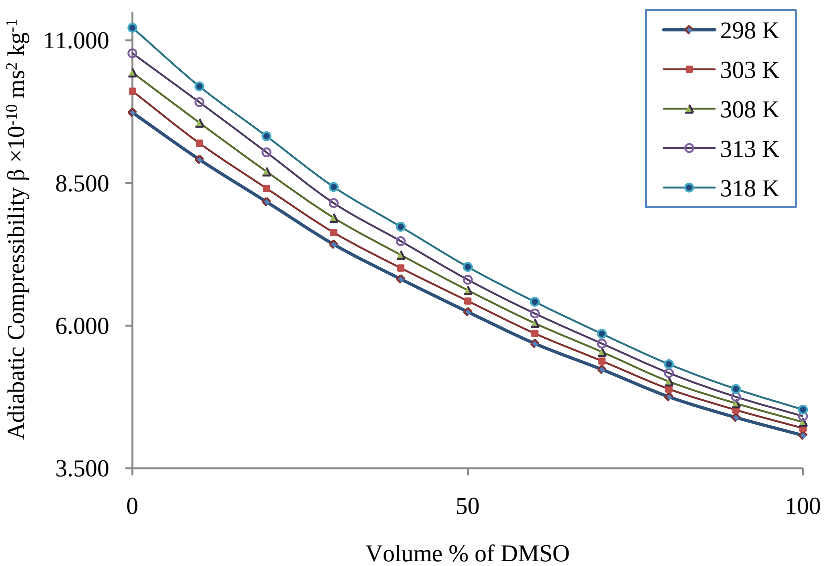

Figure-4: Adiabatic compressibility against volume % of DMSO

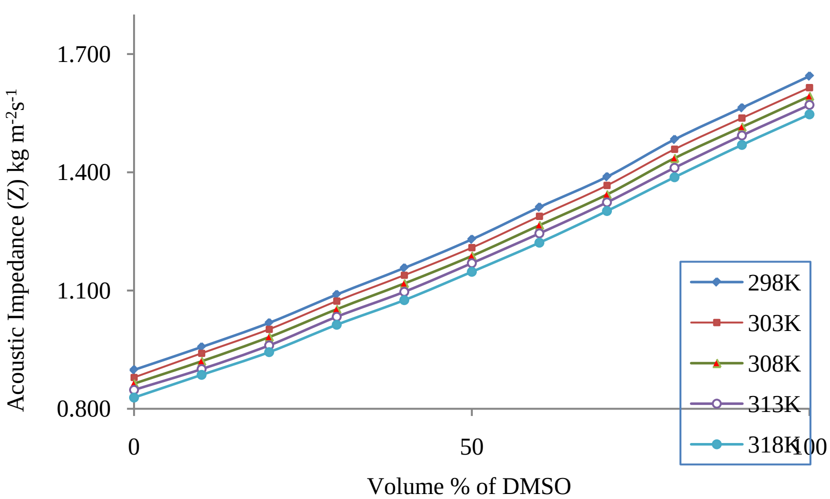

Figure-5: Acoustic impedance against volume % of DMSO

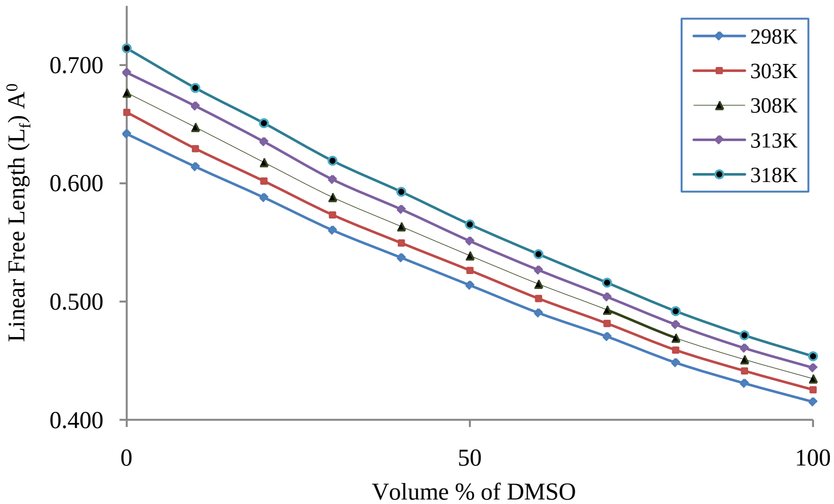

Figure-6: Linear free length against volume % of DMSO

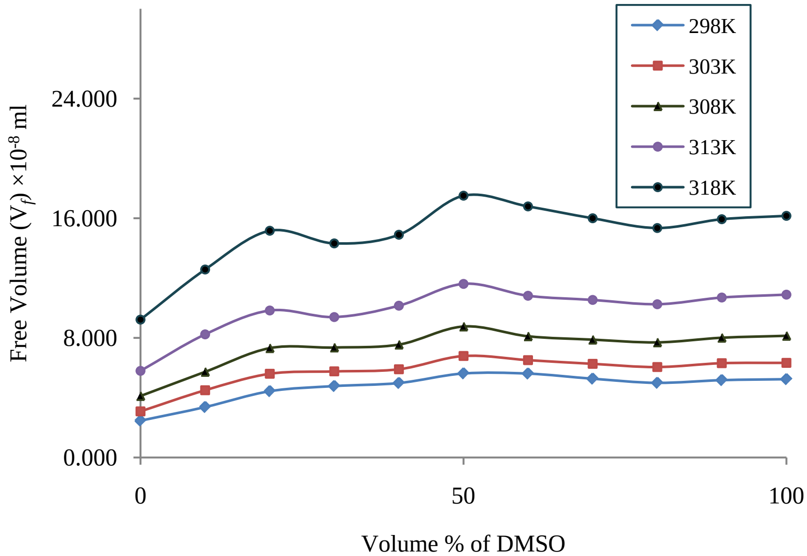

Figure-7: Free volume against volume % of DMSO

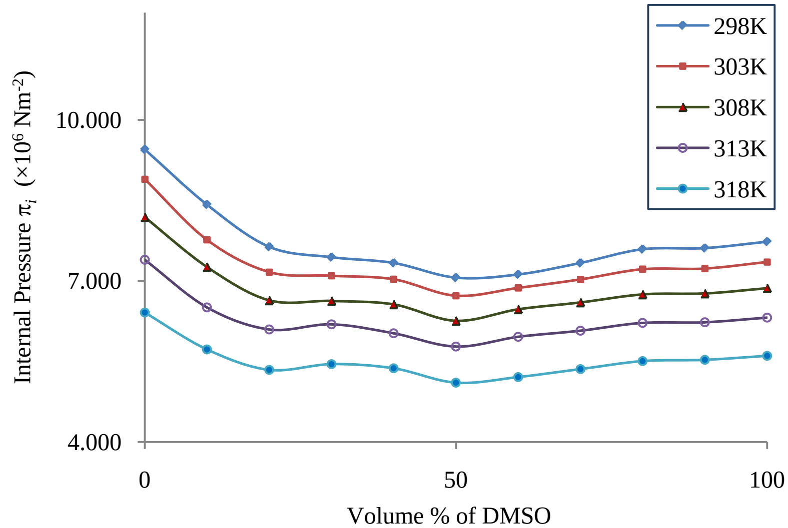

Figure-8: Internal pressure against volume % of DMSO

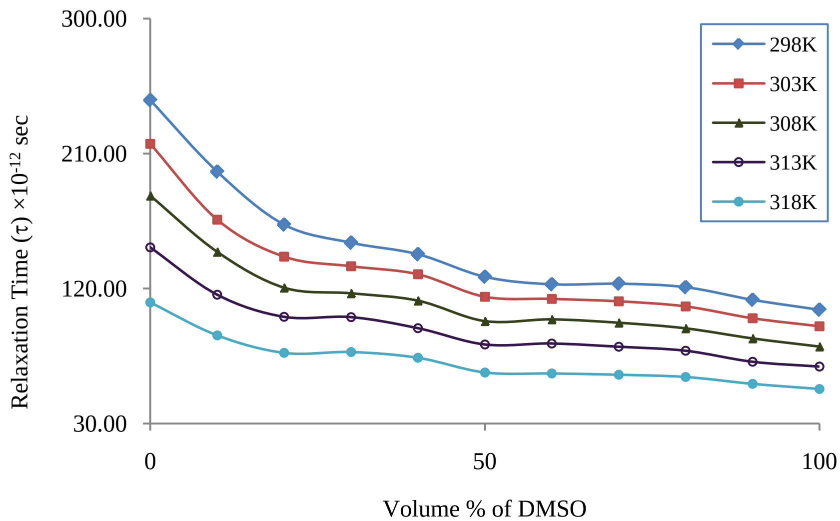

Figure-9: Relaxation time against volume % of DMSO

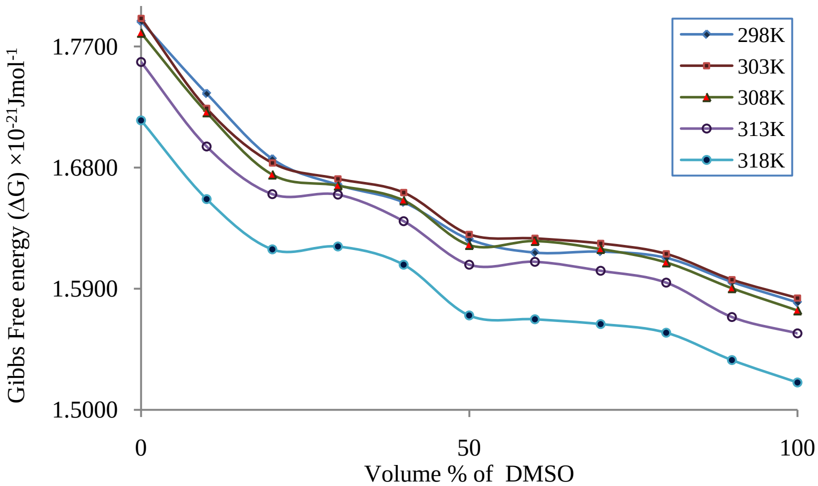

Figure-10: Gibbs free energy against volume % of DMSO

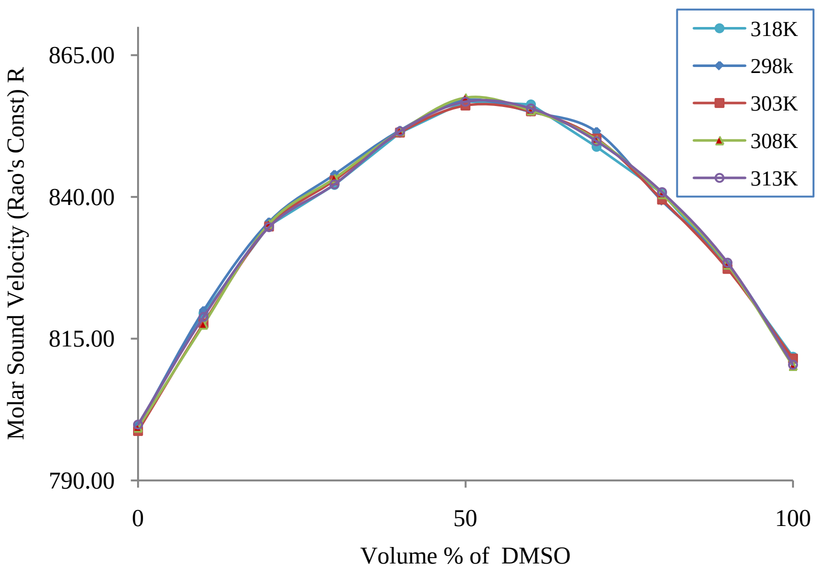

Figure-11: Molar sound Velocity against volume % of DMSO

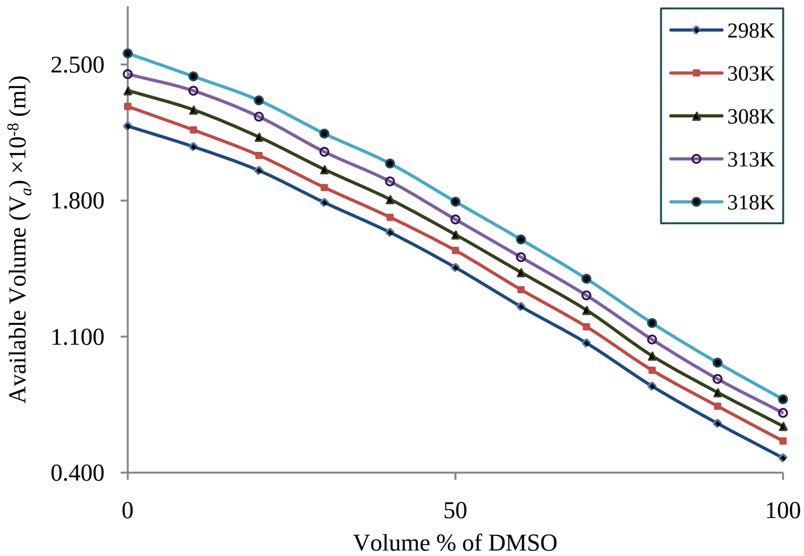

Figure-12: Available volume against volume % of DMSO

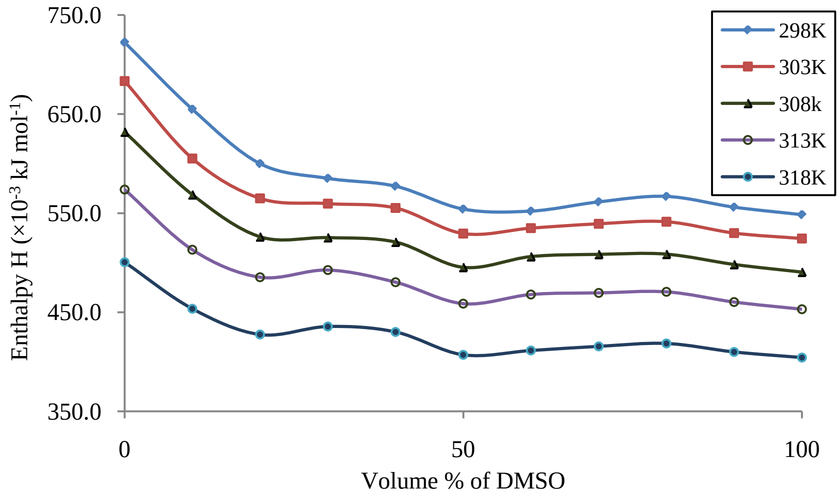

Figure-13: Enthalpy against volume % of DMSO

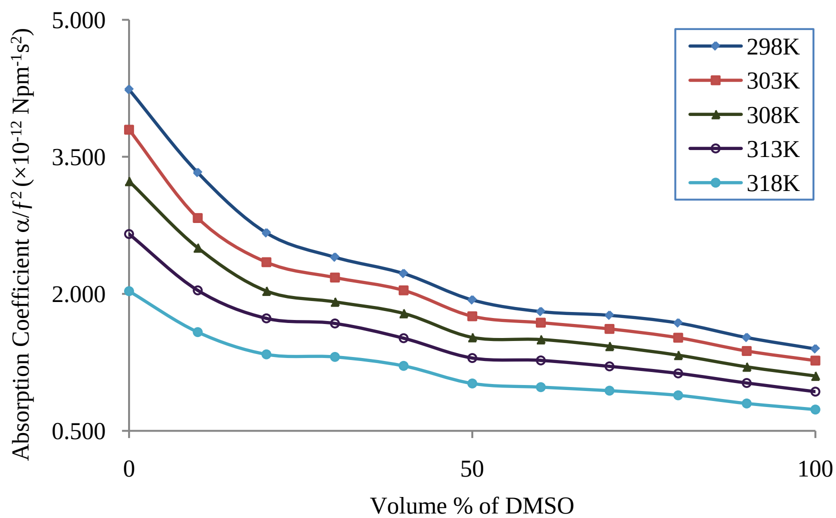

Figure-14: Absorption coefficient against volume % of DMSO

Table 3: The Excess values of adiabatic compressibility (β^E), acoustic impedance (Z^E), free length (L_f^E), free volume (V_f^E), available volume (V_a^E) and internal pressure (π_i^E).

Volume % of DMSO	**□^{E} ×10^{-10} $ms^2\ kg^{-1}$**	**Z^E×10^6 $kg\ m^{-2}s^{-1}$**	**L_f^E×10^{-9} m**	**V_f^E×10^{-6} ml**	**V_a^E×10^{-6} ml**	**π_i^E×10^3 Nm^{-2}**
298.15K						
0	0.000	0.000	0.000	0.000	0.000	0.000
10	-0.449	-0.043	-0.019	0.548	0.025	-1.066
20	-0.787	-0.078	-0.034	1.267	0.038	-1.861
30	-1.102	-0.098	-0.048	1.290	0.017	-2.026
40	-1.238	-0.116	-0.055	1.184	0.013	-2.062
50	-1.303	-0.124	-0.059	1.527	-0.009	-2.219
60	-1.297	-0.116	-0.060	1.246	-0.040	-1.989
70	-1.133	-0.106	-0.054	0.648	-0.046	-1.544
80	-0.929	-0.070	-0.045	0.141	-0.073	-0.988
90	-0.532	-0.040	-0.026	0.117	-0.053	-0.589
100	0.000	0.000	0.000	0.000	0.000	0.000
303.15K						
0	-0.0001	-0.0004	0.0000	0.000	0.000	0.000
10	-0.5204	-0.0382	-0.0209	1.000	0.009	-1.171
20	-0.8852	-0.0720	-0.0368	1.696	0.015	-1.785
30	-1.2055	-0.0905	-0.0513	1.473	-0.008	-1.833
40	-1.3349	-0.1094	-0.0585	1.253	-0.011	-1.838
50	-1.3761	-0.1187	-0.0619	1.793	-0.022	-2.039
60	-1.3598	-0.1119	-0.0625	1.194	-0.053	-1.742
70	-1.1973	-0.0996	-0.0564	0.647	-0.060	-1.375
80	-0.9765	-0.0663	-0.0470	0.166	-0.086	-0.912
90	-0.5563	-0.0371	-0.0276	0.182	-0.056	-0.554
100	-0.0002	-0.0004	-0.0005	0.000	0.000	0.000

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308.15K						
0	-0.0002	-0.0004	-0.0004	0.000	0.000	0.000
10	-0.4629	-0.0416	-0.0192	1.089	0.029	-0.972
20	-0.8751	-0.0738	-0.0364	2.172	0.024	-1.612
30	-1.2103	-0.0921	-0.0512	1.728	-0.001	-1.613
40	-1.3470	-0.1108	-0.0586	1.474	-0.005	-1.631
50	-1.4088	-0.1191	-0.0627	2.250	-0.027	-1.850
60	-1.3791	-0.1134	-0.0627	1.198	-0.050	-1.504
70	-1.2166	-0.1008	-0.0566	0.608	-0.059	-1.196
80	-1.0035	-0.0669	-0.0477	0.093	-0.094	-0.804
90	-0.5739	-0.0376	-0.0280	0.109	-0.064	-0.479
100	0.0000	-0.0004	-0.0002	0.000	0.000	0.000

Table 3: continued….

Volume % of DMSO	**□^{E} ×10^{-10} ms^2 kg^{-1}**	**Z^E×10^6 kg m^{-2}s^{-1}**	**L_f ^{E}×10^{-9} m**	**V_f ^{E}×10^{-6} ml**	**V_a ^{E}×10^{-6} ml**	**π_i^{E}×10^3 Nm^{-2}**
313.15K						
0	-0.0001	-0.0002	-0.0004	0.000	0.000	0.000
10	-0.4208	-0.0443	-0.0175	1.763	0.043	-0.937
20	-0.8332	-0.0764	-0.0345	2.709	0.044	-1.378
30	-1.2238	-0.0918	-0.0511	1.656	0.005	-1.280
40	-1.3563	-0.1117	-0.0581	1.833	0.004	-1.417
50	-1.4544	-0.1164	-0.0637	2.746	-0.031	-1.598
60	-1.4149	-0.1124	-0.0634	1.447	-0.052	-1.310
70	-1.2520	-0.0989	-0.0574	0.710	-0.062	-1.042
80	-1.0106	-0.0693	-0.0473	0.010	-0.086	-0.694
90	-0.5918	-0.0367	-0.0283	0.098	-0.068	-0.419

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100	-0.0004	-0.0003	0.0001	0.000	0.000	0.000
318.15K						
0	-0.0004	0.0004	0.0001	0.000	0.000	0.000
10	-0.5641	-0.0380	-0.0216	2.403	0.012	-0.746
20	-0.9432	-0.0720	-0.0375	4.085	0.025	-1.165
30	-1.3084	-0.0896	-0.0532	2.375	-0.002	-1.071
40	-1.4421	-0.1096	-0.0604	2.142	-0.002	-1.135
50	-1.5363	-0.1150	-0.0659	4.004	-0.035	-1.359
60	-1.4841	-0.1123	-0.0653	2.602	-0.053	-1.172
70	-1.3205	-0.0967	-0.0595	1.192	-0.064	-0.904
80	-1.0574	-0.0688	-0.0488	0.002	-0.085	-0.591
90	-0.6141	-0.0364	-0.0291	0.129	-0.062	-0.352
100	-0.0004	-0.0003	-0.0003	0.000	0.000	0.000

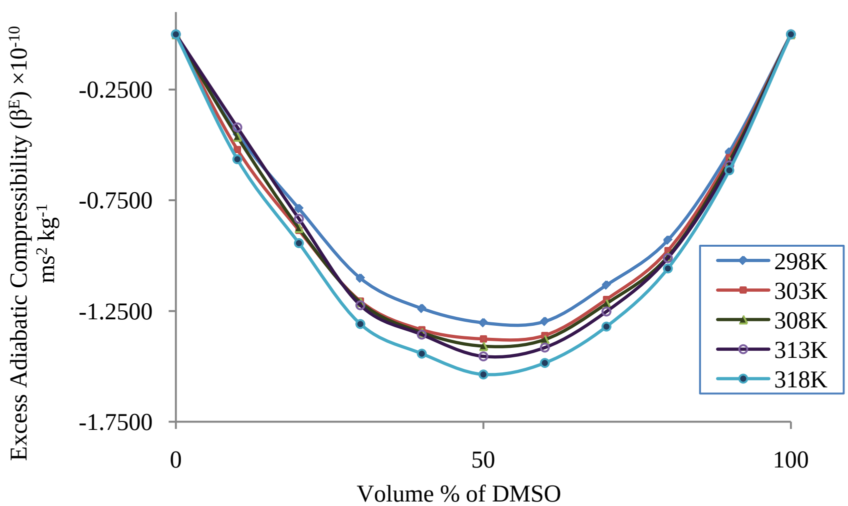

Figure-15: Excess adiabatic compressibility against volume % of DMSO

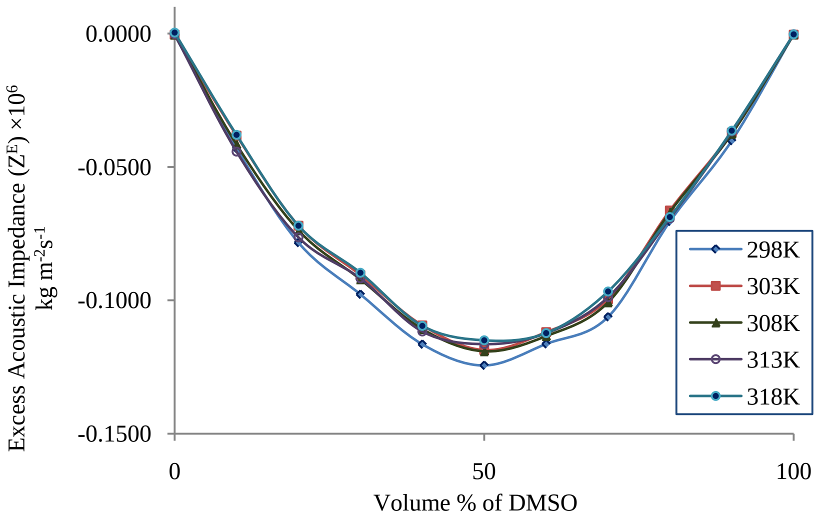

Figure-16: Excess Acoustic impedance against volume % of DMSO

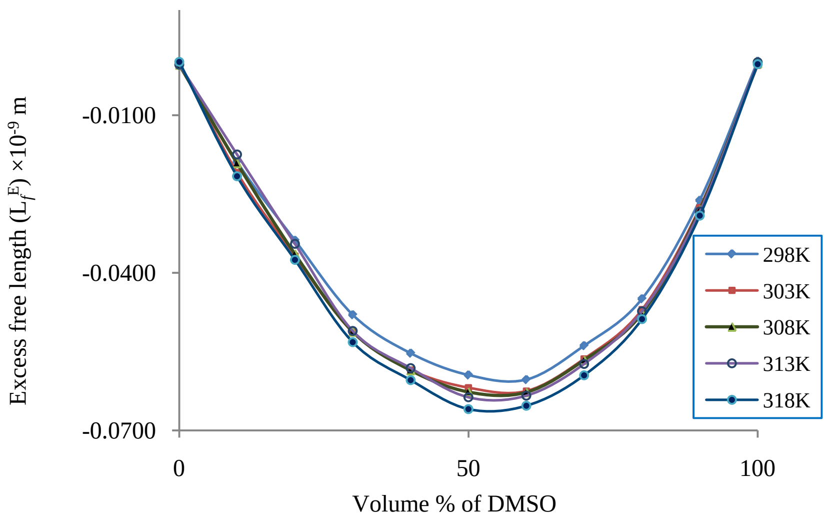

Figure-17: Excess free length against volume % of DMSO

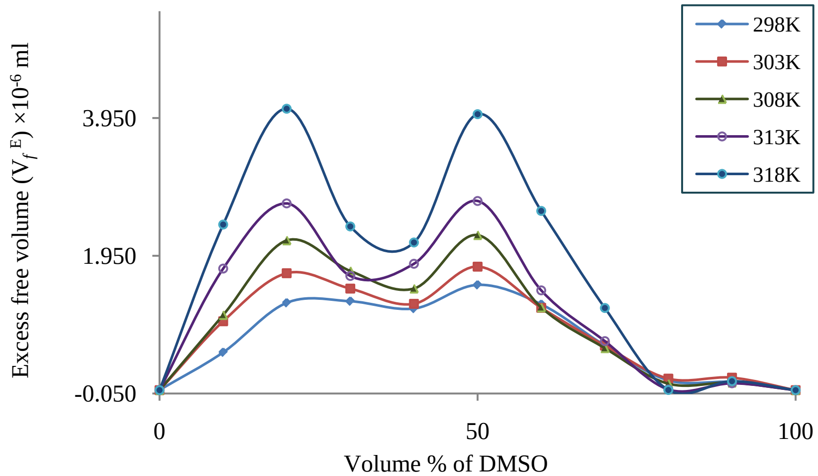

Figure-18: Excess free volume against volume % of DMSO

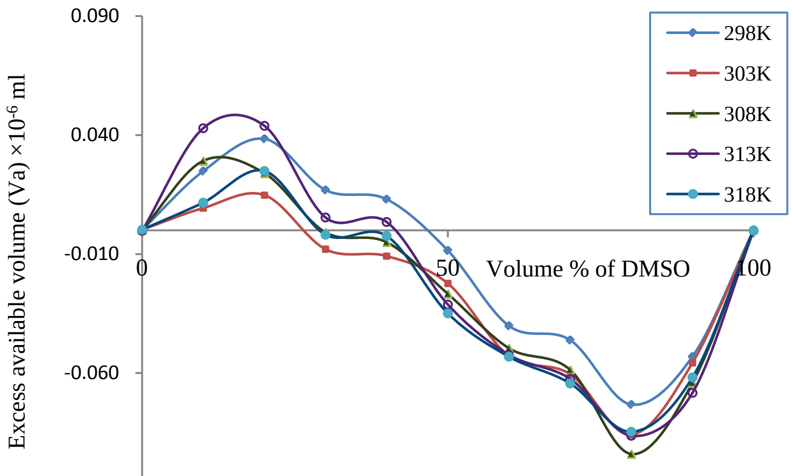

Figure--19: Excess available volume against volume % of DMSO

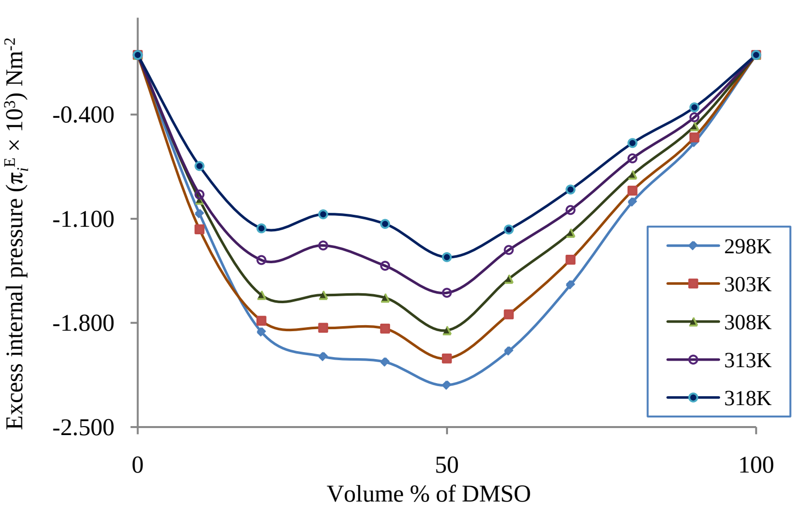

Figure-20: Excess internal pressure against volume % of DMSO