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NON-LINEARITY PARAMETER B/A AND AVAILABLE VOLUME VA OF BINARY LIQUID MIXTURES: THERMO-ACOUSTICAL APPROACH

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ABSTRACT

When high amplitude sound waves propagate through liquid mixtures, various non-linear phenomena can occur, and ultrasonic research in these systems can reveal important details about their structure and interaction. Thermoacoustical parameters have been calculated for a binary system containing 1,4-butanediol(1,4-BD) + o-cresol(OC) or m-cresol (MC) or p-cresol(PC) at varying concentrations and temperatures ranging from 303.15 to 318.15 K. These parameters have been used to calculate available volume by using two different approaches. The results of both methods are used to examine the existence and intensity of interactions between the molecules in the systems under study. Additionally, several methods have also been used to derive the non-linearity parameter, or B/A. The excess values of B/A have also been calculated. In order to determine whether molecular interactions exist, a comparison analysis was conducted.

1. INTRODUCTION

When researching various thermodynamic properties and intermolecular interactions, the quantity known as accessible volume, or Va, is highly helpful. It is simply estimable using the characteristics of thermos-acoustics. The B/A parameter can reveal information about the medium's structural characteristics and calculates the nonlinear adjustment to velocity resulting from nonlinear effects brought on by the propagation of a finite amplitude wave (Hartman, 1979; Beyer, 1960; Sehgal, 1995; Thakur, 1978; Bjorno, 2002; Duck, 2002). A review of the literature indicates that there have been fewer attempts to use thermos-acoustical characteristics in pure liquids and liquid mixtures to determine Va, the non-linearity parameter, and B/A. There are two principal methods for determining the nonlinearity parameter B/A: The measurement of the amplitude of the second harmonic produced by the propagating sinusoidal wave's distortion is the basis of the finite amplitude approach. (Krishna et al., 2021; Aditi Prabhune et al., 2022; Nain, 2022). Density, sound velocity, absolute temperature, specific heat capacity at constant pressure, and volume coefficient of thermal expansion are the foundations of the thermodynamic approach. Many scholars have estimated the non-linearity parameter of binary and multicomponent liquid mixtures (Bhatia et al., 2011; Pandey et al., 2000; Anjali & Aashees, 2017). This encourages us to continue our study in order to use thermos-acoustical characteristics to compute Va and B/A in pure liquids and liquid mixtures at different

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temperatures and link the results with those derived from thermodynamic relations. The computation's required data were extracted from our earlier work (Srinivasu et al., 2017).

2. PROCEDURE

Materials: The Cresols and 1,4-butanediol were of the Chemlab (purity 0.99) variety. Standard techniques were employed to further purify these (Vogel, 1989; Riddick et al., 1986).To lower the water content, all of the compounds were carefully dried over 0.4 nm molecular sieves for 72 hours while being securely sealed off from ambient pressure. A vacuum pump was used to partially degas each liquid before any experimental observations were made. With an accuracy of ± 0.1 mg, the weights were measured using an electronic balance.

2.1 Apparatus and methods

A Borosil glass single-capillary pycnometer was used to measure liquid densities. The capillary included graded markings, a consistent diameter, and a glass cap that fit snugly to seal it shut. Triple-distilled water was used to calibrate the capillary markings. The densities of pure water were obtained from the literature at the necessary temperature (Stokes & Mills, 1965). The density measurements were repeatable to within an error of ± 2 x 10-5 g.cm-3. The temperature of a thermostatically controlled, well-stirred water bath was maintained at ± 0.02K during the experimental procedures. Using a single-crystal ultrasonic interferometer (Mittal Enterprises, India) running at a frequency of 2 MHz, the sound speeds at various temperatures were measured. Using a high frequency generator, the quartz crystal, which was fixed at the bottom of the measuring cell, was excited at its resonance frequency to create sound waves in the test liquid inside the cell that had a frequency of 2 MHz. There was a micrometer located at the cell's top. The wavelength of the sound waves was measured by measuring the distance that a metallic reflector plate covered between consecutive resonance peaks. The metallic reflector plate may be elevated or lowered through a known distance in the test liquid. Water from a thermostatically controlled water bath was circulated through the water jacketed cell to keep the solution's temperature constant. The accuracy of the speed readings was within ± 0.2 m s−1.

2.2 Theory

The following relations can be used to get the reduced volume ($\hat{V}$), Molelwyn-Hughes parameter (C1), and Sharma parameter (S*) from the thermal expansivity (α) and absolute temperature (T):

$$\hat{V} = \left[1 + \frac{\alpha T}{3(1+\alpha T)}\right]^3 \tag{1}$$

$$C_1 = \frac{13}{3} + \frac{1}{\alpha T} + \frac{4}{3}\alpha T \tag{2}$$

$$S^* = 1 + \frac{4\alpha T}{3} \tag{3}$$

The coefficient of internal pressure (X) at isochoric temperature has been calculated using the following relation:

$$X = \frac{-2(1+2\alpha T)}{\hat{V}^{C_1}} \tag{4}$$

The isobaric acoustical parameter (K), isothermal acoustical parameter (K′), and isochoric acoustical parameter (K") can be computed using the values of , S*, and X.

$$K = \frac{1}{2}\left[1 + \frac{S*(1+\alpha T)}{\alpha T}\right] \tag{5}$$

$$K' = \frac{1}{2}\left[3 + \frac{S*(1+\alpha T)+X}{\alpha T}\right] \tag{6}$$

$$K'' = 1 + \frac{X}{2\alpha T} \tag{7}$$

The thermo-acoustical parameter K′ can be used to calculate the accessible volume as follows:

$$V_a = \frac{V_m}{K'+1} \tag{8}$$

The relation can be used to compute accessible volume using the thermodynamic relation and the critical temperature:

$$V_a = V - \left[V(1 - \frac{T}{T_C})^{0.3}\right] \tag{9}$$

It is necessary to employ the coefficient of thermal expansion, , and isothermal compressibility, T, in order to calculate the non-linearity parameter, B/A.
The following equation is used to calculate β_T,

$$\beta_T = \frac{1.71*10^{-3}}{T^{4/9}u^2\rho^{4/3}} \tag{10}$$

where u, ρ and T are the ultrasonic velocity, density and temperature of the liquid system respectively.

Using the expression for the sound velocity u, the non-linearity parameter is further generalized in terms of the acoustical characteristics of liquids by adding the contributions from the isobaric and isochoric acoustic parameters, K and K″.

The expression for B/A can be expressed as,

B/A = 2K + 2γK″

$$(B/A)_{\text{thermoacoustical(I)}} = 2K + 2\gamma(i)K'' \tag{11}$$

where $\gamma(i) = \beta_{T(i)}/\beta_s$

B/A = 2K + 2γK″

$$(B/A)_{\text{thermoacoustical(II)}} = 2K + 2\gamma(ii)K'' \tag{12}$$

where

γ(ii) = αΓT + 1

where Γ, the pseudo Gruneisen parameter, has been computed using,

$$\Gamma = \frac{2}{3}\alpha T + \frac{3+4\alpha T}{2\alpha T}$$

Hartmann and Balizer obtained the following relation for B/A:

$$\frac{B}{A} = 2 + \frac{0.98*10^4}{u} \quad (13)$$

where u is in m/s.
An empirical relation proposed by Ballou is given by,

$$\frac{B}{A} = -0.5 + \frac{1.2*10^4}{u} \quad (14)$$

The excess values of nonlinearity parameter $(B/A)^E$ are calculated by the relation:

$$(B/A)^E = (B/A)_{mix} - (B/A)_{ideal} \quad (15)$$

$$(B/A)_{ideal} = \sum_{i=1}^{n} X_i \left(\frac{B}{A}\right)_i \quad (16)$$

where, X_i is the mole fraction of pure components.

3. RESULTS AND DISCUSSION

Table 1 displays the computed values of the following: isobaric acoustical parameter, K; isothermal acoustical parameter, K′; reduced volume, $\hat{V}$; Moelwyn-Hughes parameter, C1; Sharma parameter, S*; isochoric temperature coefficient of internal pressure, *X*; isobaric acoustical parameter, K; and isochoric acoustical parameter, K″. Table 2 displays the accessible volume (Va) values that were determined using the two approaches. Table 3 displays the non-linearity parameter, B/A, which was determined using equations (11) through (14). Table 4 lists the values of the following parameters: isochoric thermo-acoustical parameter, *⊿*, isothermal Gruneisen parameter, Γ_{ith}, isochoric Gruneisen parameter, Γ_{ich}, isobaric Gruneisen parameter, Γ_{iba}, isothermal Anderson-Gruneisen parameter, δ, and reduced bulk modulus, B.

A detailed examination of Table 1 shows that in all three systems, the values of $\hat{V}$ are nearly increasing with temperature and decreasing with mole fraction of 1,4-BD.

As a stringent test for equation of state for liquids and solids, Moelwyn-Hughes established the dimensionless thermodynamic parameter C1, which is defined as the pressure coefficient of bulk modulus. In certain materials, this value provides the most straightforward scale for determining molecular ordering, structure, inter-chain, and anharmonicity. The C1 behaves in a completely different way from α.

For each of the three systems, it is found that the values of the Sharma parameter, S*, decrease as the mole fraction increases and increase as the temperature rises. The isochoric temperature coefficient of internal pressure has negative computed values for quantity *X*. *X's* absolute values vary from roughly 0.199 to 0.331. It is shown that the negative values rise with rising temperatures and fall with rising mole fractions. For all three of the systems, the same pattern is seen.

It is found that as the mole fraction of 1,4-BD increases, the isobaric and isothermal acoustical characteristics increase and decrease with temperature. On the other hand, it is noticed that the values of the isochoric acoustical parameter increase with temperature and decrease with mole fraction. Table 2 shows that the accessible volume increases as the temperature rises. It results from a decrease in intermolecular attraction and an increase in molecular mobility. Va results obtained using the two methods appear to be quite consistent. There is the greatest agreement at T=303.15K. These findings demonstrate how the thermoacoustical parameter can be used to calculate accessible volume in both pure liquids and liquid mixtures.

A consistent drop in accessible volume is shown with a rise in the mole percentage of 1,4-butanediol, as shown in Figures 1, 2, and 3. The reason for this is that 1,4-butanediol's accessible volume is smaller than that of o-, m-, or p-cresol. This study sheds insight on two strategies for determining available volume: one involves measuring thermo-acoustical characteristics in binary mixes. It is observed that the current method for calculating available volume is straightforward and accurate, offering a new avenue for the purposeful investigation of available volume in liquid mixtures (Narendra et al., 2022). Data from aqueous solutions of both organic and inorganic substances indicate that B/A depends on the solute's molecular structure and the chemical makeup of the solution (Apfel & Everbach, 1989; Sehgal et al., 1986; Coppens et al., 1965). The amount that represents the degree of liquid hardness has been determined by interpreting the B/A values for the liquids. When the concentration of 1,4-BD increases, the values of B/A computed using Hartmann and Ballou relations exhibit a declining trend, as can be seen by closely examining the data in Table 3.

Table 3, when closely examined, indicates that the following pattern can be seen in the variations of the computed values of B/A from thermo-acoustical methods, Hartmann relation, and Ballou relation: 1,4-BD+o-cresol < 1,4-BD+p-cresol < 1,4-BD+m-cresol. The same table also shows that the B/A values for thermo-acoustical methods increase with an increase in the mole fraction of 1,4-BD. The interaction between the components of the binary mixes is stronger at lower concentrations of 1,4-BD and decreased at higher values.

Figs. 4 to 6 display the excess values of B/A for various models at 303.15K for each of the three systems. It can be shown from Figs. 4 to 6 that, in comparison to the other two models, the thermoacoustical models have larger negative excess B/A values. For 1,4-BD+p-cresol combinations, the excess B/A values are observed to be positive and negative for models H & B and Ballou, but they are observed to be negative for the other two systems. As a measure of the anharmonicity of molecular vibrations, the Gruneisen parameter is a significant quantity of current interest that has proven to be highly helpful in the investigation of the internal structure, molecular order, and other thermo-acoustic features. Table 4 shows that as the mole fraction of 1,4-BD increases, the values of the reduced bulk modulus and Gruneisen parameters increase while the isochoric thermo-acoustic parameter decreases. For each of the three systems, the same pattern is seen. The same table also shows that, for a given mole percentage, values for the Gruneisen and decreased bulk modulus fall with increasing temperature, while values for the isochoric thermo-acoustic parameter increase.

Table 1. The following parameters were measured as a functions of mole fraction 1,4-BD at four different temperatures: Thermal expansivity,α, Molar volume, V_m, Reduced volume, $\hat{V}$, Moelwyn-Hughes parameter, C_1, Sharma Parameter, S*, isochoric temperature coefficient of internal pressure, X, isobaric acoustical parameter, K, isothermal acoustical parameter, K′ and isochoric acoustical parameter, K″

x_1	$\alpha\ (10^3)$	$V_m\,(10^6)$	$\hat{V}\ (10^6)$	C_1	S*	X	K	K′	K″
1,4-butanediol + o-cresol									
T= 303.15K									
0.0000	1.032	104.32	1.258	7.954	1.417	-0.325	3.473	3.954	0.480
0.1001	0.976	102.67	1.246	8.113	1.395	-0.315	3.553	4.021	0.468
0.2001	0.921	101.08	1.234	8.295	1.372	-0.304	3.644	4.099	0.455
0.3002	0.865	99.52	1.222	8.503	1.350	-0.293	3.748	4.189	0.441
0.4002	0.809	97.99	1.210	8.742	1.327	-0.282	3.868	4.294	0.426
0.5002	0.754	96.48	1.198	9.020	1.305	-0.270	4.007	4.417	0.410
0.6002	0.698	94.98	1.185	9.346	1.282	-0.257	4.170	4.563	0.393
0.7002	0.643	93.50	1.172	9.732	1.260	-0.244	4.363	4.738	0.375
0.8001	0.587	92.05	1.159	10.196	1.237	-0.230	4.595	4.950	0.355
0.9001	0.532	90.63	1.145	10.761	1.215	-0.215	4.877	5.211	0.334
1.0000	0.476	89.28	1.131	11.462	1.192	-0.199	5.228	5.539	0.311
T= 308.15K									
0.0000	1.027	104.90	1.260	7.922	1.422	-0.327	3.458	3.941	0.483
0.1001	0.980	103.24	1.250	8.054	1.403	-0.319	3.524	3.996	0.472
0.2001	0.933	101.62	1.240	8.202	1.383	-0.310	3.598	4.059	0.461
0.3002	0.886	100.03	1.230	8.368	1.364	-0.300	3.681	4.130	0.450
0.4002	0.839	98.46	1.220	8.555	1.345	-0.291	3.774	4.211	0.437
0.5002	0.791	96.91	1.209	8.766	1.325	-0.281	3.880	4.304	0.424
0.6002	0.744	95.38	1.198	9.006	1.306	-0.270	4.000	4.410	0.411
0.7002	0.697	93.87	1.187	9.281	1.286	-0.259	4.137	4.533	0.396
0.8001	0.650	92.39	1.176	9.599	1.267	-0.248	4.296	4.677	0.381
0.9001	0.603	90.93	1.165	9.969	1.248	-0.236	4.481	4.846	0.364
1.0000	0.556	89.51	1.154	10.405	1.228	-0.224	4.699	5.046	0.347
T= 313.15K									
0.0000	1.021	105.37	1.262	7.894	1.426	-0.329	3.444	3.929	0.485
0.1001	0.983	103.72	1.254	8.000	1.410	-0.322	3.497	3.973	0.477
0.2001	0.944	102.09	1.246	8.116	1.394	-0.315	3.555	4.022	0.468
0.3002	0.906	100.48	1.238	8.243	1.378	-0.307	3.618	4.077	0.458
0.4002	0.868	98.88	1.229	8.382	1.362	-0.300	3.688	4.137	0.449
0.5002	0.829	97.31	1.221	8.536	1.346	-0.292	3.765	4.203	0.439
0.6002	0.791	95.76	1.212	8.707	1.330	-0.283	3.850	4.278	0.428
0.7002	0.753	94.23	1.203	8.896	1.314	-0.275	3.945	4.362	0.417
0.8001	0.715	92.72	1.194	9.107	1.298	-0.266	4.050	4.456	0.405
0.9001	0.676	91.24	1.185	9.344	1.282	-0.257	4.169	4.562	0.393
1.0000	0.638	89.78	1.176	9.612	1.266	-0.248	4.302	4.683	0.380
T= 318.15K									
0.0000	1.015	105.88	1.264	7.867	1.431	-0.331	3.430	3.918	0.488
0.1001	0.985	104.22	1.258	7.948	1.418	-0.325	3.470	3.951	0.481
0.2001	0.956	102.58	1.252	8.033	1.406	-0.320	3.513	3.988	0.474
0.3002	0.926	100.95	1.245	8.126	1.393	-0.314	3.560	4.027	0.467
0.4002	0.897	99.33	1.239	8.225	1.380	-0.308	3.609	4.069	0.460
0.5002	0.867	97.74	1.232	8.331	1.368	-0.302	3.662	4.115	0.452
0.6002	0.838	96.17	1.226	8.447	1.355	-0.296	3.720	4.164	0.444
0.7002	0.808	94.62	1.219	8.571	1.343	-0.290	3.782	4.218	0.436
0.8001	0.779	93.10	1.212	8.706	1.330	-0.283	3.849	4.277	0.428
0.9001	0.749	91.58	1.205	8.852	1.318	-0.277	3.923	4.342	0.419
1.0000	0.720	90.08	1.198	9.011	1.305	-0.270	4.002	4.413	0.410

1,4-butanediol + m-cresol									
T= 303.15K									
0.0000	0.796	105.43	1.198	9.009	1.306	-0.270	4.001	4.412	0.411
0.0992	0.764	103.70	1.190	9.202	1.292	-0.262	4.098	4.498	0.400
0.1986	0.732	102.02	1.183	9.405	1.279	-0.255	4.199	4.589	0.390
0.2982	0.700	100.35	1.176	9.619	1.266	-0.247	4.306	4.686	0.380
0.3979	0.668	98.71	1.169	9.843	1.254	-0.240	4.418	4.788	0.370
0.4979	0.636	97.09	1.162	10.079	1.243	-0.233	4.536	4.896	0.360
0.5979	0.604	95.48	1.155	10.327	1.232	-0.226	4.660	5.010	0.350
0.6982	0.572	93.89	1.149	10.589	1.221	-0.219	4.791	5.131	0.340
0.7986	0.540	92.32	1.143	10.864	1.211	-0.212	4.929	5.259	0.331
0.8992	0.508	90.78	1.137	11.155	1.202	-0.205	5.074	5.395	0.321
1.0000	0.476	89.28	1.131	11.462	1.192	-0.199	5.228	5.539	0.311
T= 308.15K									
0.0000	0.798	105.82	1.212	8.716	1.330	-0.283	3.855	4.282	0.427
0.0992	0.774	104.11	1.205	8.861	1.317	-0.276	3.927	4.346	0.419
0.1986	0.750	102.42	1.198	9.012	1.305	-0.270	4.002	4.413	0.410
0.2982	0.726	100.75	1.192	9.167	1.294	-0.264	4.080	4.482	0.402
0.3979	0.702	99.09	1.186	9.327	1.283	-0.258	4.160	4.554	0.394
0.4979	0.678	97.45	1.180	9.493	1.273	-0.252	4.243	4.629	0.386
0.5979	0.653	95.83	1.174	9.664	1.264	-0.246	4.328	4.706	0.378
0.6982	0.629	94.22	1.169	9.840	1.254	-0.240	4.417	4.787	0.370
0.7986	0.605	92.63	1.164	10.022	1.245	-0.235	4.508	4.870	0.362
0.8992	0.580	91.06	1.158	10.211	1.237	-0.229	4.602	4.957	0.355
1.0000	0.556	89.51	1.154	10.405	1.228	-0.224	4.699	5.046	0.347
T= 313.15K									
0.0000	0.802	106.29	1.225	8.456	1.354	-0.296	3.725	4.168	0.444
0.0992	0.786	104.58	1.219	8.563	1.344	-0.290	3.778	4.215	0.437
0.1986	0.769	102.88	1.214	8.672	1.333	-0.285	3.833	4.263	0.430
0.2982	0.753	101.21	1.208	8.783	1.324	-0.280	3.888	4.312	0.423
0.3979	0.737	99.54	1.203	8.896	1.314	-0.275	3.945	4.361	0.417
0.4979	0.720	97.88	1.198	9.011	1.305	-0.270	4.002	4.412	0.410
0.5979	0.704	96.24	1.193	9.127	1.297	-0.265	4.060	4.464	0.404
0.6982	0.688	94.60	1.189	9.245	1.289	-0.261	4.119	4.517	0.398
0.7986	0.671	92.98	1.184	9.366	1.281	-0.256	4.179	4.571	0.392
0.8992	0.655	91.37	1.180	9.488	1.274	-0.252	4.241	4.627	0.386
1.0000	0.638	89.78	1.176	9.612	1.266	-0.248	4.302	4.683	0.380
T= 318.15K									
0.0000	0.805	106.69	1.238	8.232	1.380	-0.308	3.612	4.072	0.459
0.0992	0.797	104.98	1.234	8.309	1.371	-0.304	3.651	4.105	0.454
0.1986	0.788	103.30	1.229	8.386	1.362	-0.299	3.690	4.138	0.449
0.2982	0.780	101.62	1.225	8.463	1.354	-0.295	3.728	4.172	0.443
0.3979	0.771	99.95	1.220	8.541	1.346	-0.291	3.767	4.206	0.438
0.4979	0.763	98.29	1.216	8.619	1.338	-0.288	3.806	4.240	0.433
0.5979	0.754	96.63	1.212	8.697	1.331	-0.284	3.845	4.274	0.429
0.6982	0.746	94.98	1.209	8.776	1.324	-0.280	3.884	4.308	0.424
0.7986	0.737	93.34	1.205	8.854	1.318	-0.277	3.924	4.343	0.419
0.8992	0.729	91.70	1.202	8.932	1.311	-0.273	3.963	4.378	0.415
1.0000	0.720	90.08	1.198	9.011	1.305	-0.270	4.002	4.413	0.410
1,4-butanediol + p-cresol									
T= 303.15K									
0.0000	1.032	105.33	1.258	7.954	1.417	-0.325	3.473	3.954	0.481
0.0961	0.979	103.68	1.247	8.107	1.396	-0.315	3.550	4.018	0.469
0.1931	0.925	102.04	1.235	8.281	1.374	-0.305	3.637	4.093	0.456
0.2909	0.870	100.42	1.224	8.482	1.352	-0.294	3.738	4.180	0.442
0.3895	0.815	98.80	1.212	8.715	1.330	-0.283	3.854	4.282	0.427
0.4890	0.760	97.19	1.199	8.987	1.307	-0.271	3.990	4.402	0.412
0.5894	0.704	95.59	1.186	9.308	1.285	-0.258	4.151	4.546	0.395
0.6907	0.648	93.99	1.173	9.693	1.262	-0.245	4.343	4.720	0.377
0.7929	0.591	92.40	1.160	10.159	1.239	-0.231	4.576	4.933	0.357
0.8960	0.534	90.83	1.146	10.735	1.216	-0.215	4.864	5.199	0.335
1.0000	0.476	89.28	1.131	11.462	1.192	-0.199	5.228	5.539	0.311

T= 308.15K									
0.0000	1.027	105.77	1.260	7.922	1.422	-0.327	3.458	3.941	0.483
0.0961	0.982	104.12	1.251	8.049	1.403	-0.319	3.521	3.994	0.473
0.1931	0.936	102.48	1.241	8.191	1.385	-0.310	3.592	4.055	0.462
0.2909	0.890	100.84	1.231	8.352	1.366	-0.301	3.673	4.123	0.451
0.3895	0.844	99.21	1.221	8.534	1.347	-0.292	3.764	4.202	0.439
0.4890	0.797	97.58	1.210	8.741	1.327	-0.282	3.867	4.293	0.426
0.5894	0.749	95.95	1.200	8.978	1.308	-0.271	3.986	4.398	0.412
0.6907	0.702	94.33	1.189	9.253	1.288	-0.260	4.123	4.521	0.398
0.7929	0.654	92.72	1.177	9.574	1.269	-0.249	4.284	4.666	0.382
0.8960	0.605	91.11	1.166	9.953	1.249	-0.237	4.473	4.838	0.365
1.0000	0.556	89.51	1.154	10.405	1.228	-0.224	4.699	5.046	0.347
T= 313.15K									
0.0000	1.021	106.13	1.262	7.894	1.426	-0.329	3.444	3.929	0.485
0.0961	0.984	104.49	1.255	7.996	1.411	-0.322	3.494	3.972	0.477
0.1931	0.947	102.86	1.247	8.107	1.395	-0.315	3.550	4.019	0.468
0.2909	0.910	101.22	1.238	8.231	1.380	-0.308	3.612	4.071	0.459
0.3895	0.872	99.59	1.230	8.367	1.364	-0.300	3.680	4.130	0.450
0.4890	0.834	97.95	1.222	8.518	1.348	-0.293	3.756	4.196	0.440
0.5894	0.795	96.32	1.213	8.688	1.332	-0.284	3.840	4.270	0.429
0.6907	0.756	94.68	1.204	8.877	1.316	-0.276	3.935	4.353	0.418
0.7929	0.717	93.05	1.195	9.091	1.300	-0.267	4.042	4.448	0.406
0.8960	0.678	91.41	1.186	9.334	1.283	-0.257	4.164	4.557	0.394
1.0000	0.638	89.78	1.176	9.612	1.266	-0.248	4.302	4.683	0.380
T= 318.15K									
0.0000	1.015	106.62	1.264	7.867	1.431	-0.331	3.430	3.918	0.488
0.0961	0.987	104.99	1.258	7.944	1.419	-0.326	3.469	3.950	0.481
0.1931	0.958	103.35	1.252	8.027	1.406	-0.320	3.510	3.985	0.475
0.2909	0.929	101.71	1.246	8.117	1.394	-0.315	3.555	4.023	0.468
0.3895	0.900	100.06	1.240	8.214	1.382	-0.309	3.604	4.064	0.461
0.4890	0.871	98.41	1.233	8.319	1.369	-0.303	3.656	4.109	0.453
0.5894	0.841	96.75	1.226	8.434	1.357	-0.297	3.714	4.159	0.445
0.6907	0.811	95.09	1.219	8.559	1.344	-0.291	3.776	4.213	0.437
0.7929	0.781	93.43	1.213	8.695	1.331	-0.284	3.844	4.273	0.429
0.8960	0.751	91.76	1.205	8.846	1.318	-0.277	3.919	4.339	0.420
1.0000	0.720	90.08	1.198	9.011	1.305	-0.270	4.002	4.413	0.410

Table 2. Available volume, **Va**, in binary liquid mixtures as a function of mole fraction 1,4-BD at four different temperatures

x_1	Va (10^{-6}) m^3 mol^{-1}		Va (10^{-6}) m^3 mol^{-1}		Va (10^{-6}) m^3 mol^{-1}		Va (10^{-6}) m^3 mol^{-1}	
	Eqn. (8)	Eqn. (9)	Eqn. (8)	Eqn. (9)	Eqn. (8)	Eqn. (9)	Eqn. (8)	Eqn. (9)
1,4-butanediol + o-cresol								
	T = 303.15 K		T = 308.15 K		T = 313.15 K		T = 318.15 K	
0.0000	21.057	16.401	21.231	16.829	21.377	17.248	21.529	17.678
0.1001	20.447	16.080	20.663	16.496	20.854	16.903	21.048	17.322
0.2001	19.823	15.763	20.086	16.166	20.327	16.562	20.566	16.970
0.3002	19.180	15.449	19.497	15.839	19.792	16.225	20.083	16.622
0.4002	18.511	15.139	18.893	15.517	19.250	15.892	19.597	16.278
0.5002	17.811	14.832	18.272	15.197	18.701	15.562	19.110	15.937
0.6002	17.075	14.528	17.630	14.881	18.143	15.235	18.622	15.600
0.7002	16.297	14.227	16.965	14.568	17.575	14.912	18.132	15.266
0.8001	15.471	13.929	16.274	14.258	16.996	14.592	17.640	14.936
0.9001	14.591	13.634	15.555	13.951	16.405	14.276	17.144	14.610
1.0000	13.653	13.342	14.805	13.648	15.799	13.962	16.643	14.286
1,4-butanediol + m-cresol								
	T = 303.15 K		T = 308.15 K		T = 313.15 K		T = 318.15 K	
0.0000	18.164	17.047	18.702	17.492	19.209	17.945	19.649	18.384
0.0992	17.649	16.530	18.233	16.955	18.777	17.388	19.252	17.810
0.1986	17.153	16.056	17.787	16.463	18.372	16.878	18.885	17.286
0.2982	16.675	15.621	17.361	16.011	17.991	16.410	18.542	16.804
0.3979	16.211	15.220	16.955	15.595	17.631	15.978	18.221	16.360
0.4979	15.760	14.848	16.564	15.209	17.289	15.579	17.919	15.949
0.5979	15.322	14.504	16.189	14.852	16.964	15.209	17.636	15.568
0.6982	14.893	14.183	15.828	14.520	16.654	14.865	17.368	15.214
0.7986	14.473	13.884	15.477	14.209	16.358	14.544	17.116	14.884
0.8992	14.060	13.605	15.136	13.919	16.073	14.243	16.874	14.575
1.0000	13.653	13.342	14.805	13.648	15.799	13.962	16.643	14.286

1,4-butanediol + p-cresol								
	T = 303.15 K		T = 308.15 K		T = 313.15 K		T = 318.15 K	
0.0000	21.262	16.357	21.408	16.760	21.531	17.156	21.680	17.580
0.0961	20.660	16.057	20.849	16.450	21.018	16.838	21.209	17.252
0.1931	20.036	15.757	20.275	16.140	20.495	16.520	20.733	16.924
0.2909	19.386	15.456	19.682	15.830	19.960	16.201	20.250	16.595
0.3895	18.707	15.155	19.070	15.519	19.413	15.882	19.759	16.266
0.4890	17.992	14.854	18.436	15.208	18.853	15.563	19.261	15.937
0.5894	17.236	14.552	17.775	14.897	18.278	15.244	18.755	15.607
0.6907	16.433	14.250	17.087	14.585	17.687	14.924	18.241	15.278
0.7929	15.574	13.948	16.365	14.273	17.078	14.604	17.718	14.947
0.8960	14.651	13.645	15.606	13.960	16.449	14.283	17.186	14.617
1.0000	13.653	13.342	14.805	13.648	15.799	13.962	16.643	14.286

Table 3. Non-linearity parameter **B/A**, values computed by four different approaches as a function of mole fraction 1,4-BD at four different temperatures.

x_1	303.15K	308.15K	313.15K	318.15K	303.15K	308.15K	313.15K	318.15K
1,4-butanediol + o-cresol								
		(B/A) – Hartmann and Balizer				(B/A) – Ballou		
0.0000	8.598	8.681	8.748	8.819	7.579	7.680	7.763	7.850
0.1001	8.524	8.601	8.666	8.734	7.489	7.583	7.663	7.745
0.2001	8.465	8.537	8.598	8.664	7.417	7.504	7.579	7.660
0.3002	8.416	8.483	8.541	8.606	7.356	7.438	7.510	7.589
0.4002	8.371	8.434	8.490	8.553	7.302	7.378	7.447	7.525
0.5002	8.328	8.386	8.440	8.502	7.249	7.320	7.386	7.462
0.6002	8.282	8.336	8.388	8.448	7.193	7.258	7.322	7.396
0.7002	8.238	8.287	8.337	8.396	7.138	7.199	7.260	7.332
0.8001	8.197	8.242	8.290	8.347	7.088	7.143	7.202	7.272
0.9001	8.167	8.209	8.254	8.311	7.051	7.102	7.158	7.228
1.0000	8.162	8.201	8.245	8.301	7.045	7.093	7.147	7.216
		(B/A) – Thermoacoustical (i)				(B/A) – Thermoacoustical (ii)		
0.0000	6.952	6.920	6.892	6.866	8.171	8.152	8.137	8.122
0.1001	7.111	7.053	6.998	6.946	8.269	8.232	8.198	8.167
0.2001	7.293	7.200	7.114	7.032	8.391	8.328	8.271	8.219
0.3002	7.500	7.366	7.241	7.124	8.541	8.443	8.355	8.277
0.4002	7.740	7.552	7.380	7.223	8.724	8.580	8.453	8.343
0.5002	8.018	7.763	7.534	7.329	8.946	8.742	8.566	8.417
0.6002	8.343	8.003	7.704	7.444	9.217	8.934	8.696	8.499
0.7002	8.729	8.278	7.894	7.569	9.548	9.162	8.845	8.592
0.8001	9.192	8.596	8.105	7.703	9.956	9.432	9.017	8.695
0.9001	9.757	8.966	8.341	7.849	10.465	9.755	9.215	8.810
1.0000	10.459	9.402	8.609	8.008	11.111	10.144	9.443	8.938
1,4-butanediol + m-cresol								
		(B/A) – Hartmann and Balizer				(B/A) – Ballou		
0.0000	8.979	9.076	9.179	9.285	8.046	8.164	8.290	8.420
0.0992	8.876	8.956	9.043	9.134	7.919	8.018	8.124	8.236
0.1986	8.772	8.844	8.923	9.007	7.792	7.880	7.977	8.080
0.2982	8.676	8.741	8.813	8.891	7.674	7.755	7.843	7.938
0.3979	8.587	8.647	8.712	8.784	7.565	7.639	7.719	7.807
0.4979	8.504	8.559	8.618	8.685	7.464	7.532	7.604	7.685
0.5979	8.428	8.477	8.532	8.593	7.371	7.431	7.498	7.573
0.6982	8.357	8.401	8.451	8.509	7.284	7.338	7.399	7.471
0.7986	8.291	8.330	8.377	8.432	7.203	7.251	7.308	7.375
0.8992	8.229	8.264	8.307	8.360	7.127	7.170	7.223	7.288
1.0000	8.162	8.201	8.245	8.301	7.045	7.093	7.147	7.216
		(B/A) – Thermoacoustical (i)				(B/A) – Thermoacoustical (ii)		
0.0000	8.006	7.714	7.454	7.230	8.937	8.703	8.506	8.347
0.0992	8.199	7.859	7.561	7.307	9.096	8.818	8.586	8.400
0.1986	8.403	8.009	7.670	7.384	9.267	8.939	8.669	8.455
0.2982	8.616	8.164	7.781	7.461	9.449	9.066	8.756	8.512
0.3979	8.840	8.324	7.893	7.539	9.644	9.200	8.845	8.569
0.4979	9.076	8.490	8.008	7.617	9.852	9.341	8.938	8.628
0.5979	9.324	8.661	8.124	7.695	10.074	9.488	9.033	8.688
0.6982	9.585	8.837	8.243	7.773	10.309	9.642	9.132	8.750
0.7986	9.861	9.019	8.363	7.851	10.560	9.802	9.233	8.812
0.8992	10.152	9.207	8.485	7.930	10.827	9.969	9.337	8.874
1.0000	10.459	9.402	8.609	8.008	11.111	10.144	9.443	8.938

1,4-butanediol + p-cresol								
		(B/A) – Hartmann and Balizer				(B/A) – Ballou		
0.0000	8.669	8.733	8.803	8.838	7.666	7.744	7.830	7.874
0.0961	8.628	8.690	8.756	8.790	7.616	7.692	7.772	7.815
0.1931	8.579	8.641	8.703	8.737	7.556	7.631	7.708	7.749
0.2909	8.527	8.584	8.641	8.677	7.492	7.562	7.632	7.676
0.3895	8.475	8.524	8.574	8.611	7.429	7.489	7.550	7.596
0.4890	8.422	8.464	8.511	8.546	7.364	7.415	7.472	7.516
0.5894	8.372	8.412	8.457	8.496	7.302	7.351	7.407	7.455
0.6907	8.322	8.366	8.412	8.455	7.242	7.295	7.352	7.404
0.7929	8.274	8.318	8.364	8.410	7.183	7.237	7.293	7.349
0.8960	8.222	8.265	8.310	8.360	7.118	7.171	7.226	7.287
1.0000	8.162	8.201	8.245	8.301	7.045	7.093	7.147	7.216
		(B/A) – Thermoacoustical (i)				(B/A) – Thermoacoustical (ii)		
0.0000	6.952	6.920	6.892	6.866	8.171	8.152	8.137	8.122
0.0961	7.105	7.047	6.994	6.943	8.265	8.228	8.196	8.165
0.1931	7.279	7.189	7.105	7.026	8.381	8.320	8.265	8.215
0.2909	7.480	7.350	7.229	7.115	8.526	8.431	8.347	8.271
0.3895	7.713	7.531	7.365	7.212	8.702	8.564	8.442	8.335
0.4890	7.984	7.738	7.516	7.317	8.919	8.722	8.552	8.408
0.5894	8.306	7.976	7.685	7.432	9.185	8.912	8.681	8.490
0.6907	8.690	8.250	7.875	7.556	9.513	9.138	8.830	8.583
0.7929	9.156	8.571	8.089	7.693	9.924	9.411	9.004	8.687
0.8960	9.732	8.949	8.331	7.843	10.442	9.741	9.206	8.805
1.0000	10.459	9.402	8.609	8.008	11.111	10.144	9.443	8.938

Table 4. Reduced bulk modulus, B, isochoric thermo-acoustical parameter, ⊿, isothermal Gruneisen parameter, Γ_{ith}, isochoric Gruneisen parameter, Γ_{ich}, isobaric Gruneisen parameter, Γ_{iba}, isothermal Anderson-Gruneisen parameter, δ, as a function of mole fraction 1,4-BD at four different temperatures.

x_1	**B**	⊿	Γ_{ith}	Γ_{ich}	Γ_{iba}	δ	**B**	⊿	Γ_{ith}	Γ_{ich}	Γ_{iba}	δ
1,4-butanediol + o-cresol												
			303.15 K						**308.15 K**			
0.0000	0.161	0.118	3.477	0.247	3.229	6.459	0.160	0.122	3.461	0.248	3.212	6.425
0.1001	0.168	0.108	3.557	0.261	3.295	6.591	0.165	0.113	3.527	0.260	3.267	6.534
0.2001	0.174	0.098	3.647	0.277	3.371	6.741	0.171	0.104	3.601	0.273	3.328	6.656
0.3002	0.181	0.088	3.751	0.294	3.457	6.914	0.177	0.096	3.684	0.288	3.397	6.793
0.4002	0.189	0.079	3.871	0.314	3.557	7.114	0.183	0.088	3.777	0.304	3.474	6.948
0.5002	0.196	0.071	4.010	0.337	3.673	7.346	0.189	0.080	3.883	0.321	3.561	7.123
0.6002	0.205	0.063	4.173	0.364	3.809	7.618	0.196	0.073	4.003	0.342	3.661	7.323
0.7002	0.213	0.056	4.366	0.395	3.971	7.942	0.203	0.066	4.140	0.364	3.776	7.552
0.8001	0.222	0.049	4.598	0.432	4.166	8.331	0.210	0.059	4.299	0.391	3.909	7.818
0.9001	0.232	0.042	4.880	0.477	4.403	8.806	0.218	0.053	4.484	0.421	4.064	8.127
1.0000	0.243	0.036	5.231	0.532	4.699	9.398	0.226	0.047	4.703	0.456	4.246	8.493
			313.15 K						**318.15 K**			
0.0000	0.159	0.127	3.447	0.250	3.197	6.394	0.158	0.131	3.434	0.251	3.182	6.365
0.1001	0.163	0.119	3.500	0.259	3.241	6.481	0.161	0.124	3.474	0.259	3.215	6.430
0.2001	0.168	0.111	3.558	0.270	3.288	6.576	0.165	0.118	3.517	0.267	3.250	6.500
0.3002	0.172	0.104	3.621	0.281	3.340	6.681	0.168	0.112	3.563	0.275	3.288	6.576
0.4002	0.177	0.097	3.691	0.293	3.398	6.796	0.172	0.106	3.612	0.284	3.328	6.657
0.5002	0.182	0.090	3.768	0.307	3.461	6.923	0.176	0.101	3.666	0.293	3.372	6.745
0.6002	0.188	0.083	3.853	0.321	3.532	7.064	0.179	0.095	3.723	0.304	3.420	6.839
0.7002	0.193	0.077	3.948	0.338	3.610	7.221	0.183	0.090	3.785	0.315	3.471	6.942
0.8001	0.199	0.071	4.054	0.356	3.698	7.396	0.187	0.085	3.853	0.326	3.526	7.053
0.9001	0.204	0.065	4.172	0.376	3.797	7.593	0.192	0.080	3.926	0.339	3.587	7.173
1.0000	0.211	0.060	4.306	0.398	3.908	7.816	0.196	0.075	4.005	0.353	3.653	7.305
1,4-butanediol + m-cresol												
			303.15 K						**308.15 K**			
0.0000	0.196	0.071	4.004	0.336	3.668	7.336	0.188	0.082	3.858	0.317	3.541	7.081
0.0992	0.201	0.066	4.101	0.352	3.749	7.498	0.192	0.077	3.931	0.329	3.601	7.202
0.1986	0.206	0.062	4.203	0.369	3.834	7.668	0.196	0.072	4.006	0.342	3.664	7.328
0.2982	0.211	0.058	4.309	0.386	3.923	7.847	0.200	0.068	4.083	0.355	3.728	7.457
0.3979	0.216	0.054	4.422	0.404	4.018	8.035	0.204	0.065	4.164	0.368	3.795	7.591
0.4979	0.220	0.051	4.539	0.423	4.117	8.233	0.208	0.061	4.246	0.382	3.864	7.729
0.5979	0.225	0.047	4.664	0.443	4.221	8.442	0.212	0.058	4.332	0.396	3.936	7.872
0.6982	0.229	0.044	4.794	0.463	4.331	8.662	0.215	0.055	4.420	0.410	4.010	8.019
0.7986	0.234	0.041	4.932	0.485	4.447	8.894	0.219	0.052	4.511	0.425	4.086	8.172

0.8992	0.238	0.039	5.078	0.508	4.569	9.139	0.223	0.050	4.605	0.440	4.165	8.330
1.0000	0.243	0.036	5.231	0.532	4.699	9.398	0.226	0.047	4.703	0.456	4.246	8.493
	313.15 K						**318.15 K**					
0.0000	0.180	0.093	3.728	0.300	3.428	6.856	0.172	0.106	3.616	0.285	3.331	6.663
0.0992	0.183	0.089	3.782	0.309	3.472	6.945	0.175	0.102	3.654	0.291	3.363	6.726
0.1986	0.186	0.085	3.836	0.319	3.518	7.035	0.177	0.098	3.693	0.298	3.395	6.789
0.2982	0.190	0.081	3.892	0.328	3.564	7.127	0.180	0.094	3.732	0.305	3.427	6.853
0.3979	0.193	0.077	3.948	0.338	3.610	7.221	0.182	0.091	3.771	0.312	3.459	6.917
0.4979	0.196	0.074	4.005	0.347	3.658	7.316	0.185	0.088	3.810	0.319	3.491	6.981
0.5979	0.199	0.071	4.064	0.357	3.706	7.413	0.187	0.085	3.849	0.326	3.523	7.046
0.6982	0.202	0.068	4.123	0.367	3.755	7.511	0.190	0.082	3.888	0.333	3.555	7.110
0.7986	0.205	0.065	4.183	0.377	3.806	7.611	0.192	0.080	3.927	0.339	3.588	7.175
0.8992	0.208	0.062	4.244	0.388	3.856	7.713	0.194	0.077	3.966	0.346	3.620	7.240
1.0000	0.211	0.060	4.306	0.398	3.908	7.816	0.196	0.075	4.005	0.353	3.653	7.305
1,4-butanediol + p-cresol												
	303.15 K						**308.15 K**					
0.0000	0.161	0.118	3.477	0.247	3.229	6.459	0.160	0.122	3.461	0.248	3.212	6.425
0.0961	0.167	0.108	3.553	0.261	3.293	6.585	0.165	0.113	3.524	0.260	3.265	6.529
0.1931	0.174	0.098	3.641	0.276	3.365	6.730	0.171	0.105	3.596	0.272	3.323	6.647
0.2909	0.181	0.089	3.741	0.293	3.448	6.897	0.176	0.096	3.676	0.286	3.390	6.780
0.3895	0.188	0.080	3.857	0.312	3.545	7.091	0.182	0.088	3.767	0.302	3.465	6.930
0.4890	0.195	0.072	3.994	0.335	3.659	7.318	0.189	0.081	3.870	0.319	3.551	7.102
0.5894	0.204	0.064	4.154	0.361	3.793	7.587	0.195	0.073	3.989	0.339	3.650	7.300
0.6907	0.212	0.057	4.346	0.392	3.954	7.909	0.202	0.066	4.127	0.362	3.764	7.529
0.7929	0.222	0.049	4.580	0.429	4.150	8.300	0.210	0.060	4.287	0.389	3.898	7.797
0.8960	0.232	0.043	4.868	0.475	4.392	8.785	0.218	0.053	4.476	0.419	4.057	8.114
1.0000	0.243	0.036	5.231	0.532	4.699	9.398	0.226	0.047	4.703	0.456	4.246	8.493
	313.15 K						**318.15 K**					
0.0000	0.159	0.127	3.447	0.250	3.197	6.394	0.158	0.131	3.434	0.251	3.182	6.365
0.0961	0.163	0.119	3.498	0.259	3.239	6.477	0.161	0.125	3.472	0.258	3.214	6.427
0.1931	0.167	0.112	3.554	0.269	3.285	6.569	0.164	0.119	3.514	0.266	3.248	6.495
0.2909	0.172	0.104	3.615	0.280	3.335	6.670	0.168	0.113	3.558	0.274	3.284	6.568
0.3895	0.177	0.097	3.683	0.292	3.391	6.783	0.171	0.107	3.607	0.283	3.324	6.648
0.4890	0.182	0.091	3.759	0.305	3.454	6.908	0.175	0.101	3.660	0.292	3.367	6.734
0.5894	0.187	0.084	3.844	0.320	3.524	7.048	0.179	0.096	3.717	0.303	3.414	6.829
0.6907	0.192	0.078	3.939	0.336	3.603	7.205	0.183	0.090	3.779	0.314	3.466	6.932
0.7929	0.198	0.071	4.046	0.354	3.691	7.383	0.187	0.085	3.848	0.326	3.522	7.044
0.8960	0.204	0.066	4.167	0.375	3.792	7.585	0.192	0.080	3.923	0.339	3.584	7.168
1.0000	0.211	0.060	4.306	0.398	3.908	7.816	0.196	0.075	4.005	0.353	3.653	7.305

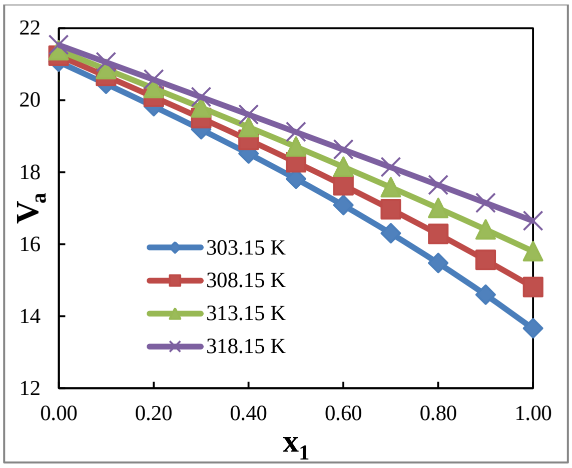

Fig. 1 Available volume in binary liquid mixtures of 1,4-butanediol + o-cresol at different temperatures.

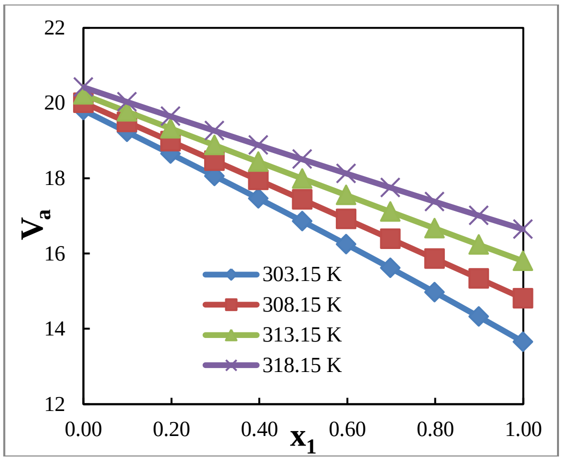

Fig. 2 Available volume in binary liquid mixtures of 1,4-butanediol + m-cresol at different temperatures.

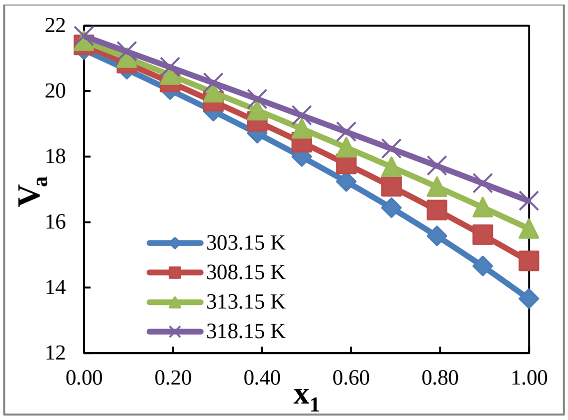

Fig. 3 Available volume in binary liquid mixtures of 1,4-butanediol + p-cresol at different temperatures.

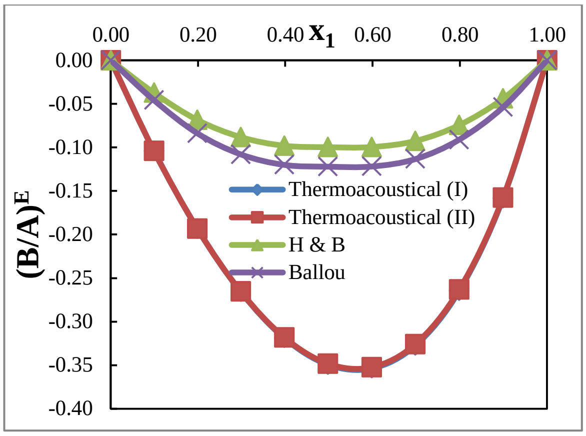

Fig. 5 Variation of excess B/A with mole fraction of 1,4-BD of 1,4-butanediol + m-cresol at T=303.15K.

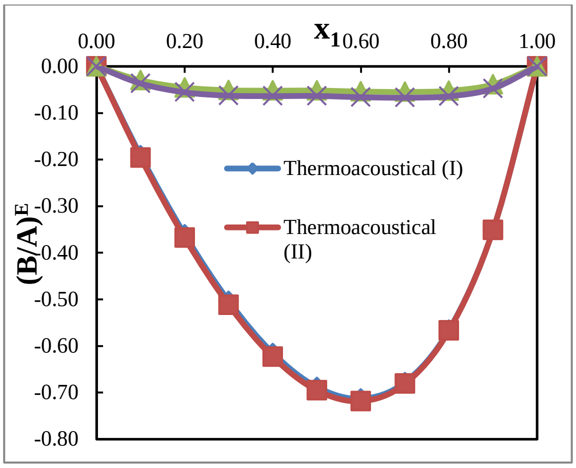

Fig. 4 Variation of excess B/A with mole fraction of 1,4-BD of 1,4-butanediol + o-cresol at T=303.15K.

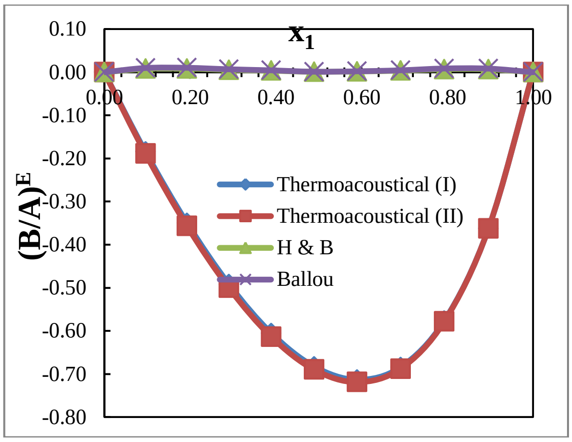

Fig. 6 Variation of excess B/A with mole fraction of 1,4-BD of 1,4-butanediol + p-cresol at T=303.15K.

4. CONCLUSIONS

A few acoustic parameters, reduced volume, the Moelwyn-Hughes parameter, and the Sharma parameter are computed. These parameters are used to compute available volume using two alternative ways. Four approaches are used to calculate the non-linearity parameter, B/A, and the results are compared. The interpretation of the magnitude of the liquid's hardness in terms of the non-linearity parameter is aided by the conclusion that the fluctuation of the computed values of B/A will rely on the ultrasonic sound wave in a particular medium. Additionally, Gruneisen parameters are computed. The present observations give more insight in to the molecular interactions between the taken binary liquid components.

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