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Research Article

Acoustic and Thermodynamic Properties of Binary Liquid Mixtures Using DMSO at Different Temperatures.

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ABSTRACT

Using fundamental parameters ultrasonic velocity, density and viscosity; different acoustic and thermodynamic properties have been studied over wide range of concentrations at different temperatures from 295.15 K to 315.15 K for binary liquid mixtures of DMSO and butanol. Isentropic compressibility, acoustic impedance, molar volume, intermolecular free length, available volume and their excess values have been calculated. Redlich-Kister polynomial equation has been used to correlate deviation in viscosity, excess isentropic compressibility and excess molar volume. Insights of non-ideal behavior of liquid mixture and intermolecular interactions have been discussed by correlating the experimental data using Jouyban-Acree model.

KEYWORDS

Acoustic, thermodynamic, binary, Jouyban-Acree model, Redlich-Kister polynomial equation.

1. INTRODUCTION

Rigorous literature survey reveals that properties of liquid mixtures have been studied by many researchers in binary, ternary or quaternary forms [1-5]. However; very few researchers have reported the study of binary liquid mixtures of dimethyl Sulfoxide (DMSO) with alcohols [6-7]. No literature has been found so far to study acoustic and thermodynamic properties of DMSO + alcohols at 295.15K, 300.15 K, 305.15 K, 310.15 K and 315.15 K temperatures. So we have undertaken the present research with basic intuition to study these properties at the temperatures mentioned above and to validate the data by different empirical, semi-empirical and theoretical models. Numerous investigations have been carried out which are concerned with theoretical characteristics of the thermodynamic properties of liquids and their mixtures. Through the these studies, there has been large expansion made at applied level in various fields such as in petrochemical industries properties of petroleum fluids are being monitored at different stages of their production, cosmetics, drugs and food emulsification etc. [8]. Acoustic, viscometric and volumetric techniques are of unlimited significance towards molecular interaction study in pure liquids as well as liquid mixtures. Precise knowledge of acoustic and thermodynamic study of binary liquid mixtures is strongly related with theoretical and applied areas. Through such studies data are generated which have been found useful in various industries like petrochemical, pharmaceutical, chemical etc. for design process. Many times in comparison with directly obtained experimental data, predictive methods for excess properties have been found more convenient. The non-ideal behavior of solution in terms of intermolecular interactions has been explained with the help of empirical approach used to calculate excess parameters. In industries, thermodynamic properties have been found more important in the designing of more precise equipments.

2. MATERIALS AND METHODS

Analar Grade DMSO and butanol have been used in the present investigation. 15 concentrations were prepared with different mole fractions. To avoid evaporation, liquid mixtures were properly stored in airtight stoppered borosil glass bottles. Weights were taken using electronic digital weighing balance (accuracy ±0.001gm, Shinko-make Model DI-150).Ultrasonic velocities have been measured using ultrasonic interferometer (Mittal Enterprises, New Delhi, Model F-81) of frequency 2MHz. 50 readings for anode current maxima were taken for each sample and instead of directly taking the difference between last and first reading of distance travelled by micrometer, average of difference between two consecutive readings was taken to maintain accuracy. Densities of liquid mixtures have been measured by 25 ml specific gravity bottle. For accuracy, the measurements were repeated three times and data have been generated by averaging the values. Ostwald's viscometer has been used to measure viscosity. The measurements of time flow of fluid have been taken in the form of average of three readings for all liquid mixtures at all temperatures.

Calculations of molar volume (V_m), isentropic compressibility (K_s), acoustic impedance (Z), intermolecular free length (L_f) and available volume (V_m) and their excess values have been done by using standard equations as described in literature [9-12]. The journey of our research was started with experimental measurements of ultrasonic velocity, density and viscosity. Using these parameters different thermodynamic and acoustic parameters have been calculated as shown in Figure 1.

Initially research was carried out for measurements of ultrasonic velocity, density and viscosity for pure DMSO and Butanol at 298.15 K, 303.15 K, 308.15 K, 313.15K and 318.15 K. Excellent agreement have been observed between experimental and literature values (Table 1). The actual research was then continued at desired temperatures i.e. 295.15 K, 300.15 K, 305.15 K, 310.15 K and 315.15 K (Table 1) for ultrasonic velocity, density and viscosity of pure liquids. No literature has been found at these temperatures to compare the data. However, Jose Maria Resa et al. have reported measurements of ultrasonic velocities at almost same temperatures taken by us for pure ethanol and 1-pentanol (not reported in this paper) [13]. Based on this an attempt has been made by us to compare, fit and validate experimental data. Excellent data fit have been observed for pure liquids for data supported by known and unknown literatures. The technique used for ethanol has been further applied to butanol and excellent results have been obtained validated by Jouyban-Acree model.

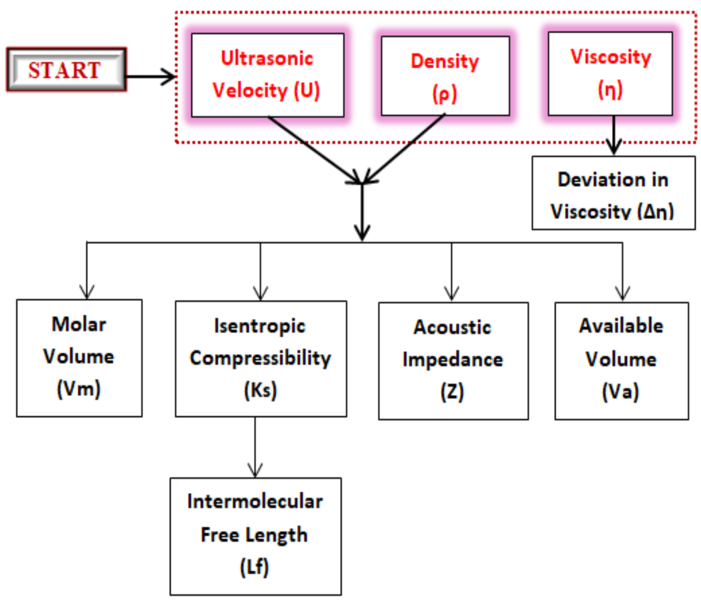

Fig. 1. Journey from ultrasound, density and viscosity to thermodynamic properties.

Table 1. Comparison of experimental ultrasonic velocity (U) in ms^{-1} with literature values where, *E*: Experimental data.

Liquid	Temperature (K)									
	295.15	**298.15**	**300.15**	**303.15**	**305.15**	**308.15**	**310.15**	**313.15**	**315.15**	**318.15**
DMSO	*E:*	1484.29	1478.0	1468.0	1461.3	1449.58	1444.0	1434.0	1427.4	1417.41
	1494.8	1484.8				1450.9				1417.4
		[*]				[*]				[*]
Butanol	*E:*	1239.98	1233.5	1223.31	1216.6	1206.50	1200.1	1189.85	1183.4	1172.95
	1250.0	1240.09		1223.25		1206.56		1189.92		1173.38
		[**]		[**]		[**]		[**]		[**]

[*:Baluja 2016, **: Papari 2013**]**

Table 2. Experimental values of density ρ (kgm^{-3}), viscosity η (mPa. S) and ultrasonic velocity U (ms^{-1}) at different temperatures for binary liquid mixture of DMSO (X_1) + Butanol.

X_1	ρ × 10^{-3}	H	U	ρ × 10^{-3}	η	U	ρ × 10^{-3}	η	U	ρ × 10^{-3}	η	U	ρ × 10^{-3}	η	U
	295.15 K			**300.15 K**			**305.15 K**			**310.15 K**			**315.15 K**		
0.000	0.808	2.789	1250.0	0.804	2.400	1233.5	0.800	2.130	1216.6	0.796	1.889	1200.1	0.792	1.677	1183.4
0.068	0.824	2.545	1268.1	0.820	2.201	1253.1	0.816	1.937	1236.4	0.813	1.724	1221.4	0.809	1.531	1206.2
0.137	0.841	2.345	1288.3	0.837	2.018	1273.8	0.833	1.792	1258.1	0.829	1.584	1243.1	0.825	1.404	1227.7
0.206	0.858	2.196	1309.4	0.854	1.885	1294.4	0.851	1.669	1278.6	0.847	1.475	1263.2	0.843	1.301	1248.1
0.275	0.876	2.073	1329.2	0.873	1.774	1313.9	0.869	1.571	1298.0	0.865	1.379	1282.7	0.861	1.213	1267.3
0.345	0.895	1.971	1348.3	0.891	1.689	1332.9	0.887	1.485	1317.1	0.883	1.304	1301.9	0.879	1.144	1285.9
0.416	0.915	1.891	1366.7	0.911	1.612	1351.5	0.907	1.418	1336.2	0.903	1.241	1320.4	0.898	1.088	1304.6
0.487	0.935	1.827	1385.1	0.931	1.558	1370.1	0.927	1.368	1354.7	0.923	1.193	1339.1	0.918	1.044	1323.1
0.559	0.956	1.774	1403.4	0.952	1.522	1388.4	0.948	1.332	1373.3	0.943	1.163	1357.9	0.939	1.018	1341.7
0.631	0.978	1.743	1421.9	0.974	1.501	1406.6	0.969	1.319	1391.6	0.965	1.152	1376.2	0.961	1.015	1360.4
0.703	1.000	1.727	1439.7	0.996	1.501	1424.8	0.992	1.328	1409.7	0.987	1.169	1394.4	0.983	1.035	1378.6
0.777	1.024	1.728	1456.5	1.02	1.526	1441.8	1.015	1.363	1427.1	1.011	1.209	1411.8	1.006	1.078	1396.2
0.851	1.048	1.768	1471.1	1.044	1.574	1456.9	1.039	1.411	1442.2	1.034	1.261	1426.6	1.03	1.136	1411.6
0.925	1.073	1.835	1484.4	1.068	1.647	1469.7	1.063	1.481	1454.8	1.059	1.331	1438.1	1.054	1.194	1422.2
1.000	1.098	1.941	1494.8	1.093	1.741	1478	1.088	1.567	1461.3	1.083	1.408	1444	1.078	1.261	1427.4

Jouyban-Acree model have been used to correlate experimental data of ultrasonic velocity, density and viscosity by calculating average percentage deviation (Table 3).

Table 3. Jouyban-Acree Model parameters (ai) and APD for Ultrasonic velocity, Density and Viscosity of binary liquid mixtures of DMSO with Butanol.

Parameter	a_0	a_1	a_2	a_3	a_4	APD
U velocity	22.1905	0.3807	14.2465	15.8497	-4.4756	0.1621
Density	-18.8929	2.8225	56.9893	0.0063	0.0026	0.5543
Viscosity	-354.5047	-18.1236	-0.0077	-0.0664	0.0283	1.6027

3. RESULTS AND DISCUSSION

The plots of excess molar volume (V_m^E), deviation in viscosity ($\Delta\eta$), excess isentropic compressibility (K_s^E), acoustic impedance (Z^E), excess intermolecular free length (L_f^E), excess available volume (V_a^E) as a function of mole fraction of DMSO have been shown in figures 2, 3, 4, 5, 6 and 7 respectively.

Figures 2 to 7 reveals that all thermodynamic excess values have negative trend with parabolic nature of graph at all temperatures. Similar results have been reported by researchers [14-15]. Such types of graphs indicate maximum interaction at equimolar composition ($X_1 \approx 0.5$) at which the values are less negative. Increase in temperature from 295.15 K to 315.15 K tends to make the values of V_m^E, K_s^E, L_f^E and V_a^E more negative whereas Δη and Z^E show opposite change (less negative). These observations match well with literature.

We have reported same change in binary liquid mixture of DMSO and Butanol (figures 8 and 9).

The positive or negative values of K_s^E signify that the properties of component molecules to donate or accept an electron and dipole interaction between the component molecules are responsible to deviate the values from ideal ones [16]. Negative L_f^E indicate presence of intermolecular interaction between dissimilar molecules of liquid mixture [17]. The results obtained for V_a^E match well with that reported by K. Rajagopal and S. Chenthilnath [18].

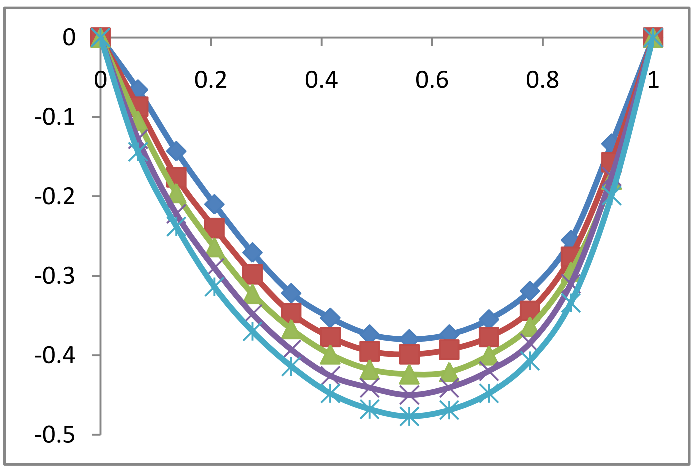

Fig. 2. V_m^E of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

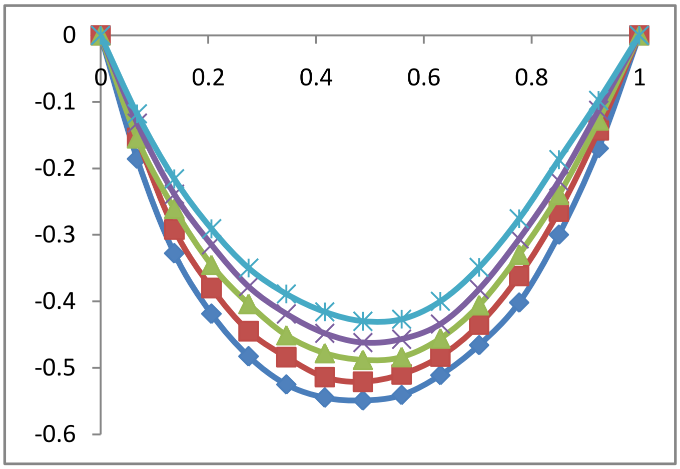

Fig. 3. Δη of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

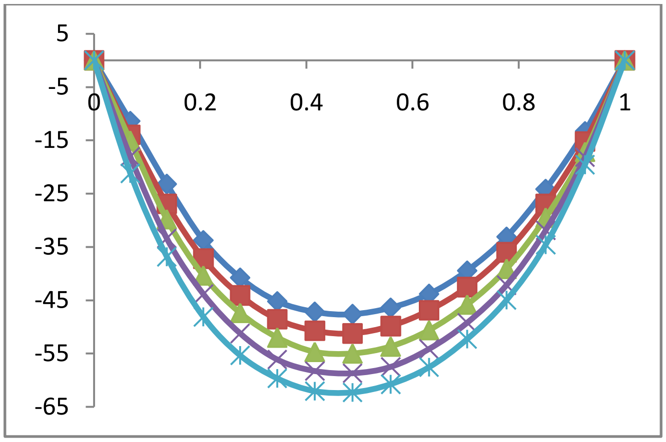

Fig. 4. K_s^E of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

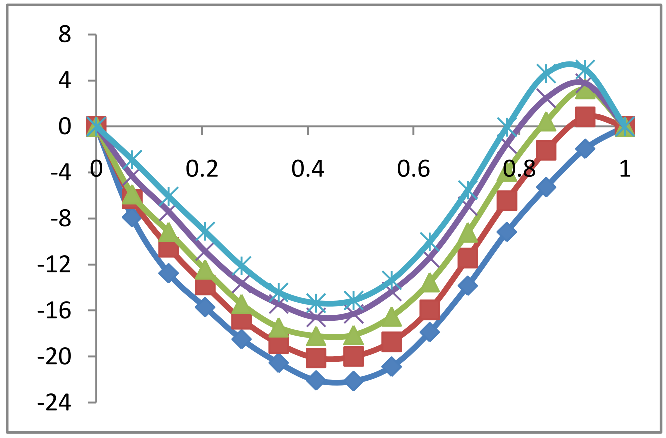

Fig. 5. Z^E of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

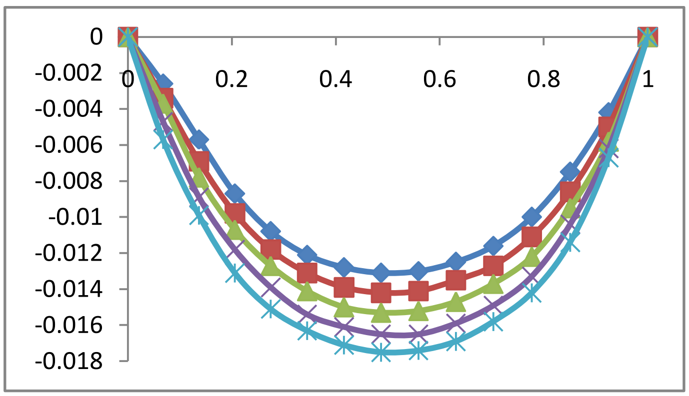

Fig. 6. L_f^E of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

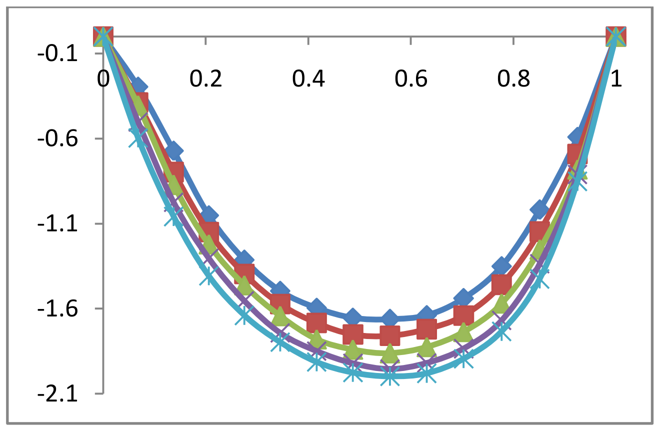

Fig. 7. V_a^E of DMSO + Butanol as function of mole fraction of DMSO at 295.15 K(♦), 300.15 K (□), 305.15 K (Δ), 310.15 K (×), and 315.15 K (*) respectively.

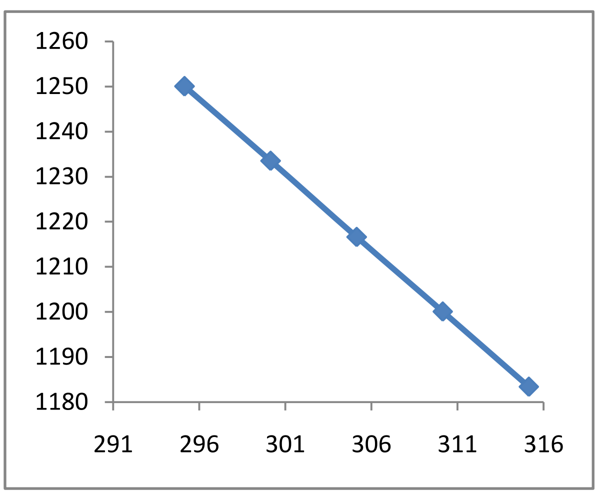

Fig. 8. Plot of Ultrasonic velocity (ms^{-1}) of pure Butanol as a function of temperature (K).

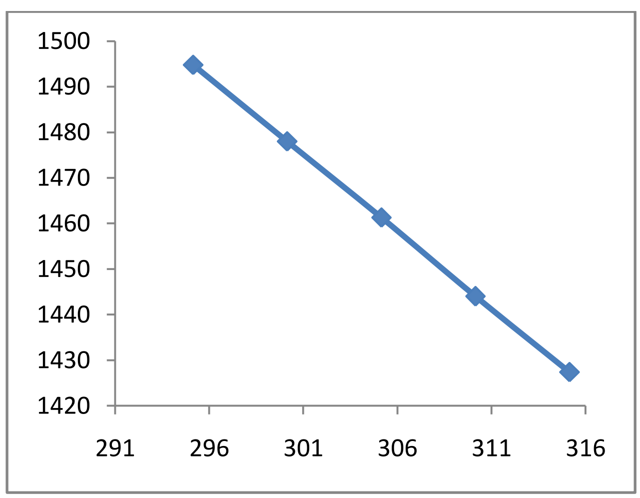

Fig. 9. Plot of Ultrasonic velocity (ms^{-1}) of pure DMSO as a function of temperature (K).

APD values listed in table 3 reveals excellent applicability of Jouyban-Acree model to the experimental data of density and viscosity. Rigorous literature survey tells that this model has not so far being used to correlate experimental data of ultrasonic velocity with calculated ones. However an attempt has been made by us to use this model for ultrasonic velocity also, as observed form table 4.4, it has been concluded that for these data also the model is most suitable.

4. CONCLUSION

We conclude that the experimental values obtained for ultrasonic velocity, density and viscosity for binary liquid mixture of DMSO and Butanol at 295.15 K, 300.15 K, 305.15 K, 310.15 K and 315.15 K are as per desired literature and thus validated. Strong intermolecular interactions occur at equimolar concentrations. The sign and magnitude of the excess values of thermodynamic parameters are attributed to appropriate combination of three main effects such as formation of hydrogen bonds between dissimilar molecules in the liquid mixture, mutual detachment of the like component after adding unlike component and size difference in the component molecules of the mixture. Experimental data obtained for density and viscosity has excellent fit with Jouyban-Acree model. It is also found most suitable for ultrasonic velocity data which is exceptional part of our research work. Thus the data generated at the temperatures mentioned in this paper would set a benchmark for upcoming researchers.

5. ACKNOWLEDGEMENT

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