VOLUMETRIC, VISCOSITY AND ULTRASONIC BEHAVIOUR OF n-BUTYL PROPIONATE + ETHER (THF, 1,4-DIOXANE, ANISOLE AND BUTYL VINYL ETHER) MIXTURES AT 303.15, 308.15 AND 313.15 K

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Density, viscosity and speed of sound of binary liquid mixtures of butyl propionate with tetrahydrofuran, 1,4-dioxane, anisole and butyl vinyl ether were measured at (303.15,308.15 and 313.15) K and over the entire composition range. From the experimental data values of excess volume V^E, viscosity deviations $\Delta\eta$, deviation in speeds of sound Δu, isentropic compressibility Ks and deviation in isentropic compressibility ΔK_S, have been determined. The speeds of sound data have been analysed on the basis of Jouyban–Acree and Vandeal–Vangeel models.

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Introduction

A number of theories[1,2] have been proposed to compute the useful thermodynamic properties of liquids and liquid mixtures. Parallel to this many experimental techniques have been developed. In liquid mixture studies attractive forces like dipole–dipole interactions, hydrogen bond type forces and dipole-induced dipole interactions lead to non ideal effects.[3] However quantitative estimation of such interactions is important in order to achieve a fundamental understanding about the liquid state properties, which are useful in many specific disciplines like chemistry, physics, engineering, and biology. Numerous studies[4-10] have been reported related to the interactions in binary liquid mixtures of esters with a variety of organic solvents. However no attempts have been made to study interactions in the binary mixtures containing butyl propionate as a common component.

Esters have found wide spread use in several industries and automotive applications due to their excellent performance characteristics such as solvency and evaporation rate. Butyl propionate is widely used for high solid coatings in automotive finishes, appliance coatings, cleaning fluids, enamels, lacquers, and printing inks. While ethers are commonly used as powerful non-polar solvents for both industrial applications and for chemical reactions. In medical applications ethers are used as a general anaesthetic for surgeries. Its use replaced chloroform which was extremely toxic. In automotive application an ether is added to the fuel in race cars for extra power. Therefore the study of interaction of esters with ethers will throw light on designing, separation operations such as distillation etc.

In view of these above importance the present research has been undertaken with the objective of investigating the molecular interactions of the binary mixtures of butyl propionate with ethers. In continuation of our earlier work,[11-14] in this paper we report the density, viscosity and speed of sound of binary liquid mixtures of butyl propionate + tetrahydrofuran, butyl propionate + 1,4-dioxane, butyl propionate + anisole, and butyl propionate + butyl vinyl ether at (303.15, 308.15 and 313.15) K over the entire range of composition of n-butyl propionate.

From the experimental values excess volume V^E, deviation in viscosity $\Delta\eta$, deviation in speeds of sound Δu, isentropic compressibility Ks and deviation in isentropic compressibility ΔK_S, have been calculated. This work also provides a test of empirical equations proposed by Jouyban–Acree[15,16] and Vandeal–Vangeel[17] to correlate speeds of sound data of the binary liquid mixtures in terms of pure component properties.

Experimental

Materials: Extra pure butyl propionate, tetrahydrofuran, 1,4-dioxane, anisole and butyl vinyl ether all Fluka AG were procured from the Aldrich company. The mass fraction purities as determined by gas chromatography (HP 8610) using FID were, butyl propionate (> 0.998), tetrahydrofuran (> 0.996), 1,4-dioxane (>0.997), anisole (> 0.998), and butyl vinyl ether (>0.996). Before use the pure chemicals were stored over 0.4 nm molecular sieves for 72 h to reduce water content if any and were degassed at low pressure.

Methods: The density of pure liquids and their binary mixtures were measured with Anton Paar DMA 4500 density meter with certified precision of better than $\pm 1 \times 10^{-5}$ $g.cm^{-3}$ operated in the static mode and the cell was regulated to ± 0.01K with solid state thermostat. The apparatus was calibrated once a day with dry air and double

distilled freshly degassed water. The uncertainty in the density measurements was found to be less than ±0.0002 g cm^{-3}. Airtight stoppered bottles were used for the preparation of the mixtures. Mass measurements accurate to ± 0.01 mg were made on a digital electronic balance (Mettler AE 240, Switzerland). Each mixture was immediately used after it was well mixed by shaking. The resulting mole fraction uncertainty was estimated to be less than ± 0.0001. Viscosities were determined using an Ubbelohde viscometer with an uncertainty of ±0.005 mPa s. The detailed method of measurement of viscosity has been described earlier.[11] The speeds of sound at frequency of 2 MHz were determined using single crystal variable path interferometer (F-8 Mittal Enterprises, New Delhi, India). The uncertainty in speed of sound was found to be ± 1 m s^{-1}.

Results and Discussion

The results of density ρ, excess volume V^E, viscosity η, and speed of sound u, isentropic compressibility K_S of the studied binary mixtures at (303.15, 308.15 and 313.15) K are given in Table 1. The excess volume V^E (cm^3 mol^{-1}) was calculated using the relation

$$V^E = \frac{(x_1M_1 + x_2M_2)}{\rho_{12}} - \left(\frac{x_1M_1}{\rho_1} + \frac{x_2M_2}{\rho_2}\right) \quad (1)$$

where x, M and ρ are the mole fraction, molar mass, and density respectively of pure components 1 and 2. ρ_{12} is the density of the liquid mixture. The isentropic compressibility K_S was calculated using Newton-Laplace equation:

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

The deviations in viscosity $\Delta\eta$, speeds of sound Δu, and isentropic compressibility ΔK_S were calculated using the general equation

$$\Delta Y = Y_m - x_1Y_1 - x_2Y_2 \quad (3)$$

where ΔY is the deviation or excess property in question, Y_m refers to the property of the mixture, x_1Y_1 and x_2Y_2 refer to the mole fraction and specific property of the pure components 1 and 2 respectively. The results of V^E, $\Delta\eta$, Δu and ΔKs, for the binary mixtures at (303.15, 308.15 and 313.15) K were graphically represented in Figures 1-4. Further these results were fitted to the Redlich-Kister[18] polynomial equation by the method of least squares to derive the binary solution coefficients A_0, A_1, A_2.

$$\Delta Y = x_1x_2\left[A_0 + A_1(x_1 - x_2) + A_2(x_1 - x_2)^2\right] \quad (4)$$

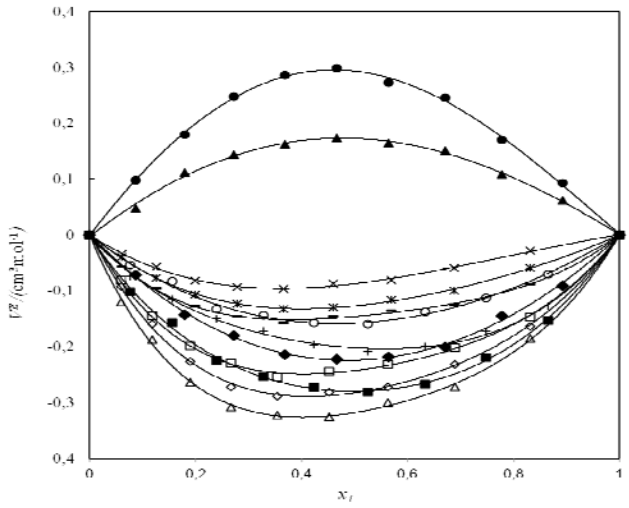

Figure 1. Curves of excess volumes (V^E) vs. mole fraction for the binary mixtures. Butyl propionate + Tetrahydrofuran at (□, 303.15 K; ◊, 308.15 K; Δ, 313.15 K; butyl propionate + 1,4-dioxane at (×, 303.15 K; ж, 308.15 K; ▬, 313.15 K; butyl propionate + anisole at O, 303.15 K; +, 308.15 K; ■, 313.15 K; butyl propionate + butyl vinyl ether ♦, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

The standard deviations for V^E, $\Delta\eta$, Δu and ΔK_S were calculated using the relation

$$\sigma(Y) = \left[\frac{\Sigma(Y^E_{\exp} - Y^E_{cal})^2}{(D - N)}\right]^{0.5} \quad (5)$$

where D and N are the number of experimental data and equation parameters respectively. The coefficients of Eq.4 and the standard deviations of Eq.5 were presented in Table 2.

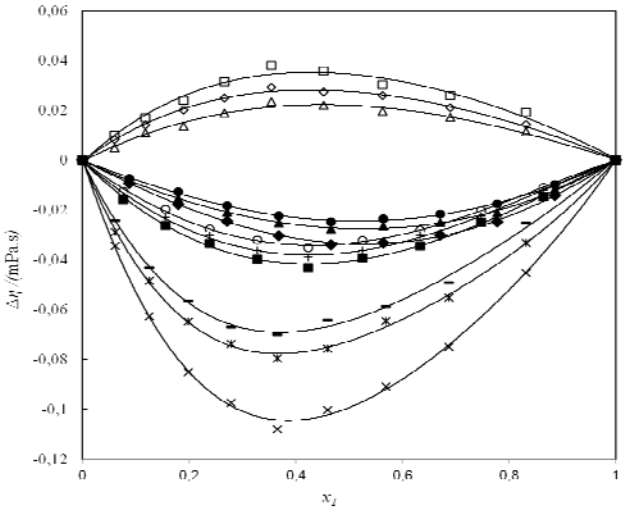

Figure 2. Curves of deviation in viscosity ($\Delta\eta$) Vs mole fraction for the binary mixtures. butyl propionate + tetrahydrofuran at (□, 303.15 K; ◊,308.15 K; Δ, 313.15 K; butyl propionate + 1,4-dioxane at ×, 303.15 K; ж, 308.15 K; ▬, 313.15 K; butyl propionate + anisole at O, 303.15 K; +, 308.15 K; ■, 313.15 K; butyl propionate + butyl vinyl ether ♦, 303.15 K; ▲, 308.15 K; ●, 313.15 K

Table 1 Values of density ρ , excess volume V^E, viscosity η , speed of sound u, isentropic compressibility K_S,for the binary liquid mixtures.

x_1	ρ, g.cm^{-3}	V^E, cm^3.mol^{-1}	η, mPa.s	u, m.s^{-1}	K_S, Tpa^{-1}
	Butyl propionate(1) + Tetrahydrofuran (2)				
	***T*=303.15 K**				
0.0000	0.8787		0.439	1248	730.7
0.0596	0.8784	-0.080	0.465	1236	745.2
0.1176	0.8780	-0.145	0.487	1224	760.2
0.1900	0.8773	-0.199	0.513	1216	770.9
0.2667	0.8764	-0.230	0.540	1208	787.1
0.3539	0.8754	-0.255	0.570	1196	798.6
0.4521	0.8741	-0.244	0.593	1192	805.2
0.5628	0.8728	-0.231	0.616	1188	811.8
0.6893	0.8714	-0.202	0.645	1184	818.6
0.8314	0.8699	-0.147	0.675	1184	820.0
1.0000	0.8679		0.700	1188	816.4
x_1	***T*=308.15 K**				
0.0000	0.8730		0.429	1228	759.6
0.0596	0.8730	-0.093	0.450	1220	769.8
0.1176	0.8727	-0.160	0.469	1212	780.3
0.1900	0.8720	-0.227	0.491	1204	791.3
0.2667	0.8712	-0.272	0.513	1196	802.6
0.3539	0.8710	-0.289	0.537	1188	814.5
0.4521	0.8688	-0.282	0.557	1184	821.3
0.5628	0.8674	-0.272	0.581	1180	828.1
0.6893	0.8659	-0.231	0.604	1176	835.2
0.8314	0.8643	-0.163	0.629	1172	842.4
1.0000	0.8621		0.653	1172	844.5
x_1	***T*=313.15 K**				
0.0000	0.8669		0.394	1212	785.3
0.0596	0.8670	-0.120	0.409	1196	806.2
0.1176	0.8668	-0.187	0.427	1184	822.8
0.1900	0.8664	-0.264	0.445	1172	840.0
0.2667	0.8657	-0.308	0.467	1164	852.2
0.3539	0.8649	-0.323	0.491	1156	864.9
0.4521	0.8638	-0.326	0.511	1148	878.0
0.5628	0.8627	-0.301	0.532	1148	879.2
0.6893	0.8615	-0.272	0.557	1144	886.6
0.8314	0.8602	-0.186	0.582	1144	888.2
1.0000	0.8583		0.607	1156	871.9
	Butyl propionate(1) + 1,4-Dioxane (2)				
x_1	***T*=303.15 K**				
0.0000	1.0228		1.090	1320	561.2
0.0612	1.0074	-0.035	1.031	1296	591.0
0.1261	0.9923	-0.057	0.978	1280	615.1
0.1987	0.9769	-0.082	0.927	1260	644.8
0.2785	0.9614	-0.093	0.882	1248	667.8
0.3653	0.9461	-0.096	0.840	1228	700.9
0.4599	0.9310	-0.088	0.810	1220	721.7
0.5687	0.9155	-0.081	0.777	1212	743.6
0.6873	0.9004	-0.059	0.747	1200	771.3
0.8318	0.8842	-0.029	0.721	1192	796.0
1.0000	0.8679		0.700	1188	816.4

Table 1. (contg.)

x_1					
			***T*=308.15 K**		
0.0000	1.0173		0.999	1312	571.3
0.0612	1.0019	-0.040	0.949	1292	597.9
0.1261	0.9869	-0.076	0.907	1276	622.3
0.1987	0.9715	-0.107	0.865	1256	652.5
0.2785	0.9560	-0.124	0.829	1240	680.3
0.3653	0.9407	-0.133	0.793	1224	709.6
0.4599	0.9256	-0.130	0.764	1212	735.5
0.5687	0.910	-0.116	0.737	1200	763.1
0.6873	0.8949	-0.100	0.705	1188	791.8
0.8318	0.8786	-0.059	0.678	1180	817.4
1.0000	0.8621		0.653	1172	844.5
x_1			***T*=313.15 K**		
0.0000	1.0116		0.946	1304	581.6
0.0612	0.9966	-0.058	0.901	1280	612.4
0.1261	0.9818	-0.096	0.860	1264	637.5
0.1987	0.9666	-0.127	0.822	1234	679.4
0.2785	0.9513	-0.146	0.786	1214	713.3
0.3653	0.9362	-0.158	0.752	1200	741.8
0.4599	0.9212	-0.146	0.726	1184	774.4
0.5687	0.9058	-0.135	0.695	1172	803.7
0.6873	0.8909	-0.125	0.664	1156	840.0
0.8318	0.8748	-0.089	0.639	1152	861.4
1.0000	0.8583		0.607	1156	871.9
Butyl propionate(1) + Anisole (2)					
x_1			***T*=303.15 K**		
0.0000	0.9853		0.9227	1388	524.6
0.0760	09739	-0.054	0.8933	1356	558.4
0.1561	0.9623	-0.083	0.8683	1330	587.5
0.2390	0.9511	-0.133	0.8419	1304	618.3
0.3282	0.9394	-0.144	0.8175	1280	649.7
0.4230	0.9277	-0.1579	0.7935	1256	683.3
0.5248	0.9158	-0.159	0.7736	1240	710.2
0.6329	0.9038	-0.138	0.7538	1228	733.7
0.7474	0.8919	-0.113	0.7363	1212	763.3
0.8646	0.8804	-0.071	0.7192	1200	788.8
1.0000	0.8879		0.7002	1188	816.4
x_1			***T*=308.15 K**		
0.0000	0.9792		0.8494	1368	542.7
0.0760	0.9680	-0.075	0.8200	1344	571.9
0.1561	0.9565	-0.115	0.7958	1324	596.4
0.2390	0.9452	-0.150	0.7720	1304	622.2
0.3282	0.9336	-0.172	0.7484	1276	657.9
0.4230	0.9220	-0.197	0.7271	1256	687.5
0.5248	0.9102	-0.210	0.7099	1238	716.8
0.6329	0.8983	-0.200	0.6948	1220	747.9
0.7474	0.8864	-0.173	0.6798	1204	778.2
0.8646	0.8741	-0.128	0.6672	1188	809.9
1.0000	0.8621		0.6528	1172	844.5

Table 1. (contg.)

x_1			*T*=313.15 K		
0.0000	0.9728		0.764	1348	561.6
0.0760	0.9621	-0.101	0.736	1324	592.9
0.1561	0.9510	-0.157	0.713	1296	626.1
0.2390	0.9402	-0.224	0.693	1276	653.2
0.3282	0.9289	-0.254	0.673	1252	686.8
0.4230	0.9175	-0.274	0.654	1228	722.8
0.5248	0.9059	-0.281	0.642	1212	751.5
0.6329	0.8942	-0.267	0.630	1196	781.8
0.7474	0.8824	-0.219	0.622	1184	808.4
0.8646	0.8710	-0.153	0.614	1168	841.6
1.0000	0.8583		0.607	1156	871.9
Butyl propionate(1) + Butyl Vinyl Ether (2)					
x_1			*T*=303.15 K		
0.0000	0.7741		0.387	1084	1099.4
0.0874	0.7839	-0.071	0.405	1104	1046.6
0.1792	0.7939	-0.143	0.425	1120	1004.1
0.2718	0.8035	-0.180	0.447	1132	971.2
0.3683	0.8132	-0.214	0.472	1144	939.6
0.4661	0.8226	-0.223	0.499	1160	905.6
0.5644	0.8317	-0.219	0.530	1168	881.3
0.6710	0.8412	-0.201	0.567	1176	859.6
0.7778	0.8502	-0.145	0.606	1184	839.0
0.8865	0.8591	-0.091	0.651	1188	824.8
1.0000	0.8679		0.700	1188	816.4
x_1			*T*=308.15 K		
0.0000	0.7682		0.374	1072	1132.8
0.0874	0.7773	0.047	0.391	1088	1086.8
0.1792	0.7865	0.111	0.409	1100	1050.8
0.2718	0.7957	0.144	0.429	1112	1016.3
0.3683	0.8051	0.163	0.452	1128	976.2
0.4661	0.8144	0.173	0.476	1140	944.8
0.5644	0.8236	0.164	0.505	1148	921.3
0.6710	0.8333	0.151	0.536	1156	898.0
0.7778	0.8429	0.108	0.570	1164	875.6
0.8865	0.8524	0.062	0.609	1168	859.9
1.0000	0.8621		0.653	1172	844.5
x_1			*T*=313.15 K		
0.0000	0.7633		0.354	1064	1157.2
0.0874	0.7721	0.098	0.369	1076	1118.5
0.1792	0.7875	0.180	0.387	1088	1081.1
0.2718	0.7905	0.248	0.405	1100	1045.5
0.3683	0.7999	0.286	0.425	1112	1011.0
0.4661	0.8093	0.298	0.447	1124	978.0
0.5644	0.8187	0.273	0.474	1132	953.2
0.6710	0.8286	0.246	0.502	1140	928.6
0.7778	0.8385	0.171	0.534	1148	904.9
0.8865	0.8483	0.093	0.569	1152	888.3
1.0000	0.8583		0.607	1156	871.9

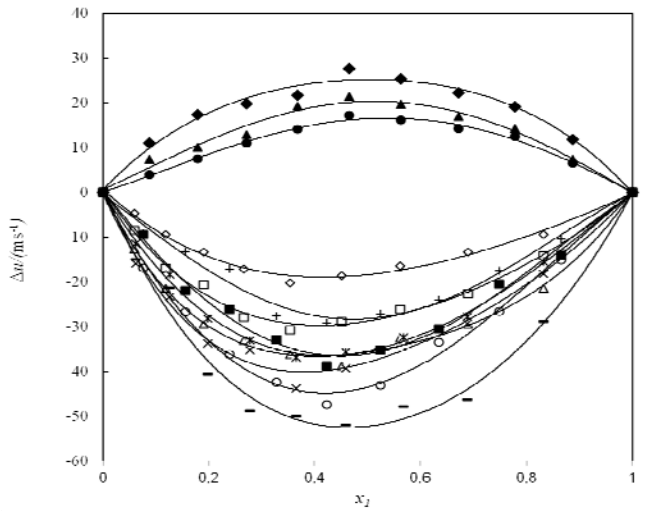

Figure 3. Curves of deviation is speed of sound (Δu) Vs mole fraction for the binary mixtures. Butyl propionate + Tetrahydrofuran at □, 303.15 K; ◊, 308.15 K; Δ, 313.15 K; Butyl propionate + 1,4-Dioxane at ×, 303.15 K; ж, 308.15 K; ▬, 313.15 K; Butyl propionate + Anisole at O, 303.15 K; +, 308.15 K; ■, 313.15 K; Butyl propionate + Butyl vinyl ether ♦, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

The excess molar volume V^E against mole fraction x_1 were graphically represented in Figure 1.The V^E values for butyl propionate with tetrahydrofuran, 1,4-dioxane, anisole are negative over the whole composition range at all studied temperatures. These negative values were found to increase with increase in temperature which suggest the increase in interactions between unlike molecules at high temperature. For the system butyl propionate + butyl vinyl ether the V^E values are negative at 303.15 K, but as the temperature is increased the V^E values change from negative to positive over the entire range of mole fraction. The negative values indicate the contraction in volume upon mixing butyl propionate with ethers due to association in dissimilar molecules[19] while the positive V^E values indicate the weak interactions and may be due to dispersive forces involving between dissimilar molecules.

The plots of $\Delta\eta$ vs. mole fraction x_1 of butyl propionate at 303.15, 308.15 and 313.15 K are presented in Figure 2. The $\Delta\eta$ values for butyl propionate + tetrahydrofuran exhibits positive deviation at all studied temperatures. These positive $\Delta\eta$ values decrease with increase in temperature. For butyl propionate + 1,4-dioxane, butyl propionate + anisole and butyl propionate + butyl vinyl ether the $\Delta\eta$ values are negative over the entire range of composition at the studied temperature. The effect of temperature on $\Delta\eta$ values is significant as these values found to either decrease or increase systematically with rise in temperature. As suggested by Fort and Moore[20] the negative $\Delta\eta$ values in our present study indicate the presence of dispersion forces, while the positive values may be due to the presence of specific interactions between the unlike molecules in the mixtures.

Figure 3 shows that deviations in speeds of sound Δu, values are negative for butyl propionate + tetrahydrofuran, butyl propionate + 1,4-dioxane, butyl propionate + anisole, while for butyl propionate + butyl vinyl ether the Δu values are positive over the entire range of composition at the studied temperature.

Figure 4 shows deviations in isentropic compressibility ΔK_S. From the curves it was observed that for the systems butyl propionate with tetrahydrofuran, 1,4-dioxane and anisole the ΔK_S values are positive, while for butyl propionate + butyl vinyl ether the ΔK_S values are negative over the entire range of composition at the studied temperature. The negative values in case of butyl vinyl ether may be attributed to the weak dipolar interactions between unlike molecules which lead to decrease in the free length, and increase in the speed of sound with increase in composition of n-butyl propionate. The positive ΔK_S values may be due to the fact that the free length is not affected much.

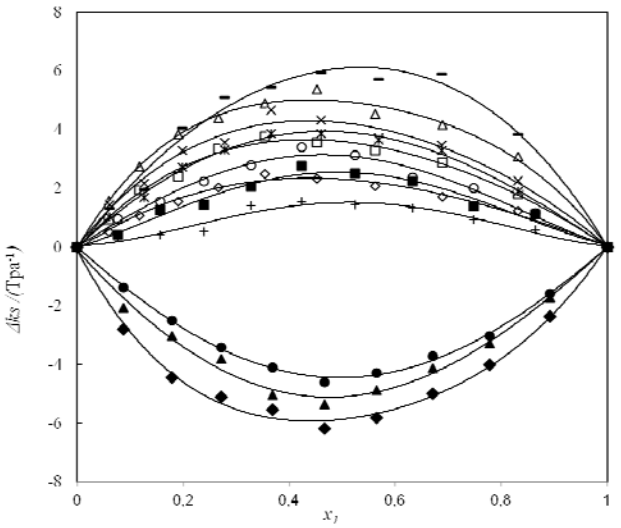

Figure 4. Curves of deviation in isentropic compressibility (ΔK_S) Vs mole fraction for the binary mixtures. Butyl propionate + Tetrahydrofuran at □, 303.15 K; ◊, 308.15 K; Δ, 313.15 K; Butyl propionate + 1,4-Dioxane at ×, 303.15 K; ж, 308.15 K; ▬, 313.15 K; Butyl propionate + Anisole at O, 303.15 K; +, 308.15 K; ■, 313.15 K; Butyl propionate + Butyl vinyl ether ♦, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

In this study an attempt has also been made to find the predictive ability of the empirical relations proposed by Jouyban–Acree[15-16] and Vandeal–Vangeel[17] to correlate the speed of sound data of the studied binary mixtures in terms of pure components. The empirical relations used are as follows:

Jouyban–Acree[15-16]

$$\ln u = x_1 \ln u_1 + x_2 \ln u_2 + A_0\left[\frac{x_1 x_2}{T}\right] + A_1\left[\frac{x_1 x_2 (x_1 - x_2)}{T}\right] + A_2\left[\frac{x_1 x_2 (x_1 - x_2)^2}{T}\right] \quad (6)$$

where

A_0, A_1, and A_2 are the model constants

u, u_1 and u_2 are the speed of sound of mixture and pure components 1 and 2 respectively.

T is the absolute temperature at which the data has been obtained.

Table 2. Derived parameters of excess functions and standard deviation of binary liquid mixtures

Function	*T*/K	A_0	A_1	A_2	σ
	Butyl propionate(1) + Tetrahydrofuran (2)				
V^E	303.15	-0.9724	0.2282	-0.4587	0.005
	308.15	-1.1318	0.2745	-0.6654	0.005
	313.15	-1.2727	0.3136	-0.6254	0.005
$\Delta\eta$	303.15	0.1385	-0.0366	0.0128	0.002
	308.15	0.1100	-0.0300	0.0118	0.001
	313.15	0.0889	-0.0206	-0.0054	0.001
Δu	303.15	-115.39	37.97	-19.48	1.3
	308.15	-73.88	23.64	-3.77	1.0
	313.15	-142.75	35.23	-65.09	1.3
ΔKs	303.15	14.409	-3.602	1.312	0.17
	308.15	9.258	-2.223	-0.226	0.14
	313.15	19.845	-3.099	7.565	0.20
	Butyl propionate(1) + 1,4-Dioxane (2)				
V^E	303.15	-0.3496	0.2294	-0.0410	0.003
	308.15	-0.5094	0.1901	-0.9365	0.003
	313.15	-0.5849	0.1625	-0.3490	0.004
$\Delta\eta$	303.15	-0.3971	0.1712	-0.0849	0.002
	308.15	-0.2922	0.1422	-0.0858	0.002
	313.15	-0.2578	0.1355	-0.0551	0.002
Δu	303.15	-151.69	66.07	-45.26	2.40
	308.15	-141.97	47.43	-5.39	1.01
	313.15	-209.34	24.27	-32.35	3.34
ΔKs	303.15	16.917	-3.857	2.780	0.27
	308.15	15.685	-2.169	-1.136	0.11
	313.15	24.397	3.278	2.443	0.39
	Butyl propionate(1) + Anisole (2)				
V^E	303.15	-0.6322	0.0830	-0.0273	0.006
	308.15	-0.8079	-0.1180	-0.3271	0.006
	313.15	-1.1195	0.0052	-0.3022	0.006
$\Delta\eta$	303.15	-0.1325	0.0463	0.0102	0.001
	308.15	-0.1473	0.0513	0.0121	0.001
	313.15	-0.1624	0.0526	-0.0004	0.001
Δu	303.15	-173.83	64.54	13.53	1.84
	308.15	-112.69	16.72	35.95	2.01
	313.15	-144.35	34.95	32.73	1.97
ΔKs	303.15	12.460	-2.451	-3.504	0.20
	308.15	6.036	0.585	-4.467	0.20
	313.15	10.184	-0.394	-4.965	0.23
	Butyl propionate(1) + Butyl Vinyl Ether (2)				
V^E	303.15	-0.9004	0.0742	-0.0093	0.005
	308.15	0.6932	-0.0686	0.0582	0.006
	313.15	1.1762	-0.2137	-0.1678	0.005
$\Delta\eta$	303.15	-0.1341	-0.0167	0.0092	0.001
	308.15	-0.1107	-0.0123	-0.0012	0.001
	313.15	-0.1029	-0.0118	-0.0003	0.001
Δu	303.15	100.44	0.56	30.81	1.62
	308.15	80.84	4.43	-15.21	1.45
	313.15	65.63	11.95	-14.63	0.65
ΔKs	303.15	-23.512	4.393	-7.344	0.23
	308.15	-20.422	2.495	1.725	0.26
	313.15	-17.834	0.440	2.316	0.11

Table 3. Adjustable parameters and standard percentage deviations of models of speed of sound for binary liquid mixtures

T/K	Jouyban-Acree				Vandeal-Vangeel
	A_0	A_1	A_2	σ (%)	σ (%)
Butyl propionate(1) + Tetrahydrofuran (2)					
303.15	10.409	-16.836	31.300	0.698	0.091
308.15	10.463	-8.731	31.299	0.564	0.159
313.15	10.768	-8.302	31.299	0.516	0.040
Butyl propionate(1) + 1,4-Dioxane (2)					
303.15	-10.231	8.199	-30.700	0.821	0.156
308.15	-9.894	8.846	-30.699	0.601	0.130
313.15	-10.958	9.682	-30.700	0.591	0.245
Butyl propionate(1) + Anisole (2)					
303.15	-10.900	5.706	-27.656	0.190	0.219
308.15	-10.900	6.047	-29.106	0.280	0.119
313.15	-10.900	5.796	-30.664	0.575	0.174
Butyl propionate(1) + Butyl Vinyl Ether (2)					
303.15	-10.900	2.036	-18.439	0.086	0.307
308.15	-2.5064	-20.80	23.333	0.190	0.263
313.15	-10.900	3.135	-17.761	0.056	0.233

Vandeal–Vangeel[17]

$$u = \left[\left(\frac{x_1}{M_1 u_1^2} + \frac{x_2}{M_2 u_2^2} \right) \left(x_1 M_1 + x_2 M_2 \right) \right]^{-0.5} \qquad (7)$$

where M_1 and M_2 are molecular weights of the pure components 1 and 2 respectively.

The speed of sound data correlated with the Eqs (6 and 7) were compared with the experimental data in terms of percentage standard deviation σ(%)as obtained by relation

$$\sigma(\%) = \left[\frac{1}{n-k} \frac{\Sigma \left\{ 100(u_{\exp} - u_{cal}) \right\}^2}{u_{\exp}} \right]^{0.5} \qquad (8)$$

where *n* represents the number of data points in each set and k the number of numerical coefficients of equation (6 and 7). u_{cal} has been obtained from model equation (6 and 7)The values of parameters of Equation 7 and the percentage standard deviations σ(%) of equation (8) are given in the Table 3. A perusal of Table 3 shows that the σ(%) values obtained by Vandeal–Vangeel relation are very low for systems butyl propionate with tetrahydrofuran, 1,4-dioxane and anisole as compared to Jouyban–Acree model. However for butyl propionate + butyl vinyl ether the σ(%) values obtained by Jouyban–Acree model are very low as compared to Vandeal–Vangeel relation. Finally it may be concluded that the Vandeal-Vangeel model despite of having no interaction parameters has predicted the speeds of sound of the studied binary mixtures more satisfactorily as compared to Jouyban–Acree model.

Conclusions

Density, viscosity and speed of sound for the binary mixtures of butyl propionate with tetrahydrofuran, 1,4-dioxane, anisole and butyl vinyl ether have been determined at (303.15, 308.15 and 313.15) K over the entire range of composition. From the experimental data excess volume V^E, deviation in viscosities $\Delta\eta$, deviation in speeds of sound Δu and deviation in isentropic compressibilities ΔK_S, were evaluated. These excess or deviation functions found to exhibit both positive and negative deviations. Further the speeds of sound data were correlated using Jouyban–Acree and Vandeal-Vangeel models to determine their predictive abilities. It was concluded that Vandeal-Vangeel relation despite having no interaction parameters has predicted the speed of sound for the studied binary mixtures more satisfactorily as compared to Jouyban–Acree model.

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