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Theoretical Evaluation of Ultrasonic Velocities in Binary Liquid Mixtures of Anisic Aldehyde with Salicylates at Different Temperatures Using Different Theories

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Abstract: *Densities and Ultrasonic velocities of the binary liquid mixtures of Anisicaldehyde with Methyl Salicylate (MS) Ethyl Salicylate (ES) and Benzyl salicylate (BS) have been measured at a temperature range from 303.15 to 318.15 K with an interval of 5 K, over the entire composition of mole fractions. The theoretical values of ultrasonic velocity were evaluated using the Nomoto's relation (UNR), Impedance relation (UIR), Ideal mixing relation (UIMR), Rao's specific velocity relation (UR) Junjie's relation (UJR) and Danusso model (UD). The variation of this interaction parameter with the mole fraction of common compound has been discussed in terms of molecular interactions.*

1. INTRODUCTION

Thermodynamic and thermo physical properties coupled with thermo acoustical properties are the most crucial parameters which are absolutely essential to characterize the physicochemical behavior of a system leading to interpretation of the molecular interactions taking place thereof. Measurement of ultrasonic velocity [1-5] has been adequately employed in understanding the molecular interactions in pure, binary, and higher order multi component liquid mixtures. The propagation of ultrasonic velocity in a medium is a thermodynamic property and has come to be recognized as a very specific and unique tool for predicting and estimating various physico - chemical properties of the systems under consideration. A sound wave is a pressure wave and can be treated as a series of compressions and rarefactions travelling along a material so that the molecular planes are displaced from their mean positions. It is assumed that these compressions and rarefactions are reversible and adiabatic. Since ultrasonic velocity data proves to be a very simple and convenient tool to determine various thermodynamic properties of liquid and liquid mixtures, not obtained so easily through other parameters, significant amount of work has been done in carrying out investigation pertaining to various thermodynamic, physicochemical and liquid state properties by correlating them with ultrasonic velocity in conjunction with density. Scarcity of data on ternary and higher multi component liquid mixtures led us to the present investigation.

Using various theories [6-12] ultrasonic sound velocities in liquid mixtures have been calculated and compared with experimental values. Comparison of theoretical values of ultrasonic velocities with those obtained experimentally in the present binary liquid mixtures is expected to reveal the nature of interaction between component molecules in the mixture. Such theoretical study is

useful in finding the comprehensive theoretical model for the liquid mixtures. These ultrasonic sound velocities of liquid mixtures are valuable in testing various theories of liquid state.

2. THEORETICAL CONSIDERATIONS

Anisic aldehyde, methyl salicylate, ethyl salicylate and benzyl salicylate from Merk were purified as described in the literature [13, 14]. The pure chemicals were stored over activated 4Å molecular sieves to reduce water content before use.

The mixtures are prepared gravimetrically using an electronic balance (ShimadzuAY20) with an uncertainty of$\pm 1x10^{-7}$kg and stored in airtight bottles. The uncertainty on mole fraction is estimated to be $1x10^{-4}$.It is ensured that the mixtures are properly mixed and the measurement of the required parameters was done within one day of preparation. The densities, ρ, of pure liquids and their mixtures are determined using a 10^{-5} m3 double-arm pycnometer, and the values from triplicate replication at each temperature are reproducible within 2 x 10^{-1} kg m^3 and the uncertainty in the measurement of density is found to be 2 parts in 10^4 parts. The reproducibility in mole fractions was within ±0.0002 Temperature control for the measurement of viscosity and density is achieved by using a microprocessor assisted circulating water bath, (supplied by Mac, New Delhi) regulated to ±0.01 K, using a proportional temperature controller.

Adequate precautions were taken to minimize evaporation losses during the actual measurements. The ultrasonic velocity of sound (U) is measured using an ultrasonic interferometer (Mittal Enterprises, New Delhi model F05) operating at 2 MHz The measured speeds of sound have a precision of 0.8 m.sec-1 and an uncertainty less than ± 0.1 $m.sec^{-1}$. The temperature stability was maintained within±0.01K.by circulating water bath around the measuring cell through a pump.

2.1. Theoretical Consideration

1. Nomoto Equation

Rao's [15] found experimentally that, for pure liquids, the ratio of temperature coefficients of sound velocity U and molar volume V remains almost constant:

$$[(1/U)\,(dU/dT)] / [(1/V)\,(dV/dT)] = -3 \quad (8.1)$$

where T is the absolute temperature. Integrating this equation one obtains:

$$VU^{1/3} = \text{const} = M/\rho U^{1/3} = R \quad (8.2)$$

where M is molecular weight and ρ is density. The constant R is called the molar sound velocity or Rao's constant. It was found to be additive i.e it can be calculated as a sum of increments from the atoms or atom groups in the molecule and from the chemical bonds.

On assuming the additivity of molar sound velocity (R) and no volume change on mixing, Nomoto established the following relation [4] for a liquid mixture

$$R = M/\rho\, U^{1/3} \quad (8.3)$$

Where U and ρ are determined experimentally and M is the mean molecular weight in a binary liquid mixture

$$M = (X_1M_1 + X_2M_2) \quad (8.4)$$

where M_1 and M_2 are molecular weights of constituent components.

Simple manipulation yields the following relation[4]

$$U_{Nomoto} = [(X_1R_1+X_2R_2) / (X_1V_1+X_2V_2)]^3 \quad (8.5)$$

2. The Van Dael and Vangeel Equation

The ideal mixing theory advanced by Van Dael and Vangeel [5] in the light of assumptions made by Blandamer and Waddington[16], yield the following relation for adiabatic compressibility $(\beta_{ad})_{imx}$

$$(\beta_{ad})_{imx} = \phi_1\gamma_1/\gamma_{imx}\,(\beta_{ad})_1 + \phi_2\,\gamma_2/\gamma_{imx}\,(\beta_{ad})_2 \quad (8.6)$$

where ϕ_1, ϕ_2 are the volume fraction of species 1 and 2, γ_1 and γ_2 are ratios of specific heats of the respective species. This relation holds good if the mixture is ideal and if $\gamma_1 = \gamma_2 = \gamma_{imx}$. Using the additional assumption that $V_1 = V_2$ the above equation can be transformed in to a linear combination of mole fraction X_1 and X_2.

$$(\beta_{ad})_{imx} = X_1(\beta_{ad})_1 + X_2(\beta_{ad})_2 \quad (8.7)$$

On the basis of this equation, Van Dael obtained the relation for ultrasonic velocity in liquid mixtures as

$$1/(X_1M_1+X_2+M_2)*1/U^2_{imx} = X_1/M_1U_1^2 + X_2/M_2U_2^2 \quad (8.8)$$

where U_{imx} is the ideal mixing ultrasonic velocity in liquid mixture.U_1 and U_2 are ultrasonic velocity in species.

3. The Impedance Relation

Impedance relation [10] $U = \Sigma X_i Z_i / \Sigma X_i\rho_i$ (8.9)

where X_i mole fraction, $\rho_{\iota,}$ is the density of the mixture and Z_i is the acoustic impedance.

4. The Rao's Specific Velocity Method Relation

Rao's specific velocity method [11] $U = (\Sigma X_i r_i d)^3$ (8.10)

where X_i mole fraction, U_i is the ultrasonic velocity, ρ_ι is the density of the mixture, r_i is the Rao's specific sound velocity = $Ui^{1/3}/\rho_i$ and Z_i is the acoustic impedance.

5. The Jungie equation

Junjie equation [8]

$$U_J = (X_1M_1/\rho_1+X_2M_2/\rho_2)/[\{X_1M_1+X_2M_2\}^{1/2}\{X_1M_1/\rho_1U_1^2+X_2M_2/\rho_2U_2^2)\}^{1/2}] \quad (8.11)$$

where M_1, M_2 are molecular weights of constituent components. ρ_1 and ρ_2 are the densities of constituent components.

6. Danusso Model

Danusso model of velocity of ultrasonic waves is given by

$$U_D = (1/\rho_{mix})\,(1/M_{eff}\,(X_1M_1/\rho_1U_1^2+X_2M_2/\rho_2^2U_2^2))^{-1/2} \quad (8.12)$$

3. DISCUSSION

Anisic Aldehyde, also known as para methoxy benzaldehyde is slightly polar (CH=O group). Oxygen is more electronegative than carbon so it has a tendency to pull electrons in a carbon-oxygen bond towards itself. The salicylates are known to exist in self associated forms having intermolecular hydrogen bonding through carbonyl oxygen and OH group in ortho position.

Table 1, 3 and 5 represent the values of ultrasonic velocities calculated using different theories along with the experimental values for three studied systems. The percentage deviations and values of interaction parameter (α) are represented in tables 2, 4 and 6.

Figure 1, 2 and 3 represent the variation of U^2/U_{imx}^2 with the mole fraction of anisic aldehyde for all three binary systems studied, and the ratio of U^2/U_{imx}^2 gives an idea of extent of interaction taking place between molecules of the mixtures. It is positive for three systems and infers strong interactions between the components. The percentage of deviation in velocity is reflecting both negative and positive magnitudes, indicating non ideal behavior of liquid mixtures. The evaluated interaction parameters are positive for all the systems, indicating stronger interactions between the mixing molecules. There are higher variations in some intermediate concentration range suggesting the existence of strong tendency of association between component molecules as a result of hydrogen bonding [17]

Nomoto's theory proposes that the volume does not change upon mixing. Therefore, no interaction between the components of liquid mixtures has been taken into account. Similarly, the assumption for the formation of ideal mixing relation is that, the ratios of specific heats of ideal mixtures and the volumes are also equal. Again no molecular interactions are taken into account.

But upon mixing, interactions between the molecules occur because of the presence of various types of forces such as dispersion forces, charge transfer, hydrogen bonding dipole-dipole and dipole-induced dipole interactions. Thus, the observed deviation of theoretical values of velocity from the experimental values shows that the molecular interactions are taking place between the unlike molecules.

There is good agreement between experimental and theoretical values in Rao's relation followed by IR relation where as higher deviations are observed in Danusso relation at all the temperatures in AA + Methyl Salicylate system.

Tables 2 - 5 show the results of anisic aldehyde + ethyl salicylate and AA + Benzyl salicylate systems. In both the systems IR relation provides the best agreement followed by Nomoto theory. Higher deviations are observed in Rao's specific velocity method. The interaction parameter values are positive for all the systems under study and observed that values increase from methyl salicylate to benzyl salicylate. Similar results were reported by others in the case of alkyl acetates [18].

Table1. *Experimental velocities (U/m.sec^{-1}), theoretical velocities ((Ux/m.sec^{-1}) for the system anisic aldehyde (AA) +methyl salicylate (MS)*

X_1	U_{exp} ms^{-1}	U_{NR} ms^{-1}	U_{imx} ms^{-1}	U_{IR} ms^{-1}	U_R ms^{-1}	U_J ms^{-1}	U_D ms^{-1}
303.15K							
0.0000	1389.50	1389.50	1389.50	1389.50	1389.50	1389.50	1389.50
0.1059	1411.60	1404.42	1404.33	1405.12	1411.97	1403.44	1402.02
0.2104	1430.20	1419.44	1419.28	1420.69	1433.51	1417.55	1414.94
0.3135	1447.70	1434.57	1434.36	1436.21	1453.72	1432.00	1428.40
0.4153	1463.90	1449.81	1449.56	1451.69	1472.57	1446.79	1442.42
0.5159	1480.00	1465.15	1464.89	1467.11	1489.61	1461.93	1457.16
0.6152	1493.70	1480.61	1480.35	1482.48	1503.22	1477.44	1473.15
0.7132	1507.50	1496.17	1495.94	1497.81	1514.87	1493.34	1489.94
0.8100	1520.90	1511.84	1511.66	1513.09	1525.31	1509.64	1507.30
0.9056	1533.00	1527.61	1527.51	1528.32	1535.01	1526.35	1525.09
1.0000	1543.50	1543.50	1543.50	1543.50	1543.50	1543.50	1543.50
308.15K							
0.0000	1374.40	1374.40	1374.40	1374.40	1374.40	1374.40	1374.40
0.1059	1395.50	1388.24	1388.21	1388.87	1396.95	1387.29	1385.57
0.2104	1413.10	1402.17	1402.11	1403.28	1417.92	1400.46	1397.32
0.3135	1429.70	1416.20	1416.11	1417.66	1437.59	1413.91	1409.57
0.4153	1445.50	1430.32	1430.21	1431.98	1456.31	1427.66	1422.21
0.5159	1459.60	1444.53	1444.42	1446.27	1472.52	1441.72	1435.74
0.6152	1471.90	1458.83	1458.72	1460.50	1484.55	1456.09	1450.72
0.7132	1484.90	1473.23	1473.13	1474.69	1494.24	1470.79	1466.57
0.8100	1496.90	1487.73	1487.65	1488.84	1503.16	1485.83	1482.80
0.9056	1508.30	1502.32	1502.27	1502.94	1510.88	1501.23	1499.56
1.0000	1517.00	1517.00	1517.00	1517.00	1517.00	1517.00	1517.00
313.15K							
0.0000	1358.00	1358.00	1358.00	1358.00	1358.00	1358.00	1358.00
0.1059	1380.30	1372.74	1372.57	1373.27	1385.29	1371.68	1368.80
0.2104	1398.90	1387.57	1387.27	1388.52	1408.12	1385.66	1381.14
0.3135	1416.40	1402.49	1402.09	1403.73	1428.87	1399.93	1394.22
0.4153	1432.90	1417.50	1417.03	1418.91	1447.42	1414.53	1408.09
0.5159	1448.40	1432.60	1432.10	1434.07	1464.09	1429.45	1422.64
0.6152	1461.40	1447.78	1447.30	1449.19	1477.25	1444.71	1438.41
0.7132	1475.00	1463.05	1462.62	1464.29	1488.56	1460.32	1454.89
0.8100	1488.00	1478.41	1478.08	1479.35	1498.79	1476.29	1471.84
0.9056	1500.00	1493.86	1493.67	1494.39	1506.59	1492.65	1489.71
1.0000	1509.40	1509.40	1509.40	1509.40	1509.40	1509.40	1509.40
318.15K							
0.0000	1343.40	1343.40	1343.40	1343.40	1343.40	1343.40	1343.40
0.1059	1366.70	1357.92	1357.71	1358.37	1371.63	1356.91	1353.68
0.2104	1385.50	1372.52	1372.14	1373.29	1395.07	1370.69	1365.59
0.3135	1403.10	1387.19	1386.69	1388.19	1415.28	1384.75	1378.57
0.4153	1419.80	1401.94	1401.36	1403.07	1434.74	1399.11	1391.83
0.5159	1435.10	1416.76	1416.16	1417.94	1451.93	1413.77	1405.87
0.6152	1447.50	1431.66	1431.07	1432.79	1464.80	1428.74	1421.35
0.7132	1460.20	1446.63	1446.11	1447.62	1475.57	1444.04	1437.57
0.8100	1472.40	1461.68	1461.28	1462.43	1485.79	1459.67	1454.05
0.9056	1484.10	1476.80	1476.57	1477.22	1491.84	1475.66	1471.99
1.0000	1492.00	1492.00	1492.00	1492.00	1492.00	1492.00	1492.00

Table2. *Percentage deviations and interaction parameters (α) for the system anisic aldehyde (AA)+methyl salicylate (MA).*

X_1	% U_{No}	% U_{imx}	% U_{IR}	% U_{Rao}	% U_J	% U_D	U^2/U_{imx}^2	A
303.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1059	-0.5088	-0.5149	-0.4590	0.0260	-0.5782	-0.6788	1.0104	0.0104
0.2104	-0.7523	-0.7632	-0.6648	0.2311	-0.8842	-1.0671	1.0154	0.0154
0.3135	-0.9069	-0.9213	-0.7935	0.4159	-1.0844	-1.3332	1.0187	0.0187
0.4153	-0.9626	-0.9793	-0.8344	0.5920	-1.1689	-1.4671	1.0199	0.0199
0.5159	-1.0032	-1.0207	-0.8710	0.6494	-1.2209	-1.5432	1.0207	0.0207
0.6152	-0.8766	-0.8937	-0.7509	0.6375	-1.0883	-1.3755	1.0181	0.0181
0.7132	-0.7518	-0.7669	-0.6427	0.4889	-0.9393	-1.1648	1.0155	0.0155
0.8100	-0.5960	-0.6076	-0.5136	0.2897	-0.7406	-0.8943	1.0123	0.0123
0.9056	-0.3513	-0.3580	-0.3053	0.1313	-0.4337	-0.5161	1.0072	0.0072
1.0000	0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	1.0000	0.0000
308.15K								
0.0000	0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	1.0000	0.0000
0.1059	-0.5202	-0.5227	-0.4753	0.1042	-0.5881	-0.7119	1.0105	0.0105
0.2104	-0.7732	-0.7778	-0.6946	0.3408	-0.8944	-1.1165	1.0157	0.0157
0.3135	-0.9443	-0.9505	-0.8423	0.5519	-1.1042	-1.4079	1.0193	0.0193
0.4153	-1.0504	-1.0575	-0.9351	0.7480	-1.2340	-1.6115	1.0215	0.0215
0.5159	-1.0325	-1.0402	-0.9136	0.8849	-1.2252	-1.6346	1.0211	0.0211
0.6152	-0.8876	-0.8951	-0.7744	0.8592	-1.0742	-1.4386	1.0181	0.0181
0.7132	-0.7856	-0.7923	-0.6873	0.6293	-0.9502	-1.2342	1.0160	0.0160
0.8100	-0.6127	-0.6179	-0.5384	0.4179	-0.7392	-0.9418	1.0125	0.0125
0.9056	-0.3966	-0.3997	-0.3551	0.1711	-0.4686	-0.5796	1.0080	0.0080
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
313.15K								
0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1059	-0.5476	-0.5598	-0.5092	0.3612	-0.6245	-0.8330	1.0113	0.0113
0.2104	-0.8097	-0.8315	-0.7423	0.6594	-0.9468	-1.2697	1.0168	0.0168
0.3135	-0.9819	-1.0105	-0.8945	0.8803	-1.1625	-1.5657	1.0205	0.0205
0.4153	-1.0748	-1.1075	-0.9760	1.0137	-1.2822	-1.7316	1.0225	0.0225
0.5159	-1.0911	-1.1254	-0.9894	1.0834	-1.3085	-1.7785	1.0229	0.0229
0.6152	-0.9320	-0.9650	-0.8352	1.0847	-1.1423	-1.5728	1.0196	0.0196
0.7132	-0.8100	-0.8391	-0.7262	0.9194	-0.9954	-1.3634	1.0170	0.0170
0.8100	-0.6442	-0.6665	-0.5810	0.7250	-0.7867	-1.0862	1.0135	0.0135
0.9056	-0.4091	-0.4217	-0.3740	0.4392	-0.4900	-0.6857	1.0085	0.0085
1.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
318.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1059	-0.6422	-0.6575	-0.6098	0.3609	-0.7166	-0.9524	1.0133	0.0133
0.2104	-0.9369	-0.9640	-0.8816	0.6904	-1.0691	-1.4373	1.0196	0.0196
0.3135	-1.1338	-1.1693	-1.0628	0.8679	-1.3077	-1.7482	1.0238	0.0238
0.4153	-1.2580	-1.2985	-1.1781	1.0525	-1.4574	-1.9699	1.0265	0.0265
0.5159	-1.2778	-1.3200	-1.1958	1.1724	-1.4865	-2.0367	1.0269	0.0269
0.6152	-1.0943	-1.1349	-1.0165	1.1950	-1.2960	-1.8065	1.0231	0.0231
0.7132	-0.9291	-0.9648	-0.8618	1.0525	-1.1068	-1.5496	1.0196	0.0196
0.8100	-0.7280	-0.7553	-0.6773	0.9093	-0.8644	-1.2462	1.0153	0.0153
0.9056	-0.4917	-0.5071	-0.4635	0.5218	-0.5690	-0.8162	1.0102	0.0102
1.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

Table3. *Experimental velocities (U/m.sec^{-1}), theoretical velocities ((Ux/m.sec^{-1}) for the system anisic aldehyde (AA) +ethyl salicylate (ES).*

X_1	U_{exp} ms^{-1}	U_{NR} ms^{-1}	U_{imx} ms^{-1}	U_{IR} ms^{-1}	U_R ms^{-1}	U_J ms^{-1}	U_D ms^{-1}
303.15K							
0.0000	1355.50	1355.50	1355.50	1355.50	1355.50	1355.50	1355.50
0.1196	1381.31	1372.41	1287.54	1375.80	1675.69	1370.22	1369.10
0.2341	1404.05	1387.63	1237.53	1393.42	1983.95	1383.78	1381.75
0.3439	1425.40	1401.79	1203.15	1409.31	2260.04	1396.69	1393.50
0.4491	1445.47	1415.46	1182.87	1424.21	2480.99	1409.40	1405.41
0.5501	1465.25	1429.23	1177.25	1438.79	2621.45	1422.50	1417.99
0.6472	1482.50	1443.78	1187.42	1453.74	2659.12	1436.64	1432.45
0.7405	1499.52	1460.08	1217.28	1469.91	2576.19	1452.89	1449.43
0.8303	1515.92	1479.67	1273.97	1488.55	2361.15	1473.00	1470.55
0.9167	1530.66	1505.41	1372.09	1511.72	2012.21	1500.47	1499.11
1.0000	1543.50	1543.50	1543.50	1543.50	1543.50	1543.50	1543.50
308.15K							

0.0000	1338.60	1338.60	1338.60	1338.60	1338.60	1338.60	1338.60
0.1196	1363.50	1354.71	1270.84	1357.78	1655.65	1352.74	1351.26
0.2341	1385.25	1369.20	1220.94	1374.45	1960.77	1365.75	1363.09
0.3439	1405.70	1382.69	1186.55	1389.49	2232.45	1378.10	1374.40
0.4491	1425.60	1395.68	1166.11	1403.61	2450.83	1390.25	1385.57
0.5501	1443.70	1408.77	1160.15	1417.44	2588.77	1402.73	1397.53
0.6472	1460.00	1422.58	1169.73	1431.63	2623.65	1416.19	1411.55
0.7405	1476.26	1438.05	1198.65	1446.99	2538.93	1431.62	1428.03
0.8303	1491.37	1456.62	1253.89	1464.70	2325.40	1450.67	1448.15
0.9167	1505.70	1480.99	1349.65	1486.74	1980.03	1476.60	1475.22
1.0000	1517.00	1517.00	1517.00	1517.00	1517.00	1517.00	1517.00
313.15K							
0.0000	1324.00	1324.00	1324.00	1324.00	1324.01	1324.00	1324.00
0.1196	1350.12	1340.72	1257.78	1343.97	1640.62	1338.58	1336.60
0.2341	1372.47	1355.75	1209.05	1361.32	1946.94	1352.00	1348.20
0.3439	1393.85	1369.75	1175.58	1376.96	2218.36	1364.77	1359.82
0.4491	1414.10	1383.24	1155.87	1391.64	2434.41	1377.34	1371.81
0.5501	1433.32	1396.84	1150.49	1406.01	2572.37	1390.27	1384.26
0.6472	1449.95	1411.19	1160.53	1420.75	2607.94	1404.23	1398.82
0.7405	1467.00	1427.26	1189.83	1436.70	2526.95	1420.26	1415.51
0.8303	1482.79	1446.57	1245.39	1455.09	2316.40	1440.08	1436.24
0.9167	1497.50	1471.92	1341.50	1477.98	1973.32	1467.12	1464.49
1.0000	1509.40	1509.40	1509.40	1509.40	1509.40	1509.40	1509.40
318.15K							
0.0000	1306.80	1306.80	1306.80	1306.80	1306.80	1306.80	1306.80
0.1196	1332.95	1323.56	1241.63	1327.40	1622.49	1321.45	1318.84
0.2341	1355.30	1338.62	1193.70	1345.18	1924.85	1334.93	1330.80
0.3439	1376.70	1352.63	1160.79	1361.07	2192.23	1347.73	1342.79
0.4491	1397.00	1366.13	1141.46	1375.83	2408.18	1360.33	1354.45
0.5501	1416.40	1379.73	1136.27	1390.17	2545.12	1373.28	1366.91
0.6472	1433.00	1394.07	1146.33	1404.78	2580.31	1387.24	1381.52
0.7405	1449.60	1410.13	1175.41	1420.52	2499.08	1403.26	1398.43
0.8303	1465.60	1429.40	1230.49	1438.60	2292.10	1423.04	1418.87
0.9167	1480.50	1454.67	1325.69	1461.09	1950.69	1449.98	1447.46
1.0000	1492.00	1492.00	1492.00	1492.00	1492.00	1492.00	1492.00

Table4. *Percentage deviations and interaction parameters (α) for the system anisic aldehyde (AA)+ethyl salicylate (ES).*

X_1	% U_{No}	% U_{imx}	% U_{IR}	% U_{Rao}	% U_J	% U_D	U^2/U_{imx}^2	A
303.15K								
0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6444	-6.7884	-0.3987	21.3115	-0.8031	-0.8838	1.1510	0.1510
0.2341	-1.1697	-11.8600	-0.7569	41.3022	-1.4437	-1.5884	1.2872	0.2872
0.3439	-1.6561	-15.5921	-1.1285	58.5548	-2.0145	-2.2377	1.4036	0.4036
0.4491	-2.0761	-18.1669	-1.4709	71.6390	-2.4951	-2.7715	1.4933	0.4933
0.5501	-2.4581	-19.6550	-1.8055	78.9079	-2.9178	-3.2255	1.5491	0.5491
0.6472	-2.6118	-19.9040	-1.9399	79.3672	-3.0935	-3.3757	1.5588	0.5588
0.7405	-2.6301	-18.8223	-1.9743	71.8009	-3.1098	-3.3406	1.5175	0.5175
0.8303	-2.3911	-15.9603	-1.8057	55.7571	-2.8310	-2.9931	1.4159	0.4159
0.9167	-1.6497	-10.3599	-1.2373	31.4601	-1.9723	-2.0613	1.2445	0.2445
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
308.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6445	-6.7957	-0.4193	21.4264	-0.7891	-0.8974	1.1511	0.1511
0.2341	-1.1583	-11.8615	-0.7798	41.5461	-1.4080	-1.5998	1.2873	0.2873
0.3439	-1.6372	-15.5903	-1.1530	58.8138	-1.9637	-2.2268	1.4035	0.4035
0.4491	-2.0986	-18.2020	-1.5427	71.9156	-2.4799	-2.8080	1.4946	0.4946
0.5501	-2.4196	-19.6406	-1.8189	79.3152	-2.8377	-3.1979	1.5486	0.5486
0.6472	-2.5629	-19.8814	-1.9434	79.7020	-3.0006	-3.3186	1.5579	0.5579
0.7405	-2.5884	-18.8050	-1.9827	71.9843	-3.0238	-3.2672	1.5168	0.5168
0.8303	-2.3301	-15.9238	-1.7883	55.9237	-2.7288	-2.8982	1.4147	0.4147
0.9167	-1.6412	-10.3641	-1.2590	31.5023	-1.9328	-2.0243	1.2446	0.2446
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
313.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6966	-6.8397	-0.4553	21.5167	-0.8550	-1.0013	1.1522	0.1522
0.2341	-1.2179	-11.9068	-0.8128	41.8565	-1.4914	-1.7684	1.2886	0.2886
0.3439	-1.7292	-15.6596	-1.2115	59.1531	-2.0866	-2.4414	1.4058	0.4058
0.4491	-2.1821	-18.2610	-1.5885	72.1526	-2.5997	-2.9907	1.4967	0.4967
0.5501	-2.5454	-19.7328	-1.9052	79.4690	-3.0035	-3.4227	1.5521	0.5521
0.6472	-2.6734	-19.9607	-2.0140	79.8644	-3.1531	-3.5265	1.5610	0.5610
0.7405	-2.7088	-18.8939	-2.0653	72.2527	-3.1862	-3.5099	1.5202	0.5202
0.8303	-2.4424	-16.0100	-1.8676	56.2197	-2.8799	-3.1393	1.4176	0.4176
0.9167	-1.7084	-10.4175	-1.3035	31.7743	-2.0288	-2.2040	1.2461	0.2461
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
318.15K								

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.7048	-6.8508	-0.4162	21.7220	-0.8627	-1.0584	1.1525	0.1525
0.2341	-1.2306	-11.9238	-0.7469	42.0242	-1.5032	-1.8077	1.2891	0.2891
0.3439	-1.7483	-15.6830	-1.1356	59.2383	-2.1042	-2.4634	1.4066	0.4066
0.4491	-2.2094	-18.2918	-1.5155	72.3819	-2.6249	-3.0460	1.4978	0.4978
0.5501	-2.5891	-19.7773	-1.8516	79.6892	-3.0444	-3.4942	1.5538	0.5538
0.6472	-2.7166	-20.0050	-1.9693	80.0638	-3.1931	-3.5927	1.5627	0.5627
0.7405	-2.7230	-18.9145	-2.0063	72.3978	-3.1969	-3.5298	1.5209	0.5209
0.8303	-2.4701	-16.0421	-1.8421	56.3932	-2.9039	-3.1884	1.4187	0.4187
0.9167	-1.7446	-10.4566	-1.3108	31.7589	-2.0617	-2.2314	1.2472	0.2472
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

Table5. *Experimental velocities (U/m.sec^{-1}) theoretical velocities ((Ux/m.sec^{-1}) for the system anisic aldehyde (AA) +benzyl salicylate (BS).*

X1	U_{exp} ms^{-1}	U_{NR} ms^{-1}	U_{imx} ms^{-1}	U_{IR} ms^{-1}	U_R ms^{-1}	U_J ms^{-1}	U_D ms^{-1}
303.15K							
0.0000	1498.60	1498.60	1498.60	1498.60	1498.59	1498.60	1498.60
0.1587	1563.04	1503.01	1471.33	1505.75	1541.72	1502.82	1501.06
0.2980	1619.98	1507.39	1458.50	1511.94	1568.94	1507.05	1503.85
0.4211	1669.22	1511.75	1453.86	1517.38	1589.10	1511.29	1506.89
0.5309	1706.94	1516.14	1457.21	1522.25	1596.58	1515.61	1510.17
0.6293	1723.67	1520.54	1464.71	1526.62	1599.76	1519.98	1513.80
0.7180	1721.92	1524.99	1475.67	1530.58	1596.16	1524.45	1518.55
0.7984	1693.35	1529.51	1489.86	1534.22	1586.34	1529.02	1524.06
0.8716	1653.11	1534.09	1505.88	1537.55	1575.14	1533.71	1529.89
0.9386	1603.19	1538.97	1529.75	1540.78	1545.77	1538.76	1536.33
1.0000	1543.50	1543.50	1543.50	1543.50	1543.48	1543.50	1543.50
308.15K							
0.0000	1485.90	1485.90	1485.90	1485.90	1485.91	1485.90	1485.90
0.1587	1571.92	1489.00	1466.71	1490.88	1494.30	1488.90	1486.85
0.2980	1639.67	1492.10	1457.56	1495.23	1502.36	1491.92	1487.97
0.4211	1693.79	1495.20	1455.12	1499.07	1509.77	1494.97	1489.38
0.5309	1729.24	1498.31	1457.33	1502.49	1516.18	1498.04	1491.23
0.6293	1739.04	1501.42	1462.87	1505.55	1521.74	1501.13	1493.45
0.7180	1729.62	1504.53	1470.85	1508.29	1524.65	1504.25	1496.64
0.7984	1700.08	1507.64	1480.65	1510.78	1526.03	1507.40	1500.45
0.8716	1663.70	1510.76	1491.81	1513.04	1525.34	1510.57	1505.06
0.9386	1602.77	1513.88	1504.01	1515.11	1522.69	1513.77	1510.68
1.0000	1517.00	1517.00	1517.00	1517.00	1517.01	1517.00	1517.00
313.15K							
0.0000	1471.80	1471.80	1471.80	1471.80	1471.81	1471.80	1471.80
0.1587	1572.06	1475.55	1454.31	1477.80	1484.29	1475.43	1472.66
0.2980	1652.92	1479.31	1446.37	1483.05	1494.83	1479.09	1474.10
0.4211	1714.93	1483.06	1444.81	1487.69	1503.63	1482.77	1476.08
0.5309	1754.58	1486.82	1447.70	1491.82	1511.50	1486.49	1478.38
0.6293	1766.85	1490.58	1453.78	1495.52	1517.76	1490.23	1481.23
0.7180	1748.42	1494.34	1462.18	1498.84	1520.87	1494.00	1485.13
0.7984	1716.44	1498.10	1472.32	1501.86	1522.45	1497.81	1489.60
0.8716	1676.86	1501.87	1483.77	1504.60	1522.04	1501.64	1494.79
0.9386	1613.72	1505.63	1496.21	1507.10	1519.44	1505.51	1501.04
1.0000	1509.40	1509.40	1509.40	1509.40	1509.42	1509.40	1509.40
318.15K							
0.0000	1457.00	1457.00	1457.00	1457.00	1456.98	1457.00	1457.00
0.1587	1571.25	1460.50	1439.19	1462.58	1471.05	1460.40	1457.19
0.2980	1658.67	1464.00	1430.96	1467.46	1482.53	1463.82	1458.13
0.4211	1720.89	1467.50	1429.14	1471.78	1491.91	1467.27	1459.68
0.5309	1755.01	1471.01	1431.77	1475.62	1499.27	1470.74	1461.86
0.6293	1765.99	1474.51	1437.59	1479.06	1505.11	1474.22	1464.51
0.7180	1747.48	1478.01	1445.75	1482.16	1508.42	1477.73	1467.98
0.7984	1714.79	1481.50	1455.65	1484.97	1509.81	1481.27	1472.10
0.8716	1673.04	1485.00	1466.85	1487.52	1508.76	1484.82	1477.04
0.9386	1605.08	1488.50	1479.05	1489.86	1504.31	1488.40	1483.38
1.0000	1492.00	1492.00	1492.00	1492.00	1492.01	1492.00	1492.00

Table6. *Percentage deviations and interaction parameters (α) for the system anisic aldehyde (AA)+benzy salicylate (BS).*

X_1	% U_{No}	% U_{imx}	% U_{IR}	% U_{Rao}	% U_J	% U_D	U^2/U_{imx}^2	A
303.15K								
0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6444	-6.7884	-0.3987	21.3115	-0.8031	-0.8838	1.1510	0.1286
0.2341	-1.1697	-11.8600	-0.7569	41.3022	-1.4437	-1.5884	1.2872	0.2337
0.3439	-1.6561	-15.5921	-1.1285	58.5548	-2.0145	-2.2377	1.4036	0.3182
0.4491	-2.0761	-18.1669	-1.4709	71.6390	-2.4951	-2.7715	1.4933	0.3721
0.5501	-2.4581	-19.6550	-1.8055	78.9079	-2.9178	-3.2255	1.5491	0.3849
0.6472	-2.6118	-19.9040	-1.9399	79.3672	-3.0935	-3.3757	1.5588	0.3616
0.7405	-2.6301	-18.8223	-1.9743	71.8009	-3.1098	-3.3406	1.5175	0.2918
0.8303	-2.3911	-15.9603	-1.8057	55.7571	-2.8310	-2.9931	1.4159	0.2051
0.9167	-1.6497	-10.3599	-1.2373	31.4601	-1.9723	-2.0613	1.2445	0.0983
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
308.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6445	-6.7957	-0.4193	21.4264	-0.7891	-0.8974	1.1511	0.1486
0.2341	-1.1583	-11.8615	-0.7798	41.5461	-1.4080	-1.5998	1.2873	0.2655
0.3439	-1.6372	-15.5903	-1.1530	58.8138	-1.9637	-2.2268	1.4035	0.3550
0.4491	-2.0986	-18.2020	-1.5427	71.9156	-2.4799	-2.8080	1.4946	0.4080
0.5501	-2.4196	-19.6406	-1.8189	79.3152	-2.8377	-3.1979	1.5486	0.4132
0.6472	-2.5629	-19.8814	-1.9434	79.7020	-3.0006	-3.3186	1.5579	0.3828
0.7405	-2.5884	-18.8050	-1.9827	71.9843	-3.0238	-3.2672	1.5168	0.3184
0.8303	-2.3301	-15.9238	-1.7883	55.9237	-2.7288	-2.8982	1.4147	0.2437
0.9167	-1.6412	-10.3641	-1.2590	31.5023	-1.9328	-2.0243	1.2446	0.1356
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
313.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.6966	-6.8397	-0.4553	21.5167	-0.8550	-1.0013	1.1522	0.1685
0.2341	-1.2179	-11.9068	-0.8128	41.8565	-1.4914	-1.7684	1.2886	0.3060
0.3439	-1.7292	-15.6596	-1.2115	59.1531	-2.0866	-2.4414	1.4058	0.4089
0.4491	-2.1821	-18.2610	-1.5885	72.1526	-2.5997	-2.9907	1.4967	0.4689
0.5501	-2.5454	-19.7328	-1.9052	79.4690	-3.0035	-3.4227	1.5521	0.4771
0.6472	-2.6734	-19.9607	-2.0140	79.8644	-3.1531	-3.5265	1.5610	0.4298
0.7405	-2.7088	-18.8939	-2.0653	72.2527	-3.1862	-3.5099	1.5202	0.3591
0.8303	-2.4424	-16.0100	-1.8676	56.2197	-2.8799	-3.1393	1.4176	0.2772
0.9167	-1.7084	-10.4175	-1.3035	31.7743	-2.0288	-2.2040	1.2461	0.1633
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
318.15K								
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
0.1196	-0.7048	-6.8508	-0.4162	21.7220	-0.8627	-1.0584	1.1525	0.1919
0.2341	-1.2306	-11.9238	-0.7469	42.0242	-1.5032	-1.8077	1.2891	0.3436
0.3439	-1.7483	-15.6830	-1.1356	59.2383	-2.1042	-2.4634	1.4066	0.4500
0.4491	-2.2094	-18.2918	-1.5155	72.3819	-2.6249	-3.0460	1.4978	0.5025
0.5501	-2.5891	-19.7773	-1.8516	79.6892	-3.0444	-3.4942	1.5538	0.5090
0.6472	-2.7166	-20.0050	-1.9693	80.0638	-3.1931	-3.5927	1.5627	0.4610
0.7405	-2.7230	-18.9145	-2.0063	72.3978	-3.1969	-3.5298	1.5209	0.3877
0.8303	-2.4701	-16.0421	-1.8421	56.3932	-2.9039	-3.1884	1.4187	0.3009
0.9167	-1.7446	-10.4566	-1.3108	31.7589	-2.0617	-2.2314	1.2472	0.1777
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

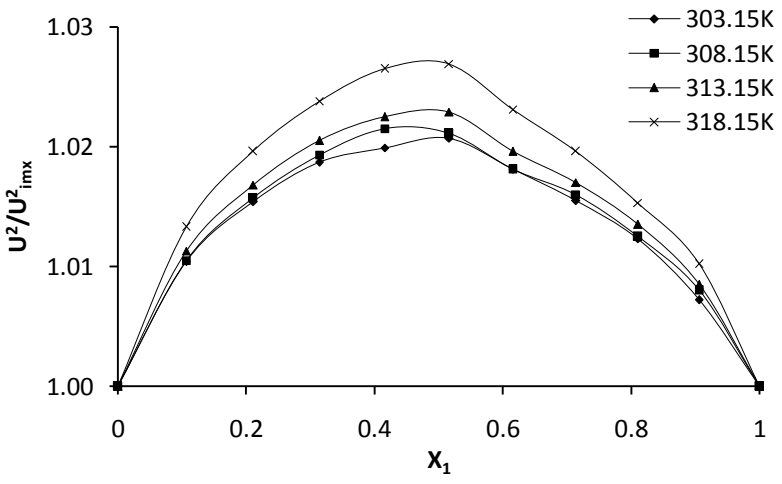

Fig1. *Variation of U^2/U^2_{imx} with the mole fraction of AA for the system AA+MS*

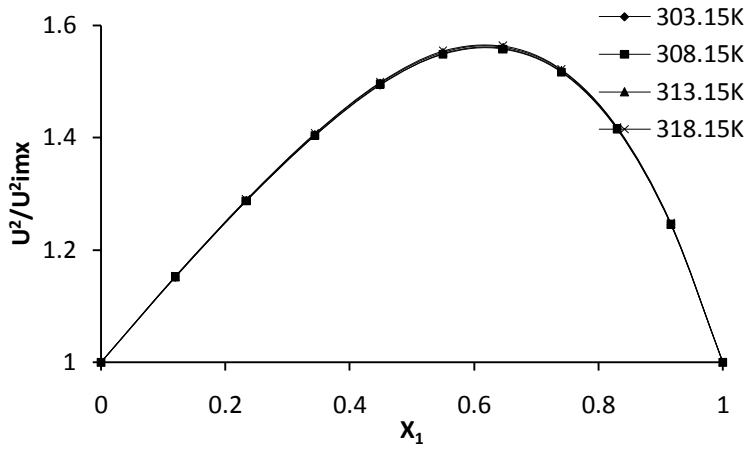

Fig2. *Variation U^2/U^2_{imx} with the mole fraction of AA for the system AA+ ES*

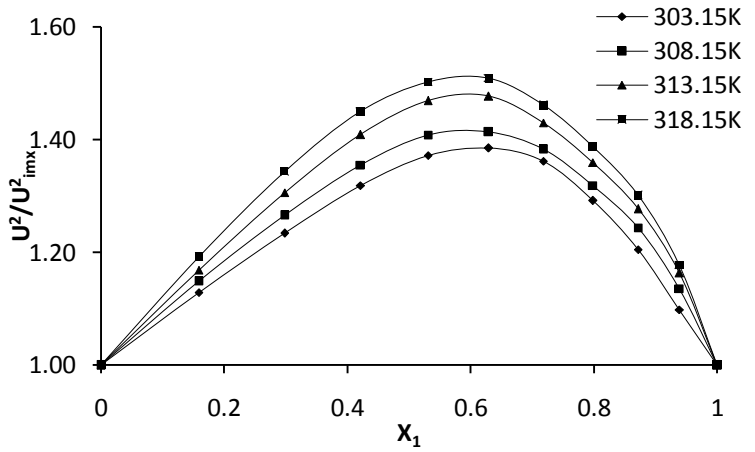

Fig3. *Variation of U^2/U^2_{imx} with the mole fraction of AA for the system AA+ BS*

4. CONCLUSIONS

From the values of experimental and evaluated velocity values, it may be concluded that, the Nomoto's relation, IR relation and Impedance relation of ultrasound velocity have provided good results. Thus, the linearity of molar sound velocity and additivity of molar volumes, as suggested by Nomoto, Rao's and Impedance relation in deriving the empirical relations have been truly observed in the aforementioned binary liquid mixtures.

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