

A Complete Ultrasonic Velocity Study of Decane-1-Ol with Various Acrylates at 303.15 And 313.15 K Temperatures

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Abstract: Ultrasonic velocities of binary liquid mixtures of methyl acrylate, ethyl acrylate, butyl acrylate and methyl methacrylate with decane-1-ol have been measured at 303.15 and 313.15 K and at atmospheric pressure. Experimentally measured ultrasonic velocities were correlated using Jouyban-Acree model. Deviations in isentropic compressibility were calculated using ultrasonic velocity and have been fitted to Redlich-Kister polynomial equation. Ultrasonic velocities were also calculated theoretically using Nomoto, Van Dael (VAN), free length theory (FLT) and collision factor theory (CFT). Different derived thermodynamic parameters like excess specific acoustic impedance, excess available volume, excess intrinsic pressure and molar sound velocity were also calculated. Graphical representations of these excess derived thermodynamic parameters used to explain type and extent of intermolecular interactions in these binary systems. Ultrasonic velocity measurement of liquid mixtures of non electrolytes provides an excellent tool to investigate inter and intramolecular interactions between like and unlike molecules. This study is a powerful means of characterizing various aspects of physicochemical behaviors of liquid mixtures and molecular interactions.

Keywords: Decane-1-ol, Free Length Theory, Jouyban-Acree Model, Ultrasonic Velocity, Van Dael.

I. Introduction

Measurements of some of bulk properties like ultrasonic velocity of liquids provide an insight into investigation of intermolecular arrangement of liquids and help to understand thermodynamic and acoustic properties of liquid mixtures. The study of thermodynamic properties involves challenges of interpreting excess quantities as a means of understanding nature of intermolecular interactions among the mixed components.

Most of techniques to know molecular interactions are based on spectroscopic investigation. But majority difficulties found in such techniques due to, intrinsic insensitivity of spectroscopic investigation and weak molecular interactions. Hence, instead of such techniques one can have a better idea about molecular interactions by investigating and monitoring thermodynamic properties which includes different volumetric, transport and ultrasonic properties. Properties of liquid-liquid binary mixtures are very important qualitatively and quantitatively as a part of studies of thermodynamic, acoustic and transport aspects. Compositional dependence of thermodynamic properties has proved to be a very useful tool in understanding nature and extent of pattern of molecular aggregation resulting from interactions.

Ultrasonic properties have practical importance in understanding interactions and physicochemical behavior. The mixing of different compounds gives rise to solutions that generally don't behave ideally. Deviation from ideality may be expressed by many thermodynamic variables, particularly by excess properties. Excess properties of mixtures correspond to difference between actual and properties if system behaves ideally and thus are useful in study of molecular interactions and arrangements. In particular, they reflect interactions that take place between solute-solute, solute-solvent and solvent-solvent species.

To best of our knowledge, no literature data is available for ultrasonic velocity study of binary liquid mixtures of decane-1-ol with methyl acrylate, ethyl acrylate, butyl acrylate and methyl methacrylate at 303.15 and 313.15 K. In view of these considerations, it is planned to study liquid-liquid binary systems containing polar and hydrogen bonded or nonpolar liquids in association with industrially as well as biologically important solvent at 303.15 and 313.15 K.

II. Materials And Methods

Chemicals used in present study were of analytical grade and supplied by S. D. Fine Chemicals Pvt., Mumbai (India) with quoted mass fraction purities: methyl acrylate, MA, (> 0.997), ethyl acrylate, EA, (> 0.998), butyl acrylate, BA, (> 0.995), methyl methacrylate, MMA, (>0.997) and decane-1-ol (> 0.998). Prior to use, all liquids were stored over 0.4 nm molecular sieves to reduce water content and were degassed. All four acrylic esters were distilled before use. The binary mixtures of varying composition were prepared by mass in special air-tight bottles. The solutions of each composition were prepared fresh and all properties were measured same day. The masses were recorded on a Mettler one pan balance, which can read up to fifth place of decimal,

with an accuracy of ± 0.01 mg. Care was taken to avoid evaporation and contamination during mixing. The estimated uncertainty in mole fraction was $< 1 \times 10^{-4}$.

2.1 Experimental

Ultrasonic velocities were measured [1] at frequency of 2 MHz by single crystal ultrasonic interferometer (Model F-81, Mittal Enterprises, New Delhi, India). Accuracy in velocity measurements is ± 0.1 %. The ultrasonic velocities of pure components at 303.15 and 313.15 K are listed in Table 1.

III. Theory And Calculations

Ultrasonic velocity measurements were performed with repetitions for each binary liquid system namely methyl acrylate (1) + decane-1-ol (2), ethyl acrylate (1) + decane-1-ol (2), butyl acrylate (1) + decane-1-ol (2) and methyl methacrylate (1) + decane-1-ol (2) over entire mole fraction range ($0 < x < 1$), at temperature 303.15 and 313.15 K and at atmospheric pressure.

It has been found that a number of derived parameters from ultrasonic sound velocity such as isentropic compressibility (κ_s), specific acoustic impedance (Z), available volume (V_a), intrinsic pressure (π_{int}) and molar sound velocity (R) have also been calculated along with their excess parameters which provide better insight in understanding of molecular interactions in pure liquids and binary liquids which are given by following relations,

$$\kappa_s = (1/ u^2 \rho) \tag{1}$$

$$Z = u \rho \tag{2}$$

$$V_a = V_m [1 - (u_{expt}/u_\infty)] \tag{3}$$

Where $u_\infty = 1600$ m/s.

For binary liquid mixtures above equation can be written as,

$$\pi_i = bRT (K \eta_{12}/u_{12})^{1/2} (\rho_{12}^{2/3}/M_{12}^{7/6}) \tag{4}$$

Where M_{12} is given by following equation,

$$M_{12} = x_1 M_1 + x_2 M_2 \tag{5}$$

Where b is packing factor, K is a constant temperature independent having value of 4.28×10^9 , R is gas constant and η_{12} , u_{12} , ρ_{12} are mixture's viscosity, ultrasonic velocity and density, respectively.

$$R = (M/\rho) u^{1/3} \tag{6}$$

The excess functions are important to understand molecular interactions between components of liquid mixtures. Excess function Y^E represents excess of a given quantity Y of a real mixture over its value for an ideal mixture Y^{id} at same conditions of temperature, pressure and composition.

It is expressed by following relation,

$$Y^E = Y - Y^{id} \tag{7}$$

Where Y denotes Z , V_a , π_{int} and Y^E represents corresponding excess thermodynamic properties such as excess specific acoustic impedance (Z^E), excess available volume (V_a^E) and excess intrinsic pressure (π_{int}^E).

Experimental ultrasonic velocities (u), deviation in isentropic compressibility ($\Delta \kappa_s$) and excess specific acoustic impedance (Z^E) for binary liquid mixtures of decane-1-ol with methyl acrylate (MA), ethyl acrylate (EA), butyl acrylate (BA) and methyl methacrylate (MMA) at both temperatures listed in Table 2.

Excess available volume (V_a^E), excess intrinsic pressure (π_{int}^E) and molar sound velocity (R) for the present binary liquid mixtures at both temperatures listed in Table 3.

Nomoto [2] investigated additivity of molar volumes in those mixtures for which deviation from linearity of molecular sound velocity is small and it was revealed that a great part of these mixtures had also a good additivity relationship of molar volumes. The sound velocity based on assumption of linearity of molecular sound velocity,

$$R = x_1 R_1 + x_2 R_2 \tag{8}$$

Where R_1 and R_2 are molar sound velocities, x_1 and x_2 are mole fractions respectively. The molar sound velocity (R) also known as Rao's constant which can be calculated using the above relation (8),

Hence, speed of sound is given by,

$$u = (R/V)^3 = [(x_1 R_1 + x_2 R_2) / (x_1 V_1 + x_2 V_2)]^3 \tag{9}$$

According to Van Dael and Vangeel [3] assumption adiabatic compressibility (Δs) of mixture given by,

$$\Delta s_{(im)} = \Delta s_1 v_1 \Delta s / v_m + \Delta s_2 v_2 \Delta s / v_{im} \tag{10}$$

Where Δs and v represent volume fraction and specific heat ratio respectively.

Schaffs [4, 5] on basis of collision factor theory gave relation for sound velocity in liquids,

$$u = u_0 \square Srf = u_0 SB/V \quad (11)$$

Where $u_0 \square = 1600$ m/s, S is collision factor and r_f ($r_f = B/V$) is space filling factor, B is actual volume of molecule per mole and V is molar volume.

The sound velocity in mixtures evaluated from Jacobson's [6, 7] free length theory is,

$$u_{mix} = K / (L_{ff(mix)} \rho_{(mix)}^{1/2}) \quad (12)$$

Where K is a temperature dependent constant.

Ultrasonic velocities from these theories with percentage error are given in Table 4.

The deviation in isentropic compressibility were fitted to RedlichKister [8] equation of type,

$$Y = x_1 x_2 \sum_i^n a_i (x_1 - x_2)^i \quad (13)$$

where Y is $\Delta\kappa_s$ and n is degree of polynomial. Coefficient a_i was obtained by fitting equation (13) to experimental results using a least-squares regression method. In each case, optimum number of coefficients is ascertained from an examination of variation in standard deviation (σ).

σ was calculated using relation,

$$\sigma(Y) = \left[\frac{\sum (Y_{\text{expt}} - Y_{\text{calc}})^2}{N - n} \right]^{1/2} \quad (14)$$

where N is number of data points and n is number of coefficients. The calculated values of coefficients a_i along with standard deviations (σ) are also given at temperatures 303.15 and 313.15 K in Table 5.

JouybanAcree [9, 10] recently proposed model for correlating density and viscosity of liquid mixtures at various temperatures. The proposed equation is,

$$\ln y_{mT} = f_1 \ln y_{1T} + f_2 \ln y_{2T} + f_1 f_2 \sum [A_j (f_1 - f_2)^j / T] \quad (15)$$

where y_{mT} , y_{1T} and y_{2T} is density or viscosity of the mixture and solvents 1 and 2 at temperature T, respectively, f_1 and f_2 are volume fractions of solvents in case of density, mole fraction in case of viscosity and A_j are the model constants. The correlating ability of the JouybanAcree model was tested by calculating the average percentage deviation (APD) between the experimental and calculated density and viscosity as,

$$APD = (100/N) \sum [(|y_{\text{expt}} - y_{\text{cal}}|) / y_{\text{expt}}] \quad (16)$$

Where N is the number of data points in each set.

The optimum numbers of constants A_j , in each case, are determined from the examination of the average percentage deviation value. The JouybanAcree model was not previously applied to ultrasonic velocity measurements, we extend JouybanAcree model to ultrasonic velocity (15) of liquid mixtures with f as the mole fraction and again apply (16) for correlating ability of the model. The proposed model provides reasonably accurate calculations for the density, viscosity and ultrasonic velocity of binary liquid mixtures and could be used in data modeling.

The constants A_j calculated from least square analysis along with average percentage deviation (APD) are presented in Table 6.

IV. Results And Discussion

Fig. 1 represents graphical variation of deviation in isentropic compressibility ($\square \square_s$) for acrylates with decane-1-ol at 303.15 K. In the present study, values of $\Delta\kappa_s$ are found to be positive for all mixtures. As the temperature increase values of $\Delta\kappa_s$ decrease. Similar results were reported earlier by Ali [11, 12]. Kiyohara and Benson [13] have suggested that, positive deviation in isentropic compressibility ($\square \square_s$) is resultant of several opposing effects.

1. Deviation in isentropic compressibility can be interpreted as:-
2. Increase in free volume in mixture compared to pure components due to rupture of alkanols aggregates with addition of second component, i. e. acrylates.

Interstitial accommodation of acrylate molecules in aggregates of alkanols.

In binary liquid mixtures, an expansion in free volume makes mixture more compressible than ideal mixtures. Negative values means mixture is less compressible than ideal one.

Alcohols exist in the form of aggregates. When they are mixed with other non-electrolyte molecules, the aggregates of alcohol dissociate and form intermolecular complexes with unlike molecules. Variations in ultrasonic velocity and compressibilities in alkanols are mainly due to H-bonds, dispersion and interaction of hydrocarbon radicals of alkanols. A strong molecular interaction through charge transfer, dipole-induced dipole, dipole-dipole [14] interactions, interstitial accommodation and orientational ordering lead to a more compact

structure, making $\Delta\kappa_s$ negative and breakup of alkanols structures tend to make $\Delta\kappa_s$ positive. Sign of $\Delta\kappa_s$ and V^E decides compactness due to molecular rearrangement. The magnitude of various contributions depends mainly on relative molecular size of the components. Positive values of $\Delta\kappa_s$ observed when H-bonded aggregates of alkanols break up progressively with addition of second component. The positive values of $\Delta\kappa_s$ for mixtures of methyl acrylate with both types of alkanols signify decreasing dipole-dipole interactions due to decreasing proton donating abilities with increasing chain length of 1-alkanols. De-clustering of 1-alkanols in the presence of acrylates may also lead to positive $\Delta\kappa_s$ values.

There is high tendency of alkanols to undergo self-association via intermolecular hydrogen bonding. It is well known that 1-alkanols form a variety of species with different degrees of association in the pure state; however, polymeric linear associates are expected to be predominant in the pure state. Thus, the addition of an acrylic ester to 1-alkanol may result in the following effects:

- i. Rupturing or disruption of associate structures in alkanols.
- ii. Formation of new species because of weak interactions between ester and alkanols.
- iii. Free volume changes upon mixing of components of different sizes.

The first effect contributes positively to excess volumes and excess isentropic compressibilities and negatively to excess viscosities. However, contributions due to effects (ii) and (iii) are in the opposite directions.

Fig.2 represents graphical variation of Z^E for acrylates with decane-1-ol at 303.15 K. In this case, all values are negative at both temperatures, but as mole fraction of acrylate increases values are becoming negative. The curves exhibit negative deviation throughout mole fraction and deviations become more negative as the chain length acrylates increases. A negative deviation in Z^E values shows weak interactions between the component molecules. Z^E are more negative for mixtures containing branched alkanols due to more steric hindrance of branched alkanols towards hetero- molecular interactions [15].

For mixture containing alkanols, negative values of Z^E suggests that, dispersive forces are dominant over the specific interaction. The positive values indicate presence of strong specific interactions and negative values corresponds mainly to the existence of dispersive forces. Thus from above discussion reinforces our views that, in present binary liquid systems dispersion forces are dominant and geometrical fitting is also observed.

The variations of excess available volume (V_a^E) for acrylates with decane-1-ol at 303.15 K are represented in Fig. 3. The positive values of V_a^E indicate presence of strong specific interaction. The V_a^E for binary mixtures of methyl acrylate with both types of alkanols are positive at all temperatures. This nature may be attributed to strong interactions between acrylates and decane-1-ol. On other hand, negative values of it means weak interactions due to, possible accommodation, large difference in molar volume, dipole-dipole interactions, dipole-induced dipole interactions and van der Waal's forces of attraction.

The variations of excess intrinsic pressure (π_{int}^E) for acrylates with decane-1-ol at 303.15 K are represented in Fig.4. Excess intrinsic pressure π_{int}^E may be used to study the intermolecular interactions in binary liquid mixtures. The values of π_{int}^E are found to be negative throughout the mole fraction in all binary mixtures of decane-1-ol with acrylate suggesting weak interactions.

The molar sound velocity (R), also known as Rao's constant, gives information on the formation of a complex and on association of components. The values of molar sound velocity are sensitive to structure of molecules. The increase in molar sound velocity with mole fraction indicates specific interactions while decrease in these values suggests presence of dispersive forces between components of binary liquid mixtures. These values are not greatly influenced by temperature. This is in accordance with theoretical expectation that R is independent of temperature [16, 17]. The values of Rao's constant are found to decrease to very less extent with mole fraction of acrylates.

Ultrasonic velocities for all binary mixtures have also been calculated theoretically over entire mole fraction range using Nomoto, Van Dael, Jacobson's free length theory (FLT) and collision factor theory (CFT) to predict the ultrasonic velocities of all binary mixtures at both temperatures. The calculated ultrasonic velocities along with average percentage error are summarized in Table 4. A close scrutiny of result indicates that CFT does succeed in computing the ultrasonic velocity value for all the mixtures studied in the present investigation to a greater degree of accuracy as compared with Nomoto, Van Dael and FLT. The Nomoto formula is based on the assumption of linearity of molar sound velocity versus mole fraction and additivity of molar volumes in liquid mixtures. Nomoto theory shows somewhat high and van deal theory shows lower value of the ultrasonic velocities. Free length theory is naturally not applicable to systems having self-associated components. The error range in the case of Van Daelis much larger for binary mixtures containing methyl acrylate (1) + decane-1-ol (2), ethyl acrylate (1) + decane-1-ol (2) and methyl methacrylate (1) + decane-1-ol (2). On the other hand, error range in the case FLT is the larger in case of the binary mixture containing butyl acrylate (1) + decane-1-ol (2). This result may be due to increase in the carbon atoms in case of the acrylates.

The Redlich- Kister equation was originally developed to correlate the excess Gibb's energy function and calculate the values of the activity coefficients. It turned out to be such a powerful and versatile correlating

tool that its use has been extended to other properties, particularly excess molar volumes and excess enthalpies of mixing. It suffers from the important drawback that, the values of the adjustable parameters change as the number in the series is increased, so that no physical interpretation can be attached to them [18]. The Redlich-Kisterregressor is very powerful and frequently used to correlate vapor-liquid equilibrium data and excess properties.

Experimentally measured fundamental thermodynamic property such as ultrasonic velocity was correlated using recently proposed Jouyban-Acree model. The constants (A_j) calculated from least square analysis along with average percentage deviation (APD) are represented in Table 6. The proposed model provides reasonably accurate calculations for fundamental thermodynamic parameters of binary liquid mixtures.

V. Tables And Figures

Table 1. Ultrasonic Velocities (u) for Pure Components at 303.15 and 313.15 K.

Component	u / (m.s ⁻¹)		u / (m.s ⁻¹)	
	Expt	Lit.	Expt	Lit.
	303.15 K		313.15 K	
Decane-1-ol	1367	1363 [19]	1335	1334 [20]
Methyl Acrylate	1163	---	1118	---
Ethyl Acrylate	1152	---	1123	---
Butyl Acrylate	1190	---	1157	---
Methyl Methacrylate	1168	---	1139	---

Table 2. Ultrasonic Velocities (u), Deviation in Isentropic Compressibility ($\Delta \kappa_s$) and Excess Specific Acoustic Impedence (Z^E) for Acrylates (1) + Decane-1-ol (2) at 303.15 and 313.15 K.

X ₁	u	$\Delta \kappa_s$	Z^E	u	$\Delta \kappa_s$	Z^E
	(m.s ⁻¹)	(TPa ⁻¹)	(Kg.m ⁻² .s ⁻¹)	(m.s ⁻¹)	(TPa ⁻¹)	(Kg.m ⁻² .s ⁻¹)
	303.15 K			313.15 K		
	MA (1) + Decane-1-ol (2)					
0	1367	0	0	1335	0	0
0.0552	1355	5.88	-4.79	1322	6.66	-4.42
0.0997	1345	10.72	-8.53	1312	11.37	-7.32
0.1555	1333	16.14	-12.63	1299	17.61	-11.18
0.1999	1324	19.71	-15.24	1288	23.15	-14.61
0.2554	1312	24.69	-18.85	1276	27.85	-17.22
0.3000	1302	28.85	-21.81	1266	31.77	-19.40
0.3555	1291	32.09	-23.94	1253	36.95	-22.29
0.3999	1281	35.71	-26.40	1244	39.05	-23.18
0.4538	1270	38.35	-28.01	1232	42.40	-24.84
0.4999	1261	39.63	-28.64	1222	44.38	-25.68
0.5554	1250	40.73	-29.10	1210	46.07	-26.29
0.5999	1241	41.20	-29.18	1200	47.23	-26.70
0.6550	1230	40.75	-28.55	1189	45.87	-25.52
0.6999	1221	39.58	-27.49	1179	45.24	-24.95
0.7555	1210	36.77	-25.29	1168	41.19	-22.36
0.7999	1201	33.71	-23.01	1158	38.47	-20.77
0.8555	1191	26.65	-18.01	1147	31.06	-16.54
0.8999	1182	20.81	-13.98	1138	23.76	-12.54
0.9555	1171	10.95	-7.31	1127	11.70	-6.11
1	1163	0	0	1118	0	0
	EA (1) + Decane-1-ol (2)					
0	1367	0	0	1335	0	0
0.0554	1354	4.81	-3.13	1322	5.14	-2.92
0.0999	1344	8.16	-5.21	1312	8.75	-4.86
0.1553	1331	12.76	-8.09	1300	12.59	-6.76
0.1998	1321	15.84	-9.89	1290	15.91	-8.45
0.2556	1309	18.97	-11.54	1277	20.45	-10.83
0.2999	1299	21.72	-13.08	1268	22.29	-11.47
0.3554	1286	25.44	-15.20	1255	26.37	-13.55
0.4000	1277	26.57	-15.54	1246	27.66	-13.88
0.4555	1265	28.47	-16.36	1234	29.84	-14.74
0.4999	1255	30.13	-17.19	1224	31.75	-15.61
0.5554	1243	31.08	-17.45	1213	31.67	-15.14
0.5999	1234	30.69	-16.94	1203	32.76	-15.60
0.6555	1222	30.47	-16.61	1192	31.42	-14.60
0.6999	1213	28.97	-15.54	1183	30.04	-13.75
0.7556	1201	27.22	-14.45	1171	28.52	-12.98
0.7999	1192	24.33	-12.75	1162	25.72	-11.56

0.8555	1181	19.31	-9.90	1151	20.79	-9.19
0.8999	1172	14.60	-7.38	1143	14.63	-6.21
0.9555	1161	6.85	-3.26	1132	6.89	-2.74
1	1152	0	0	1123	0	0
BA (1) + Decane-1-ol (2)						
0	1367	0	0	1335	0	0
0.0555	1357	1.57	-1.15	1324	2.56	-1.75
0.0998	1348	3.71	-2.76	1316	3.71	-2.42
0.1556	1338	5.07	-3.68	1306	5.01	-3.16
0.1998	1330	6.13	-4.38	1297	7.15	-4.57
0.2554	1319	8.34	-5.97	1287	8.30	-5.19
0.3000	1311	9.21	-6.50	1279	9.12	-5.61
0.3556	1301	10.17	-7.08	1269	10.04	-6.08
0.3998	1293	10.89	-7.50	1261	10.72	-6.41
0.4555	1283	11.57	-7.86	1251	11.36	-6.70
0.5000	1275	11.99	-8.06	1243	11.74	-6.85
0.5555	1266	11.25	-7.41	1233	12.09	-6.99
0.5999	1258	11.40	-7.44	1225	12.23	-7.01
0.6555	1248	11.41	-7.39	1215	12.20	-6.94
0.6999	1241	10.05	-6.39	1208	10.70	-5.95
0.7554	1231	9.60	-6.08	1198	10.21	-5.66
0.7999	1223	9.04	-5.71	1191	8.25	-4.46
0.8545	1214	7.07	-4.42	1181	7.51	-4.10
0.8999	1207	4.55	-2.79	1174	4.79	-2.54
0.9550	1197	3.20	-2.10	1164	3.37	-1.92
1	1190	0	0	1157	0	0
MMA (1) + Decane-1-ol (2)						
0	1367	0	0	1335	0	0
0.0554	1355	4.78	-3.69	1323	5.17	-3.51
0.0999	1346	7.96	-6.10	1314	8.58	-5.75
0.1553	1334	12.50	-9.51	1302	13.50	-8.98
0.1998	1325	15.34	-11.53	1293	16.59	-10.90
0.2556	1313	19.44	-14.46	1282	19.93	-12.88
0.2999	1304	21.92	-16.13	1273	22.65	-14.49
0.3554	1293	24.42	-17.73	1262	25.43	-16.05
0.4000	1284	26.33	-18.94	1253	27.58	-17.24
0.4555	1272	29.24	-20.83	1242	29.60	-18.27
0.4999	1264	29.37	-20.69	1233	31.10	-19.04
0.5554	1253	30.15	-21.00	1222	32.15	-19.47
0.5999	1244	30.58	-21.12	1214	31.49	-18.82
0.6555	1233	30.16	-20.61	1203	31.27	-18.50
0.6999	1224	29.50	-20.00	1195	29.45	-17.23
0.7556	1214	26.29	-17.62	1184	27.65	-16.04
0.7999	1205	24.25	-16.14	1176	24.36	-13.98
0.8555	1195	19.07	-12.55	1165	20.58	-11.74
0.8999	1187	13.94	-9.08	1157	15.45	-8.74
0.9555	1176	7.50	-4.89	1147	7.61	-4.28
1	1168	0	0	1139	0	0

Table 3. Excess Available Volume (V_a^E), Excess Intrinsic Pressure (\square_{int}^E) and Molar Sound Velocity (R) for Acrylates (1) + Decane-1-ol (2) at 303.15 and 313.15 K.

X_1	V_a^E	\square_{int}^E	R	V_a^E	\square_{int}^E	R
	($m^3 \cdot mol^{-1}$)	(atm)		($m^3 \cdot mol^{-1}$)	(atm)	
	303.15 K			313.15 K		
	MA (1) + Decane-1-ol (2)					
0	0	0	2.135	0	0	2.136
0.0552	0.778	-323.60	2.068	0.854	-267.38	2.069
0.0997	1.381	-383.30	2.015	1.423	-311.31	2.015
0.1555	1.996	-520.37	1.948	2.105	-421.61	1.947
0.1999	2.365	-553.49	1.895	2.652	-441.89	1.894
0.2554	2.832	-652.95	1.829	3.064	-525.82	1.827
0.3000	3.183	-661.24	1.776	3.369	-530.78	1.774
0.3555	3.395	-730.66	1.710	3.723	-589.60	1.708
0.3999	3.624	-715.60	1.657	3.805	-577.55	1.655
0.4538	3.719	-752.43	1.594	3.934	-611.10	1.592
0.4999	3.699	-728.27	1.540	3.951	-592.11	1.537
0.5554	3.622	-738.71	1.475	3.893	-605.95	1.472
0.5999	3.515	-685.64	1.423	3.812	-560.99	1.420

0.6550	3.301	-677.18	1.359	3.525	-561.47	1.356
0.6999	3.067	-608.34	1.307	3.308	-504.39	1.304
0.7555	2.693	-577.16	1.242	2.857	-487.76	1.240
0.7999	2.352	-488.97	1.191	2.525	-411.84	1.189
0.8555	1.765	-439.10	1.127	1.924	-378.20	1.126
0.8999	1.306	-332.87	1.076	1.399	-291.25	1.075
0.9555	0.638	-260.31	1.012	0.648	-239.74	1.012
1	0	0	0.962	0	0	0.962
EA (1) + Decane-1-ol (2)						
0	0	0	2.135	0	0	2.136
0.0554	0.719	-278.94	2.079	0.730	-226.08	2.079
0.0999	1.193	-338.20	2.034	1.212	-266.53	2.035
0.1553	1.782	-457.00	1.978	1.698	-361.08	1.979
0.1998	2.149	-489.97	1.933	2.076	-382.09	1.935
0.2556	2.492	-577.79	1.878	2.540	-450.86	1.879
0.2999	2.760	-587.84	1.834	2.710	-456.66	1.835
0.3554	3.079	-642.46	1.778	3.043	-502.40	1.780
0.4000	3.138	-633.25	1.734	3.112	-493.18	1.736
0.4555	3.228	-661.88	1.680	3.216	-518.81	1.682
0.4999	3.286	-632.58	1.636	3.285	-493.67	1.638
0.5554	3.245	-636.51	1.581	3.164	-502.65	1.584
0.5999	3.109	-591.96	1.538	3.132	-464.75	1.541
0.6555	2.941	-574.22	1.484	2.891	-456.81	1.487
0.6999	2.706	-513.19	1.441	2.670	-408.35	1.444
0.7556	2.411	-475.37	1.387	2.394	-384.74	1.391
0.7999	2.077	-400.20	1.345	2.075	-323.63	1.349
0.8555	1.580	-346.55	1.292	1.597	-284.81	1.296
0.8999	1.149	-257.54	1.249	1.107	-215.57	1.254
0.9555	0.524	-186.78	1.196	0.506	-163.98	1.202
1	0	0	1.154	0	0	1.160
BA (1) + Decane-1-ol (2)						
0	0	0	2.135	0	0	2.136
0.0555	0.312	-198.14	2.101	0.426	-152.98	2.101
0.0998	0.653	-262.09	2.073	0.646	-199.28	2.073
0.1556	0.897	-363.02	2.038	0.885	-275.16	2.039
0.1998	1.073	-404.78	2.011	1.172	-301.61	2.011
0.2554	1.370	-471.98	1.977	1.349	-354.98	1.977
0.3000	1.491	-492.57	1.949	1.465	-368.44	1.949
0.3556	1.611	-533.78	1.915	1.581	-401.33	1.915
0.3998	1.687	-534.65	1.888	1.652	-399.88	1.888
0.4555	1.744	-550.79	1.854	1.704	-414.68	1.854
0.5000	1.765	-534.71	1.827	1.720	-401.03	1.827
0.5555	1.658	-529.43	1.794	1.712	-399.30	1.793
0.5999	1.631	-497.15	1.766	1.680	-373.37	1.766
0.6555	1.566	-470.19	1.733	1.608	-355.90	1.732
0.6999	1.390	-424.18	1.706	1.425	-321.27	1.706
0.7554	1.263	-379.53	1.673	1.291	-289.71	1.672
0.7999	1.134	-320.24	1.646	1.061	-245.67	1.646
0.8545	0.869	-259.85	1.613	0.886	-201.44	1.613
0.8999	0.578	-189.79	1.586	0.589	-149.22	1.586
0.9550	0.340	-113.56	1.553	0.344	-93.50	1.553
1	0	0	1.526	0	0	1.526
MMA (1) + Decane-1-ol (2)						
0	0	0	2.135	0	0	2.136
0.0554	0.680	-269.37	2.077	0.693	-218.95	2.078
0.0999	1.104	-322.94	2.032	1.125	-255.18	2.033
0.1553	1.661	-435.84	1.975	1.694	-343.40	1.976
0.1998	1.984	-465.68	1.930	2.025	-362.23	1.930
0.2556	2.410	-548.73	1.873	2.354	-430.40	1.874
0.2999	2.638	-556.73	1.828	2.593	-433.41	1.829
0.3554	2.836	-612.78	1.772	2.804	-480.01	1.773
0.4000	2.963	-601.73	1.727	2.942	-469.63	1.728
0.4555	3.137	-630.65	1.670	3.032	-497.49	1.672
0.4999	3.072	-603.94	1.626	3.074	-472.23	1.627
0.5554	3.025	-610.69	1.570	3.041	-483.00	1.572
0.5999	2.958	-565.78	1.526	2.895	-447.72	1.528
0.6555	2.789	-553.00	1.471	2.743	-442.48	1.473

0.6999	2.622	-493.01	1.426	2.506	-394.69	1.429
0.7556	2.250	-462.66	1.372	2.235	-375.26	1.374
0.7999	1.985	-389.39	1.328	1.906	-316.49	1.331
0.8555	1.500	-341.70	1.273	1.517	-283.60	1.276
0.8999	1.064	-255.36	1.230	1.097	-213.88	1.233
0.9555	0.532	-164.66	1.175	0.514	-169.08	1.179
1	0	0	1.132	0	0	1.136

Table 4. Comparison of experimental ultrasonic velocity with various theories like NOMOTO, VAN, CFT and FLT with % errors for Acrylates (1) + Decane-1-ol (2) at 303.15 K.

X ₁	Ultrasonic Velocity					% Errors for Ultrasonic Velocity			
	Expt.	NOM	VAN	CFT	FLT	NOM	VAN	CFT	FLT
MA (1) + Decane-1-ol (2)									
0	1367	1367	1367	1367	1368	4.85	27.80	1.44	2.24
0.0552	1355	1361	1329	1358	1353				
0.0997	1345	1356	1303	1351	1343				
0.1555	1333	1350	1274	1342	1329				
0.1999	1324	1344	1254	1335	1318				
0.2554	1312	1337	1232	1325	1305				
0.3000	1302	1331	1217	1318	1295				
0.3555	1291	1323	1201	1308	1281				
0.3999	1281	1316	1189	1300	1271				
0.4538	1270	1307	1178	1290	1258				
0.4999	1261	1299	1169	1282	1248				
0.5554	1250	1288	1161	1271	1235				
0.5999	1241	1279	1156	1262	1224				
0.6550	1230	1267	1152	1250	1212				
0.6999	1221	1257	1149	1241	1201				
0.7555	1210	1243	1148	1228	1188				
0.7999	1201	1231	1148	1218	1177				
0.8555	1191	1214	1150	1204	1164				
0.8999	1182	1200	1153	1192	1153				
0.9555	1171	1180	1158	1176	1139				
1	1163	1163	1163	1163	1128				
EA (1) + Decane-1-ol (2)									
0	1367	1367	1367	1367	1368	3.17	13.49	0.70	0.48
0.0554	1354	1360	1336	1357	1355				
0.0999	1344	1353	1315	1348	1344				
0.1553	1331	1345	1290	1338	1330				
0.1998	1321	1339	1273	1329	1320				
0.2556	1309	1330	1253	1319	1306				
0.2999	1299	1323	1239	1310	1296				
0.3554	1286	1313	1224	1299	1283				
0.4000	1277	1305	1212	1290	1273				
0.4555	1265	1295	1200	1279	1260				
0.4999	1255	1286	1191	1269	1250				
0.5554	1243	1274	1182	1258	1237				
0.5999	1234	1265	1175	1248	1227				
0.6555	1222	1252	1168	1236	1214				
0.6999	1213	1241	1164	1226	1204				
0.7556	1201	1227	1159	1213	1191				
0.7999	1192	1215	1156	1203	1181				
0.8555	1181	1199	1153	1189	1169				
0.8999	1172	1185	1152	1178	1158				
0.9555	1161	1167	1152	1164	1146				
1	1152	1152	1152	1152	1134				
BA (1) + Decane-1-ol (2)									
0	1367	1367	1367	1367	1368	0.61	1.54	0.13	35.52
0.0555	1357	1359	1351	1358	1363				
0.0998	1348	1353	1339	1350	1360				
0.1556	1338	1345	1324	1341	1355				
0.1998	1330	1338	1314	1334	1352				
0.2554	1319	1329	1301	1324	1349				
0.3000	1311	1323	1291	1317	1346				
0.3556	1301	1314	1280	1307	1342				
0.3998	1293	1306	1271	1299	1340				
0.4555	1283	1297	1261	1290	1337				
0.5000	1275	1289	1253	1282	1334				

Fig 1. Variation of deviation in isentropic compressibility ($\Delta\kappa_s$) for Acrylates (1) + Decane-1-ol (2) at 303.15 K.

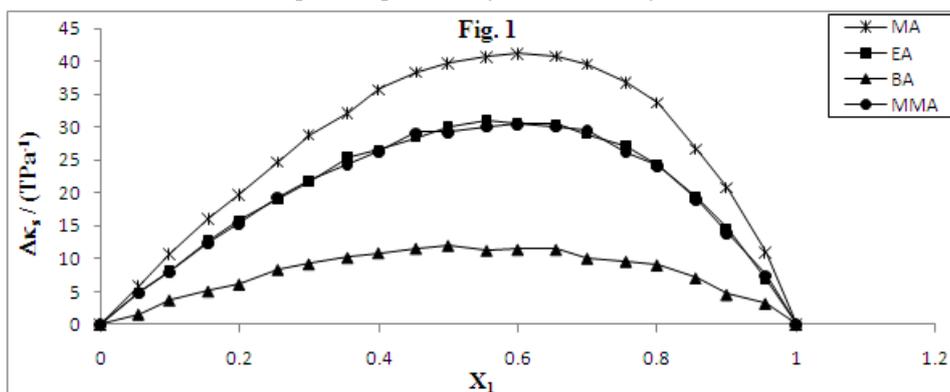


Fig. 2. Variation of excess specific acoustic impedance (Z^E) for Acrylates (1) + Decane-1-ol (2) at 303.15 K

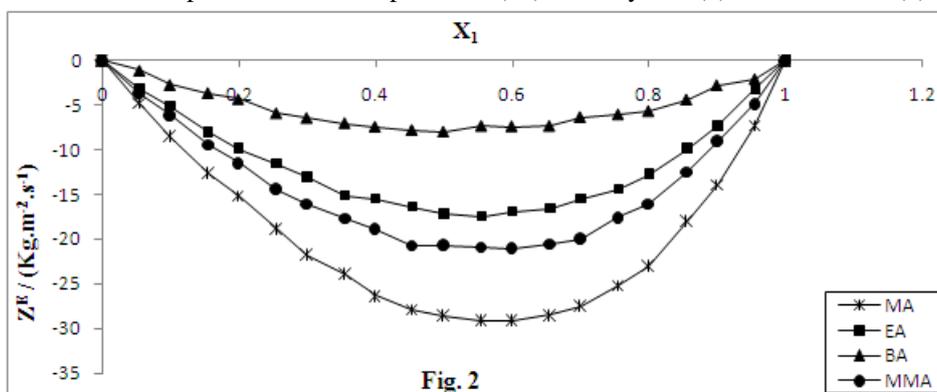


Fig. 3. Variation of excess available volume (V_a^E) for Acrylates (1) + Decane-1-ol (2) at 303.15 K

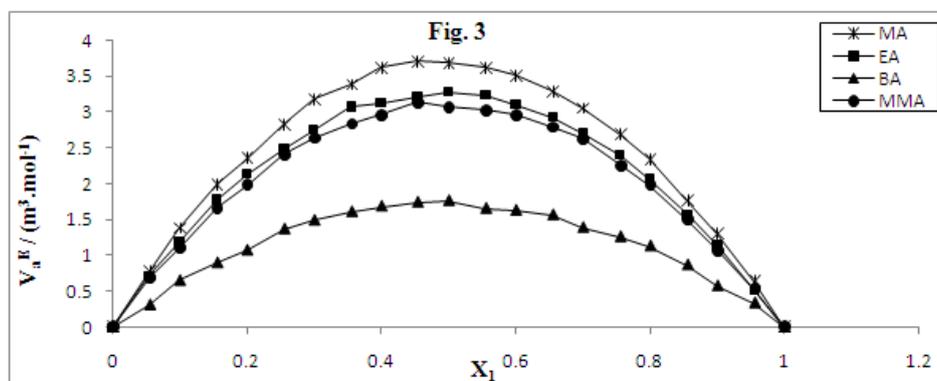
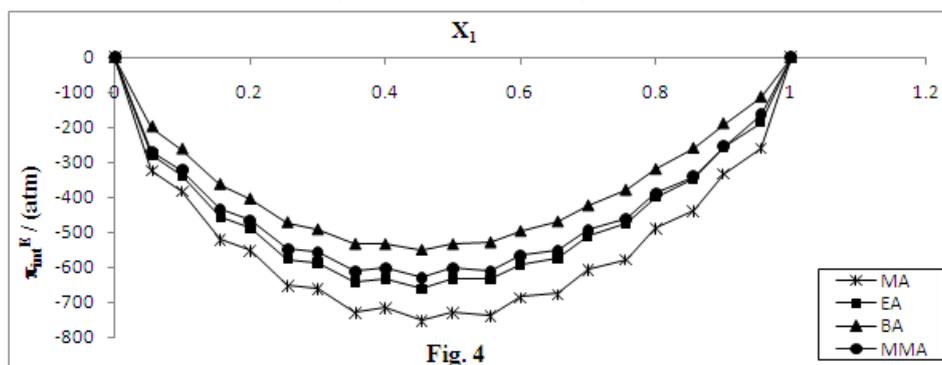


Fig. 4. Variation of excess intrinsic pressure (π_{int}^E) for Acrylates (1) + Decane-1-ol (2) at 303.15 K.



VI. Conclusion

Positive values of deviation in isentropic compressibility ($\Delta \kappa_s$) suggest a mixture is more compressible than corresponding ideal one. Excess specific acoustic impedance (Z^E) are more negative for mixtures containing alkanols due to more steric hindrance of alkanols towards hetero molecular interactions. Positive values of excess available volume (V_a^E) mean strong interactions. Less magnitude of excess intrinsic pressure (π_{int}^E) suggests that, weak type of intermolecular interactions are present with some dispersion due to dissociation of decane-1-ol aggregates with addition of solute (acrylates) in present binary liquid mixtures. The positive values of molar sound velocity (R) clearly indicate presence of specific interactions between acrylates and decane-1-ol.

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