International Letters of Chemistry, Physics and Astronomy
ISSN: 2299-3843, Vol. 18, pp 1-7
doi:10.18052/www.scipress.com/ILCPA.18.1
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Online: 2013-09-28

Study of acoustical parameters in binary liquid mixture containing 1-butanol and hexane at temperatures 313.15 K, 318.15 K and 323.15 K

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ABSTRACT

The values of ultrasonic velocity (u), density (ρ), and viscosity (η) have been measured experimentally in the binary liquid mixture containing 1-butanol and hexane over the entire range of composition at different temperatures 313.15 K, 318.15 K and 323.15 K. This experimental data have been used to calculate the acoustical parameters such as adiabatic compressibility (β), free length (L_f), molar volume (V_m) and acoustic impedance(z). The results have been qualitatively used to explain the molecular interactions between the components of the liquid mixture.

Keywords: Density; ultrasonic velocity; viscosity; 1-butanol; hexane; adiabatic compressibility; free length and molar volume

1. INTRODUCTION

Ultrasonic investigations find extensive application in characterizing physico-chemical behaviour of liquid mixtures. The compositional dependence of thermodynamic properties has proved to be a very useful tool in understanding the nature of molecular interactions [1,2]. The non-ideal behaviour has been studied by several research scholars [3-5]. Compressibility and viscosity are the static and transport properties of liquid respectively and are the most important amongst properties of liquid. The study of molecular interactions in the liquid mixtures is of considerable in the elucidation of the structural properties of the molecules. The intermolecular interactions influence the structural arrangement along with the shape of the molecules. In the recent years, ultrasonic technique has been found to be one of the most powerful technique for studying the nature of molecular interactions in liquid mixtures.

Acoustical parameters are used to understand different kinds of association, the molecular packing, molecular motion, physico-chemical behaviour and various types of intermolecular interactions and their strengths, influenced by the size in pure components and in the mixtures. As a part of today's progressive and ongoing research [6,7] on thermodynamic and acoustic properties of binary liquid mixtures, we report here the results of study on binary mixture of 1-butanol and hexane over the entire range of composition at T = 313.15 K, 318.15 K and 323.15 K. With the help of experimentally measured values like ultrasonic velocity (u), density (ρ) and viscosity (η), acoustical parameters such as adiabatic compressibility (β), free length (L_f), molar volume (V_m) and acoustic impedance(z) have been estimated using standard relations.

2. MATERIALS AND METHODS

The chemicals used were of AR grade and are all were purified by standard procedure [8]. Job's method of continuous variation was used to prepare the mixtures of required proportions. The various concentrations are prepared by varying mole fractions. The prepared mixtures were preserved in well-Stoppard conical flasks. After mixing the liquids thoroughly, the flasks were left undisturbed to allow them to attain thermal equilibrium. The ultrasonic velocities were measured by using single crystal ultrasonic pulse echo interferometer(Mittal enterprises, India; Model: F-80X). It consists of a high frequency generator and a measuring cell. The measurements of ultrasonic velocities were made at a fixed frequency of 3 MHz. The capacity of the measuring cell is 12ml. The ultrasonic velocity has an accuracy of ±0.5 $m \cdot s^{-1}$. The temperature was controlled by circulating water around the liquid cell from thermostatically controlled constant temperature water bath (accuracy ±0.01 K). The densities of pure liquids and liquid mixtures were measured by using a specific gravity bottle with an accuracy of ±0.5 %. An electronic balance (Shimadzu AUY220, Japan), with a precision of ±0.1 mg was used for the mass measurements. Averages of 4 to 5 measurements were taken for each sample. Viscosities were measured at the desired temperature using Ostwald's viscometer, which was calibrated using water and benzene. The flow time has been measured after the attainment of bath temperature by each mixture. The flow measurements were made with an electronic stopwatch with a precision of 0.01 s. The viscosities η, were obtained from the following relation:

$$\text{Viscosity } \eta = k \cdot \rho \cdot t \qquad \text{---} \quad (1)$$

where k, ρ and t, are viscometric constant, density of liquid and time of efflux for a constant volume of liquid respectively. For all pure compounds and mixtures, 4 to 5 measurements were performed and the average of these values was used in all calculations. The values are accurate to ±0.001 cP.

3. THEORY

From the experimental data of density, viscosity and ultrasonic velocity, various acoustical parameters are evaluated using the standard relations. The values of adiabatic compressibility (β) can be calculated by the following relation:

$$\text{Adiabatic compressibility } \beta = 1/pu^2 \qquad \text{---} \quad (2)$$

where p is the density of the mixture and u is the ultrasonic velocity. The values of free length (L_f) can be calculated by the following relation

$$\text{Free length } L_f = K_T \beta^{1/2} \quad \text{--- (3)}$$

where K_T is temperature dependent constant. The values of molar volume (V_m) can be calculated by the following relation.

$$\text{Molar volume } (V_m) = M_{eff}/p \quad \text{--- (4)}$$

where M_{eff} is the effective mass of the liquid mixtures.

The values of acoustic impedance (Z) can be calculated by the following relation

$$\text{Acoustic impedance } Z = u \times p \quad \text{--- (5)}$$

where u is ultrasonic velocity and p is density. The experimentally measured values of pure components are compared with the literature [9-12, 14-17] values and are given in (Table 1).

Table 1. Experimental and literature values of density and ultrasonic velocity of pure liquids at 303.15 K.

Liquids	**Density(ρ) kg·m^{-3}**		**Ultrasonic velocity(u) m·s^{-1}**	
	Experimental	**Literature**	**Experimental**	**Literature**
1-butanol	1227.4	1228.8[*9]	801.7	801.8[*10]
hexane	1058.2	1057.0[*11]	650.1	649.3[*12]

Table 2. Densities (ρ), viscosities (η) and ultrasonic velocities (u) of liquid mixture at T = 313.15 K, 318.15 K and 323.15 K.

Molefraction of 1-butanol (x)	**u (ms^{-1})**	**ρ (Kgm^{-3})**	**η (X10^{-3} Nsm^{-2})**
T = 313.15 K			
0.0000	1020.7	638.4	0.0300
0.1364	1036.0	656.0	0.0313
0.2623	1057.0	672.8	0.0330
0.3791	1078.3	690.3	0.0368
0.4871	1098.8	709.2	0.0460
0.5875	1120.0	727.4	0.0613
0.6812	1137.0	744.7	0.0837

0.7688	1156.0	758.0	0.1110
0.8507	1173.0	769.5	0.1320
0.9277	1186.0	782.5	0.1490
1.0000	1198.8	794.3	0.1630
T = 318.15 K			
0.0000	1002.0	632.7	0.0200
0.1364	1019.0	650.5	0.0215
0.2623	1040.0	667.0	0.0220
0.3791	1063.0	684.0	0.0260
0.4871	1085.0	701.7	0.0360
0.5875	1104.0	720.0	0.0500
0.6812	1124.0	736.5	0.0720
0.7688	1141.0	750.5	0.1000
0.8507	1158.0	764.0	0.1210
0.9277	1172.0	776.8	0.1370
1.0000	1184.0	790.5	0.1540
T = 323.15 K			
0.0000	0982.0	627.2	0.0103
0.1364	1000.0	644.0	0.0110
0.2623	1022.0	660.0	0.0120
0.3791	1046.0	678.2	0.0151
0.4871	1066.0	695.5	0.0260
0.5875	1087.2	713.5	0.0400
0.6812	1107.1	730.5	0.0600
0.7688	1125.1	744.7	0.0860
0.8507	1140.0	757.8	0.1090
0.9277	1156.0	771.2	0.1280
1.0000	1170.0	785.3	0.1450

Table 3. Adiabatic compressibility (β), Free length (L_f), molar volume (V_m) and acoustic impedance (π) of liquid mixture at T = 313.15 K, 318.15 K and 323.15 K.

Mole fraction of 1-butanol (x)	β_{ad} 10^{-10} m^2N^{-1}	L_f 10^{-11} m	V_m 10^{-7} m^3	Z 10^6 $m^{-2}s^{-1}$
T = 313.15 K				
0.0000	15.0353	8.1935	1.3499	0.6516
0.1364	14.2029	7.9634	1.2886	0.6796
0.2623	13.3034	7.7072	1.2339	0.7111
0.3791	12.4590	7.4585	1.1822	0.7444
0.4871	11.6787	7.2212	1.1323	0.7793
0.5875	10.9595	6.9953	1.0874	0.8147
0.6812	10.3872	6.8102	1.0469	0.8467
0.7688	9.8722	6.6393	1.0146	0.8762

0.8507	9.4449	6.4940	0.9866	0.9026
0.9277	9.0854	6.3692	0.9583	0.9280
1.0000	8.7604	6.2542	0.9331	0.9522
		T = 318.15 K		
0.0000	15.7422	8.4583	1.3621	0.6340
0.1364	14.8049	8.2026	1.2995	0.6629
0.2623	13.8614	7.9369	1.2446	0.6937
0.3791	12.9383	7.6681	1.1931	0.7271
0.4871	12.1057	7.4173	1.1444	0.7613
0.5875	11.3954	7.1964	1.0985	0.7949
0.6812	10.7472	6.9887	1.0586	0.8278
0.7688	10.2348	6.8201	1.0248	0.8563
0.8507	9.7609	6.6603	0.9937	0.8847
0.9277	9.3721	6.5263	0.9654	0.9104
1.0000	9.0239	6.4039	0.9376	0.9360
		T = 323.15 K		
0.0000	16.5337	8.7446	1.3740	0.6159
0.1364	15.5280	8.4744	1.3127	0.6440
0.2623	14.5062	8.1909	1.2578	0.6745
0.3791	13.4766	7.8948	1.2033	0.7094
0.4871	12.6529	7.6497	1.1546	0.7414
0.5875	11.8573	7.4054	1.1085	0.7757
0.6812	11.1688	7.1871	1.0673	0.8087
0.7688	10.6081	7.0044	1.0327	0.8379
0.8507	10.1540	6.8528	1.0019	0.8639
0.9277	9.7033	6.6990	0.9724	0.8915
1.0000	9.3024	6.5592	0.9438	0.9188

4. RESULTS AND DISCUSSION

Ultrasonic velocity, density and viscosity were measured at fixed frequency for the binary liquid mixture over the entire range of composition at different temperatures 313.15 K, 318.15 K and 323.15 K are presented in Table 2. From Table 2 it is observed that the ultrasonic velocity increases with increase in mole fraction of 1-butanol. This may be due to association of a very strong dipole-induced dipole interaction between the component molecules. The calculated thermoacoustical parameters such as adiabatic compressibility (β), free length (L_f), molar volume (V_m) and acoustic impedance (z) and their variations are given in Table 3. Adiabatic compressibility is a measure of intermolecular association or dissociation or repulsion. It is independent of temperature and pressure for unassociated and weakly associated molecules. It also determines the orientation of the solvent molecules around the liquid molecules. The structural arrangement of the molecule affects the adiabatic compressibility. From Table 3 and it is observed that adiabatic compressibility decreases with increase in mole fraction of 1-butanol in the mixture taken up for study. As adiabatic compressibility is inversely proportional to ultrasonic velocity, since ultrasonic velocity increases with mole fraction, so that adiabatic compressibility decreases with mole fraction of

1-butanol. The free length is the distance between the surfaces of the neighbouring molecules. Generally, when the ultrasonic velocity increases, the value of the free length decreases. The observed increase in ultrasonic velocity and corresponding decrease in free length with mole fraction of 1-butanol in the binary liquid mixture is in accordance with the proposed by theory [13]. From Table 3, it is studied that the values of adiabatic compressibility and free length increases with increase in temperatures, it clearly reveals that interaction become stronger at lower temperatures. Similar variations are observed in case of molar volume given in Table 3. Also it is observed from Table 3, that acoustic impedance increases with increase in mole fraction of 1-butanol.

5. CONCLUSION

Ultrasonic velocity, density and viscosity values are measured experimentally. By using these values various acoustical parameters like adiabatic compressibility (β), free length (L_f), molar volume (V_m) and acoustic impedance (z) are calculated by using standard relations. It is very obvious from values of ultrasonic velocity, density, viscosity and calculated acoustical parameter of the binary liquid mixture containing 1-butanol and hexane at 298.15 K, 303.15 K and 308.15 K that there exists a strong molecular association between the components of the liquid mixture.

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(Received 21 August 2013; accepted 26 August 2013)