

Ultrasonic Study of Effect of Temperature and Concentration on Molecular Interaction in Ternary Liquid Mixture (Propylene Glycol + Benzene + Ethanol)

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Ultrasonic velocity, density and viscosity in the ternary mixture of propylene glycol, benzene and ethanol have been measured at 303, 308, 313 and 318 K and 2 MHz. The values of excess thermo-acoustic parameters u^E , η^E , K_s^E , L_f^E , V_m^E , Z^E ; and the Lennard-Jones potential repulsive term exponent (n) have been calculated by using the values of measured parameters. The variation in values and signs of excess parameters with increase in concentration of propylene glycol and temperature is explained by the mechanism of changing the nature of molecular interactions between unlike molecules. Further, the experimental ultrasonic velocities are compared with theoretical values calculated by using various theories like Nomoto's relation (NR), Schaaffs's collision factor theory (CFT) and Jacobson's free length theory (FLT). The relative applicability of these theories is discussed in terms of average percentage errors (APE). The average percentage errors follows the order CFT < NR < FLT at each temperature.

Keywords: Thermo-acoustic parameters, Molecular interaction, Ternary mixture, Ultrasonic study.

INTRODUCTION

Thermodynamic properties are essential for the application of liquid mixture in the designs involving heat shift, chemical partition, mass shift and fluid flow, *etc.* Change in the extent and strength of interaction in the mixture affects the values of thermodynamic properties of solution [1,2]. Spectroscopic methods *viz.* NMR, absorption, IR, ultrasonic methods, *etc.* provide information about the intermolecular interactions [3-6]. Ultrasonic technique is the best technique to detect the interaction in liquids, due to the fact that the natural frequencies of ultrasonic waves are comparable to the natural frequencies of vibration and rotation of molecules of the matter [7]. Thus, ultrasonic study is used for the qualitative estimation of thermodynamic properties and the molecular interactions in the solutions [8-10]. The ultrasonic studies of a liquid mixture containing polar and non-polar components have been attracting the researchers from the last few decades [11-15], but to the best of our knowledge a systematic ultrasonic study of diol in a ternary system with benzene has been scarcely reported.

Benzene has some degree of polar attraction (polar hydrogen- π ($H\pi$ - π) interaction [16,17] or cation- π interaction [18] due

to its negative quadrupole moment. Benzene molecules interact *via* π -stacking in pure state and possess either the permanent dispersive or the temporary dipole nature or both in a polar environment [15]. Alcohols are strongly associated because of dipole-dipole interaction and H-bonding. In non-polar environment, because of a large dipole moment the inductive effect in alcohol leads to dipole-induced dipole interaction [19,20]. So, alcohol can interact with both polar as well as non-polar groups. Glycols have activated hydrogen atoms of hydroxyl groups which are available for interaction with proton acceptors for the formation of hydrogen bonds. Hence, the self-associated glycol molecules are disrupted in mixing with proton acceptor solvents and a hetero-association takes place [21-24]. Propylene glycol (1,2-propanediol) has a wide range of applications. It is used as a solvent in many industries like pharmaceutical, petroleum, cosmetic, oil and food industries. Thus, the physico-chemical properties of propylene glycol solution with different solvents are very important.

In present work, we have measured the ultrasonic velocity, density and viscosity of ternary mixture of propylene glycol with benzene in ethanol at different concentration in mole fraction at different temperatures *viz.* 303, 308, 313 and 318 K.

From the experimental values of u , ρ and η , the values of various excess thermodynamic parameters: excess acoustic velocity (u^E), excess viscosity (η^E), excess adiabatic compressibility (K_s^E), excess intermolecular free length (L_f^E), excess molar volume (V_m^E), excess acoustic impedance (Z^E); and Lennard-Jones potential repulsive term exponent (n) are calculated. The variations in these parameters with composition of mixture are discussed in the terms of molecular interaction between the components of mixture. Moreover, experimentally evaluated ultrasonic velocity is compared with the theoretical values calculated by using various theories like Nomoto's relation (NR) [25], Schaaffs's collision factor theory (CFT) [26] and Jacobson's free length theory (FLT) [27]. The deviations of theoretical ultrasonic velocity values from their experimental values are explained in the terms of molecular interaction and the best suitable theory is suggested.

EXPERIMENTAL

The AR (analytic reagent) grade chemicals *viz.* propylene glycol, benzene and ethanol with minimum assay of 99 % were used without further purification.

General procedure: The mixtures of various concentrations in mole fraction were prepared by mass using a digital balance (manufactured by Aczet) with a precision of ± 1 mg. Firstly, the masses of component liquids required for preparing the mixture of known composition were calculated and then a pseudo-ternary mixture of particular mole fraction was prepared. In all systems, mole fraction of second component, ethanol ($x_2 = 0.4$) was kept fixed while the mole fractions of other two (x_1 of propylene glycol and x_3 of benzene) varied from 0.0 to 0.6; to have the mixture of different compositions.

Detection method: The ultrasonic velocities in liquid mixtures have been measured using a Mittal type (M-81D) ultrasonic interferometer working at 2 MHz (1.9858 ± 0.0001 MHz) frequency with an accuracy of ± 0.1 m s⁻¹ (by the method as described elsewhere [28]). Circulating water from thermostatically regulated bath (manufactured by Mittal Enterprises, New Delhi), around the doubled walled sample holder was used to maintain the temperature of liquid constant with a precision ± 0.1 K.

Density measurements were carried out using relative density (RD) bottle of 10 mL. The RD bottle with the reference liquid (distilled water) was kept in double walled glass jacket (supplied by Saber Scientific, Ahmedabad, India) with circulating water from water bath, for some time to attain the experimental temperature. Then weighing was done by using single pan digital electronic balance supplied by Aczet Pvt. Ltd. India (Model CY 132) to an accuracy of ± 1 mg. Water is replaced with a mixture and weighed by following the same procedure.

The viscosity measurements were carried out using an Ostwald's viscometer with accuracy ± 0.001 (Ns m⁻²). The viscometer was pre-calibrated by double distilled water. The Ostwald's viscometer with the reference liquid (distilled water) was immersed in a double walled glass jacket for some time to attain the experimental temperature. Using a suitable arrangement, water was sucked above the marked level and then allowed to flow freely. The flow time was measured using a digital racer stopwatch with an accuracy of 0.01 s. An average of three sets of efflux time for each measurement was taken into consid-

eration to reduce the possible experimental error. Then water was replaced with a mixture and its flow time at the experimental temperature was noted by using the same procedure.

RESULTS AND DISCUSSION

From the observed values of ultrasonic wave velocity (u) and density (ρ) the excess thermo-acoustic parameters were calculated using following formulas [27-32]:

Isentropic compressibility (K_s or β) [29]:

$$K_s = \frac{1}{u^2 \rho} \quad (1)$$

Intermolecular free length (L_f) [27,30]:

$$L_f = K_T \sqrt{K_s} \quad (2)$$

where, K_T is temperature dependent empirical constant, proposed by Jacobson and given as $K_T = (93.875 + 0.375 \times T) \times 10^{-8}$ at temperature T.

Molar volume (V_m):

$$V_m = \frac{M_{\text{eff}}}{\rho} \quad (3)$$

where M_{eff} is the effective molar mass, given as $M_{\text{eff}} = \sum M_i x_i$, M_i and x_i are the molar mass and mole fraction of the individual component.

Acoustic impedance (Z) [31]:

$$Z = \rho u \quad (4)$$

Lennard-Jones potential repulsive term exponent (n) [32]:

$$n = \left(\frac{6V_m}{V_a} \right) - 13 \quad (5)$$

Excess thermodynamic parameter:

$$A^E = A_{\text{exp}} - A_{\text{id}} \quad (6)$$

$$A_{\text{id}} = \sum_{i=1}^3 A_i x_i \quad (7)$$

where A^E denotes the excess property of thermodynamic parameter, A_{exp} and A_{id} are the corresponding experimental and ideal value. A_i and x_i are the value of thermodynamic parameter and mole fraction of i^{th} component, respectively.

The ultrasonic velocity, density and viscosity of pure components-propylene glycol, benzene and ethanol and their ternary liquid mixture (of different compositions) have been measured at different temperatures 303, 308, 313 and 318 K. The values of excess thermo-acoustic parameters such as excess acoustic velocity (u^E), excess viscosity (η^E), excess adiabatic compressibility (K_s^E), excess intermolecular free length (L_f^E), excess molar volume (V_m^E), excess acoustic impedance (Z^E); and Lennard-Jones potential repulsive term exponent (n) have been calculated by using the values of measured parameters (Tables 1 and 2).

Excess thermodynamic properties of the mixtures correspond to the difference between the property obtained experimentally and the property if the system behaves ideally. The signs and the magnitudes of excess thermodynamic property give the information about the strength of interaction between unlike molecules and are useful in the study of molecular interactions and the arrangements of molecules [33-36].

Liquid	Temp. (K)	u (m s^{-1})	ρ (Kg m^{-3})	η (N s m^{-2})
1,2-propylene glycol (PG)	303	1484.7	1032.51	28.301
	308	1475.1	1024.08	22.523
	313	1468.4	1020.41	19.009
	318	1448.2	1018.16	14.208
Ethanol	303	1126.4	782.25	0.936
	308	1103.3	778.52	0.840
	313	1090.8	774.77	0.799
	318	1074.5	770.97	0.689
Benzene	303	1263.6	868.07	0.570
	308	1240.3	859.76	0.530
	313	1218.3	855.18	0.510
	318	1192.7	851.86	0.473

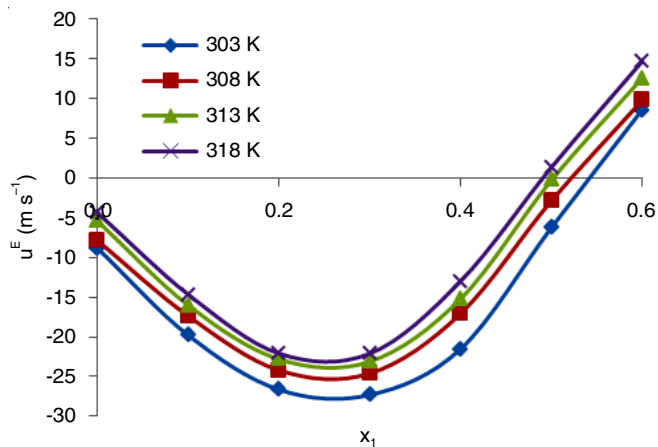


Fig. 1. Plot of excess ultrasonic velocity u^E vs. mole fraction x_1 of propylene glycol

The excess acoustic velocity (u^E) in ternary mixture shows minima in the mole fraction x_1 ranging from 0.2 to 0.4 (Fig. 1). In general, the negative value of u^E indicates the presence of dispersive force arising from the weak molecular interaction between unlike molecules while the positive value shows the

presence of strong attractive interaction such as dipole-dipole, hydrogen bonding, *etc.* In present study, negative value of u^E is a result of breaking of H-bonded structure of ethanol on adding benzene and formation of a comparatively weaker Hp- π interaction between them (Du *et al.* [37] suggested that Hp- π

x_1	u (m s^{-1})	ρ (kg m^{-3})	$\eta \times 10^{-3}$ (Ns m^{-2})	u^E (m s^{-1})	$\eta^E \times 10^{-3}$ (Ns m^{-2})	$K_s^E \times 10^{-10}$ ($\text{N}^{-1} \text{m}^2$)	$L_r^E \times 10^{-11}$ (m)	$V_m^E \times 10^{-6}$ ($\text{m}^3 \text{mol}^{-1}$)	Z^E ($\text{kg m}^{-2} \text{s}^{-1}$)	n
303 K										
0.6	1349.9	955.62	6.734	8.6	-10.620	-0.925	-0.272	-0.716	17840.393	25.390
0.5	1313.0	934.50	3.835	-6.2	-10.747	-0.742	-0.197	-0.613	-1585.464	20.449
0.4	1275.6	914.09	2.338	-21.5	-9.471	-0.508	-0.109	-0.485	-18942.198	16.595
0.3	1247.7	893.69	1.564	-27.3	-7.472	-0.326	-0.049	-0.278	-26295.215	14.252
0.2	1226.3	874.11	1.097	-26.6	-5.166	-0.187	-0.011	-0.054	-25881.200	12.687
0.1	1211.0	855.66	0.779	-19.8	-2.711	-0.108	0.001	0.155	-17979.417	11.679
0.0	1199.9	838.33	0.596	-8.8	-0.121	-0.074	-0.006	0.339	-4688.059	10.993
308 K										
0.6	1336.2	948.37	5.729	9.8	-8.121	-1.007	-0.294	-0.680	17249.037	23.391
0.5	1300.1	928.31	3.447	-2.8	-8.204	-0.847	-0.228	-0.657	1341.498	19.007
0.4	1262.4	907.95	2.118	-17.1	-7.333	-0.617	-0.142	-0.537	-14926.515	15.434
0.3	1231.3	888.21	1.403	-24.6	-5.849	-0.410	-0.073	-0.386	-22984.728	13.041
0.2	1208.3	868.25	1.000	-24.2	-4.052	-0.253	-0.030	-0.135	-23174.525	11.506
0.1	1191.6	849.73	0.729	-17.4	-2.124	-0.162	-0.015	0.077	-15276.087	10.506
0.0	1177.6	832.24	0.551	-7.9	-0.103	-0.093	-0.012	0.275	-3325.310	9.729
313 K										
0.6	1330.0	943.89	5.069	12.6	-6.656	-1.077	-0.315	-0.635	18286.749	22.551
0.5	1292.1	923.89	3.076	-0.2	-6.799	-0.916	-0.249	-0.623	2349.987	18.179
0.4	1252.1	904.00	1.899	-15.2	-6.127	-0.677	-0.159	-0.546	-13832.496	14.598
0.3	1219.2	884.51	1.302	-23.1	-4.873	-0.461	-0.087	-0.423	-21693.047	12.212
0.2	1194.5	865.53	0.951	-22.8	-3.374	-0.302	-0.044	-0.263	-20575.171	10.676
0.1	1176.3	846.66	0.696	-16.0	-1.779	-0.196	-0.026	-0.030	-12904.273	9.657
0.0	1161.9	828.00	0.528	-5.4	-0.097	-0.120	-0.022	0.270	-1127.138	8.913
318 K										
0.6	1313.5	940.25	4.427	14.7	-4.373	-1.138	-0.333	-0.588	18900.211	20.503
0.5	1274.6	920.62	2.743	1.4	-4.684	-0.974	-0.265	-0.611	3155.088	16.498
0.4	1234.7	900.88	1.734	-13.0	-4.320	-0.736	-0.176	-0.553	-12079.155	13.277
0.3	1200.0	881.56	1.195	-22.1	-3.486	-0.497	-0.096	-0.451	-20659.158	10.999
0.2	1174.4	862.54	0.838	-22.1	-2.468	-0.326	-0.050	-0.296	-19663.510	9.558
0.1	1156.3	843.63	0.617	-14.7	-1.316	-0.223	-0.034	-0.066	-11317.429	8.636
0.0	1141.0	825.03	0.477	-4.4	-0.082	-0.136	-0.028	0.223	435.196	7.917

x_1 = propylene glycol; x_2 = ethanol; x_3 = benzene

interaction is weaker as compared to conventional H-bonding). The more negative values with increasing x_1 are attributed to increasing strength of the dispersive Hp- π interaction between two -OH group of propylene glycol with benzene rather than with ethanol molecules (due to their small size). At higher x_1 lower number of benzene molecules causes increasing strength of H-bonding between propylene glycol and ethanol molecules and leading to the positive value of u^E . The similar trend of negative values of u^E was reported for benzene with 1-alkanols (C₅, C₇, C₈) [38]. With increase in the temperature, higher negative value of u^E represents that the dispersive nature of interaction increases, while the higher positive value indicates the increasing strength of the attractive interaction.

According to Kauzman and Eyring [39], the viscosity of a mixture strongly depends on the entropy of mixture, which is related with the liquid's structure and enthalpy (consequently with molecular interactions between the components of the mixture). Therefore, the viscosity deviations in liquid mixtures depend on physical properties such as size and shape of molecules as well as on molecular interactions [40-42]. Islam and Ali [43] suggest that the viscosity of a system decreases with increasing number of smaller entities or/and decreasing number of bulk entities in the system. The trend of η^E values (Fig. 2) from $x_1 = 0.0$ to 0.5 attributed to dispersive forces as well as difference in molecular size of components of mixture (molar volume follow the order: V_m (ethanol) < V_m (propylene glycol) < V_m (benzene) for all temperatures) while from $x_1 = 0.5$ to 0.6 a flat curve is result of strong H-bonding between unlike molecules. With increasing temperature increased energy speed up the flow of liquid and results in less negative values of η^E .

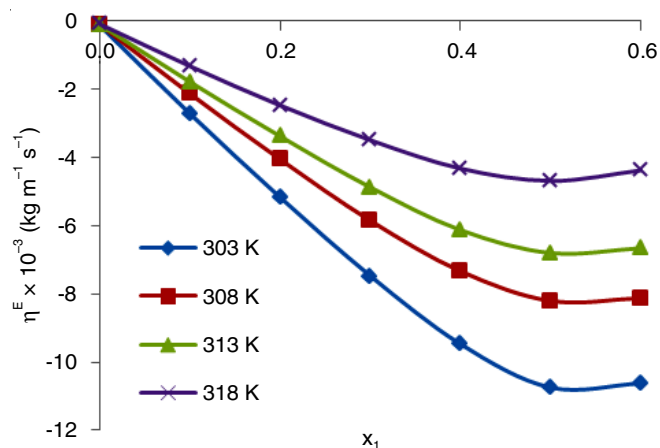


Fig. 2. Plot of excess viscosity η^E vs. mole fraction x_1 of propylene glycol

Fig. 3 shows that the excess adiabatic compressibility K_s^E decreases with the increasing x_1 . The negative values of K_s^E show that system is less compressible than the ideal mixture. This close packing of molecules is supported by the negative value of excess free length (L_f^E) (Fig. 4) and excess molar volume (V_m^E) (Fig. 5). Patil *et al.* [44] suggests that the formation of bonds and the differences in the molar volume and free volume between the components yield the greater geometrical fitting of molecules which results into negative V_m^E . Similarly, the smaller molecular size of ethanol than that of propylene glycol and benzene (molar volume follow the order: V_m (ethanol) < V_m (propylene glycol) < V_m (benzene) at all temperature)

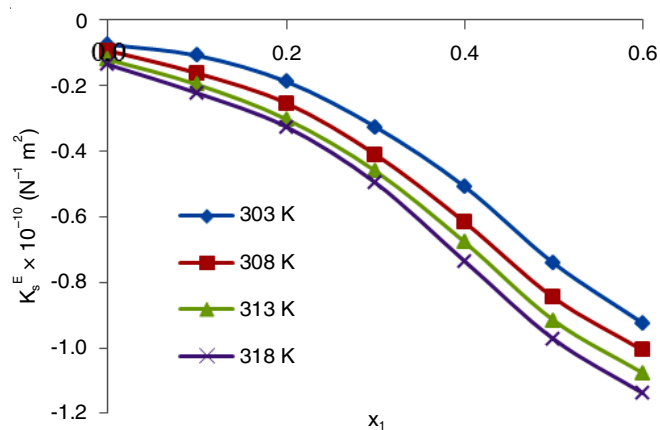


Fig. 3. Plot of excess adiabatic compressibility K_s^E vs. mole fraction x_1 of propylene glycol

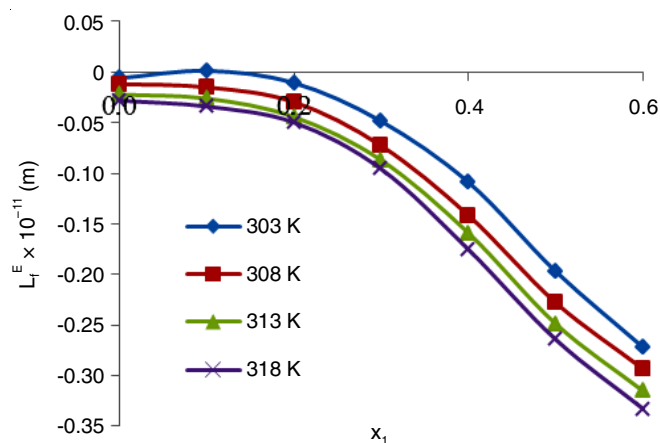


Fig. 4. Plot of excess free length L_f^E vs. mole fraction x_1 of propylene glycol

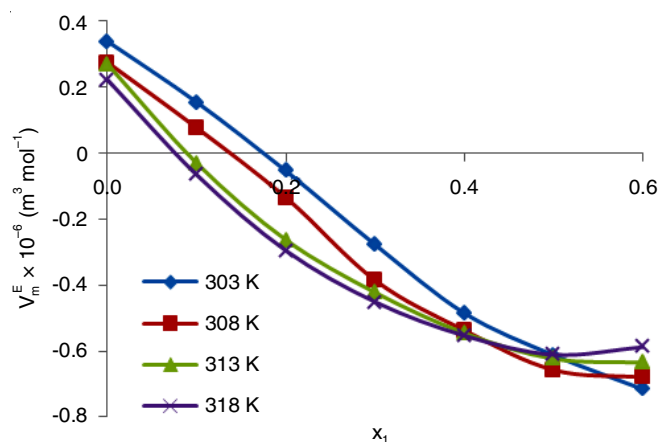


Fig. 5. Plot of excess molar volume V_m^E vs. mole fraction x_1 of propylene glycol

favours the interstitial accommodation of smaller molecules into the voids created by bigger molecules of larger molar volume and results into more compact structure.

Excess acoustic impedance (Z^E) shows minima in the mole fraction x_1 ranging from 0.2 to 0.4 (Fig. 6). The dispersive interaction between molecules decreases the pressure generated by the vibration at that frequency and leads to negative value of Z^E [45]. Variation of Z^E with concentration x_1 is attributed to change in molecular interaction from dispersive to strong forces. Negative values of Z^E have been reported for benzene

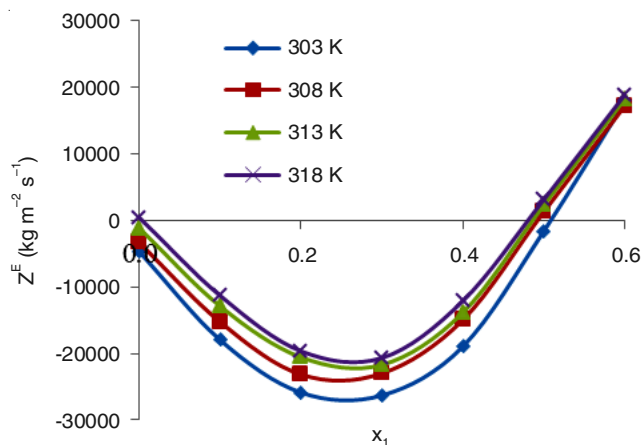


Fig. 6. Plot of excess acoustic impedance Z^E vs. mole fraction x_1 of propylene glycol

with 1-alkanols (C_5 , C_7 , C_8) [38], while positive values of Z^E have been reported for ethanol with 1-alkanols (C_6 , C_8) [10]. The monotonic increase in Lennard-Jones potential repulsive term exponent (n) with increasing x_1 (Fig. 7) indicates that the strong forces dominate over the repulsive forces. Decrease in n with temperature is attributed to increase in repulsive forces with temperature.

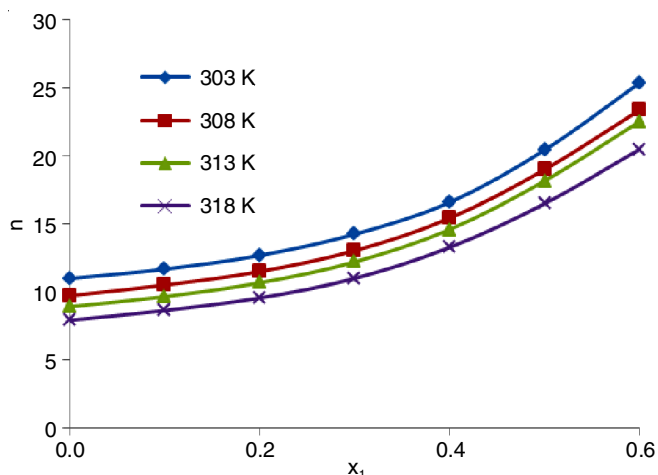


Fig. 7. Plot of Lennard-Jones potential repulsive term exponent (n) vs. mole fraction x_1 of propylene glycol

The difference in the Z^E values at 303, 308, 313 and 318 K is more at lower x_1 as compared to that at higher mole fraction (Fig. 6). Therefore, dispersive interaction between the components at the lower concentration is more temperature dependent as compared to the strong H-bonding interaction at the higher concentration. The same is affirmed by the fact that interaction energy of $H\pi$ - π interaction is less than that of H-bonding [46]. With increasing temperature the increased energy causes the stretching of molecules which results into their geometrical fitting and make the system more compact as suggested by the more negative values of K_s^E , L_f^E and V_m^E (Figs. 3-5). Sujata and Rita [47] show that the K_s^E and L_f^E become more negative with increase in the temperature. Also increasing temperature results into the stretching of molecules which reduces the crowding of -OH groups in propylene glycol and they become more available to interact with unlike molecules (ethanol and benzene).

This results into an increased strength of dispersive (reduction in 'n' with temperature, Fig. 6) as well as of strong interaction.

Further, ultrasonic velocity in liquid mixtures is also calculated by using the following empirical and semi-empirical formulae [25-27]:

Free length theory (FLT):

$$u_{FLT} = \frac{K_T}{L_{f,mix} (\rho_{mix})^{1/2}} \quad (8)$$

Schaff's collision factor theory (CFT):

$$u_{CFT} = u_{\infty} \left(\frac{(\sum x_i S_i)(\sum x_i B_i)}{V_m} \right) \quad (9)$$

Nomoto's relation (NR):

$$u_{NR} = \left(\frac{\sum x_i R_i}{\sum x_i V_i} \right)^3 \quad (10)$$

Average percentage error (APE):

$$APE = \frac{1}{a} \left(\frac{u_{\text{experimental}} - u_{\text{theoretical}}}{u_{\text{experimental}}} \right) \times 100 \quad (11)$$

where, a is the number of data points.

Values of acoustic velocities determined from various theoretical models and their deviation from experimentally measured values are shown in Table-3. Their deviations are due to the approximation integrated in these theories.

In Jacobson free length theory [27], the molecules are treated as a rigid sphere and the distance between them is considered to be fixed. But the variation in L_f^E with the temperature and the concentration shows that the distance between the molecules is not fixed. Also a strong specific interaction results into deviation from a rigid sphere shape. Thus, FLT shows a large deviation at higher x_1 where interactions are specifically strong (Table-3). Nomoto's relation is based on additivity of molar sound velocity and the isochoric condition under which the volume remains unchanged even after mixing the components, but the excess molar volume (V_m^E) shows that the volume does not follow additivity *i.e.* ideal behaviour. So Nomoto's relation shows the deviation with the experimental values. In CFT [26], the molecules are treated as real non-elastic substances and the molecular interaction is considered to be the result of active collision between the molecules. As CFT incorporates the molecular interaction, the APE is least for CFT as compared to NR and FLT (Table-2) at each temperature. Also FLT is more suitable than NR at lower x_1 . But at higher x_1 , NR is better than FLT. For every temperature the order of APE is CFT < NR < FLT. This suggests that the relative applicability of these theories in the ternary system follow the order: CFT > NR > FLT.

Conclusion

The thermo-acoustic study of ternary system of propylene glycol, benzene and ethanol has been done experimentally. The values of the excess parameters suggest the presence of the molecular interaction in the system. It is concluded that the presence of ethanol makes the structure of ternary mixture compact while π -electron density of benzene causes $H\pi$ - π interaction with ethanol and propylene glycol molecules. The tempe-

TABLE-3
VALUES OF EXPERIMENTAL AND THEORETICAL ULTRASONIC VELOCITY CALCULATED FROM DIFFERENT THEORIES AND THEIR PERCENTAGE DEVIATION FROM EXPERIMENTAL VALUES AT DIFFERENT TEMPERATURES

x_1	u	ρ	u(FLT)	Δu (FLT)	u(CFT)	Δu (CFT)	u(NR)	Δu (NR)
303 K								
0.6	1349.94	955.62	1273.18	5.69	1355.44	-0.41	1352.61	-0.20
0.5	1313.00	934.50	1249.97	4.80	1330.96	-1.37	1327.38	-1.10
0.4	1275.62	914.09	1232.43	3.39	1306.29	-2.40	1303.60	-2.19
0.3	1247.73	893.69	1214.45	2.67	1280.48	-2.63	1281.16	-2.68
0.2	1226.27	874.11	1200.93	2.07	1254.79	-2.33	1259.94	-2.75
0.1	1211.00	854.53	1186.44	2.03	1228.11	-1.41	1239.85	-2.38
0.0	1199.88	835.36	1173.26	2.22	1201.10	-0.10	1220.81	-1.74
APE				3.26		-1.52		-1.86
308 K								
0.6	1336.20	948.37	1249.48	6.49	1339.43	-0.24	1337.99	-0.13
0.5	1300.07	928.31	1234.04	5.08	1315.16	-1.16	1311.05	-0.84
0.4	1262.37	907.95	1216.12	3.66	1289.25	-2.13	1285.69	-1.85
0.3	1231.35	888.21	1201.87	2.39	1263.08	-2.58	1261.79	-2.47
0.2	1208.26	868.25	1185.89	1.85	1235.58	-2.26	1239.23	-2.56
0.1	1191.60	848.71	1171.68	1.67	1207.69	-1.35	1217.89	-2.21
0.0	1177.63	829.78	1159.84	1.51	1179.78	-0.18	1197.69	-1.70
APE				3.24		-1.41		-1.68
313 K								
0.6	1329.96	943.89	1234.05	7.21	1329.30	0.05	1328.83	0.09
0.5	1292.10	923.89	1217.86	5.75	1303.72	-0.90	1299.91	-0.60
0.4	1252.14	904.00	1202.39	3.97	1277.09	-1.99	1272.74	-1.65
0.3	1219.24	884.51	1189.18	2.47	1249.92	-2.52	1247.16	-2.29
0.2	1194.52	865.53	1178.19	1.37	1222.44	-2.34	1223.05	-2.39
0.1	1176.29	846.66	1166.94	0.79	1194.14	-1.52	1200.28	-2.04
0.0	1161.90	828.30	1157.35	0.39	1165.68	-0.33	1178.74	-1.45
APE				3.14		-1.36		-1.48
318 K								
0.6	1313.46	940.25	1219.92	7.12	1309.54	0.30	1309.83	0.28
0.5	1274.56	920.62	1204.14	5.52	1284.07	-0.75	1280.13	-0.44
0.4	1234.67	900.88	1188.00	3.78	1257.27	-1.83	1252.25	-1.42
0.3	1199.98	881.56	1174.26	2.14	1229.94	-2.50	1226.03	-2.17
0.2	1174.43	862.54	1161.84	1.07	1202.01	-2.35	1201.33	-2.29
0.1	1156.30	843.63	1149.51	0.59	1173.27	-1.47	1178.03	-1.88
0.0	1141.04	825.03	1138.11	0.26	1144.09	-0.27	1156.01	-1.31
APE				2.93		-1.27		-1.32

temperature dependence of ultrasonic velocity is attributed to the two -OH groups of propylene glycol behaving differently at low and higher mole fraction of mixture. In this mixture, initially when the concentration of benzene is more; dispersive force, due to weak Hp- π interaction, increases. But as the concentration of propylene glycol increases and that of benzene decreases the strong H-bonding dominates. The molecular interaction causes deviation of theoretical acoustic velocity from the experimental value. Three theoretical models for ultrasonic velocity: CFT, NR and FLT have been studied, out of which CFT is best suited in the system as it incorporates the aspects of molecular interaction.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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