Available online at **www.joac.info**

ISSN: 2278-1862

Journal of Applicable Chemistry

2019, 8 (3): 1417-1425

(International Peer Reviewed Journal)

Correlation between Experimental and Theoretical Ultrasonic Velocities in Binary Mixtures of Furfuryl Alcohol with Glycols at 303.15 K

M. Silpa[1], K.A. Sasikala[1], G. Srinivasa Rao[2]*, P.V.S. Sairam[2] and M.V. Basaveswara Rao[3]

1. Dhanekula Institute of Engineering and Technology, Ganguru, Andhra Pradesh, **INDIA**
2. Department of Physics, Andhra Loyola College, Krishna University, Andhra Pradesh, **INDIA**
3. Department of Chemistry, Krishna University, Machilipatnam, Andhra Pradesh, **INDIA**

Email: gsrinivasarao64@yahoo.com

Accepted on 9th May, 2019

ABSTRACT

Ultrasonic velocities and densities of the binary liquid mixtures of Furfuryl alcohol with different glycols like ethylene glycol, diethylene glycol and triethylene glycol have been measured at temperature 303.15 K over the entire composition range. Various theories of ultrasonic velocity were applied to experimental values in evaluating the velocities using viz., Nomoto, impedance, Van Dael and Vangeel, Junjie, Rao and collision factor theories. Scaled particle theory is applied to these mixtures by considering different shapes viz., sphere, cube, tetrahedron, disc A, disc B, disc C and disc D for both the participating components i.e., Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol. The combinations of different molecular shapes and thermodynamic states at 303.15 K are in close agreement between theoretically predicted ultrasonic velocities and the experimental values by using Nomoto and Scaled particle theories. The molecular interaction parameter (χ) has been evaluated from the values of experimental and theoretical velocities. The variation of this interaction parameter with the composition mixture has been discussed in terms of molecular interactions.

Highlights

- Binary liquid mixtures of Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol are investigated.
- The experimental and theoretical ultrasonic velocities are correlated.
- In scaled particle theory the shapes and thermodynamic states of the molecules are considered.
- Scaled particle theory accurately predicted the speeds of sound in the mixtures studied.
- By determining standard deviation and by applying Chi-square test Statistical analysis is made.

Keywords: Ultrasonics, Thermodynamic parameters, Scaled particle theory, *Chi*-square.

INTRODUCTION

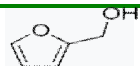
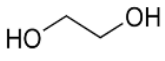
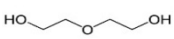
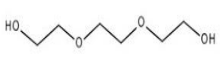
In recent years measurement of ultrasonic investigations find extensive applications in determining the physicochemical behavior of liquid mixtures [**1**-**5**]. Several researchers [**6**-**9**] carried out ultrasonic investigations and correlated the experimental results of ultrasonic velocity with the theoretical

relations of Nomoto [10], Van Dael and Vangeel ideal mix relations[11] impedance relation[12] Rao's Specific velocity[13] and Junjie[14] and interpreted the results in terms of molecular interactions. Ultrasonic study of liquid mixtures, due to its non destructive nature, has been extensively carried out in different branches of science to measure the thermodynamic properties and to predict the nature of molecular interaction between the molecules in a medium. The ultrasonic sound velocity and the thermodynamic parameters derived from it have been widely used to interpret the interactions between unlike molecules in the binary liquid mixtures. Samal *et al.,* [15], Aziz *et al.*,[16, 17] and Younglove [18] showed that there is close relation between ultrasonic velocity and thermodynamic properties. This investigation presents the application and evaluation of ultrasonic velocity theories like Nomoto's relation, ideal mixing relation, impedance relation, Rao's specific velocity relation, Junjie's relation and scaled particle theory relations for the binary mixtures of Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol at temperatures 303.15K, over the entire composition range. The objective of the present work is to compare the merits of the theoretically calculated ultrasonic velocities in the binary liquid mixtures of Furfuryl alcohol with ethylene glycol diethylene glycol and triethylene glycol at a temperature 303.15K over the entire composition range using different theories *viz*., Nomoto, impedance, Van Dael and Vangeel, Junjie, Rao, collision factor and scaled particle theories with the experimentally measured values. An attempt is made to study the change in the shapes and thermostatic states of the interacting molecules using scaled particle theory.

MATERIALS AND METHODS

For the preparation of various compositions of the liquid mixtures, Shimadzu AY120, a single pan electronic balance with an uncertainty of ±0.01 milligram is used. The uncertainty in the mole fraction is of 1×10^{-4} and the prepared mixtures are stored in air-tight glass bottles. For the determination of the ultrasonic velocity and density, the liquids are thoroughly mixed before transferring in to the apparatus used. The required properties are measured within 24 h of the preparation of the mixture. Ultrasonic velocity is measured with the help of single crystal variable path fixed frequency interferometer, Model-F05 supplied by Mittal Enterprises, New Delhi at affixed frequency of 2 MHz with an uncertainty less than 0.1%. Temperature of the mixture is kept constant for the measurement of speeds of sound using a microprocessor assisted circulating water bath, (supplied by Mac, New Delhi) regulated to ±0.01K.The densities of the mixtures are measured using a vibrating-tube Rudolph Research Analytical density meter, mode lDDM-2911 automatically thermostated within ±0.01K. The uncertainty in density measurements is$\pm1x10^{-5}$ g.cm^{-3}. The information of chemicals used, their purity and purification techniques etc. are given in Table 1.

Table 1. Details of Studied Chemicals, CAS Number, Source, Purification Method, chemical structure and molar masses

Chemical	CAS number	Supplier	Purification Technique (Purity% GC)	Chemical Structure	Molar mass 10^{-3} kg mol^{-1}
Furfuryl Alcohol	98-00-0	S.D Fine	Fractional distillation (99.8)		98.10
Ethylene Glycol	107-21-1	Merck	Fractional distillation (99.7)		62.07
Diethylene Glycol	111-46-6	Merck	Fractional distillation (99.5)		106.12
Triethylene Glycol	112–27–6	Merck	Fractional distillation (99.5)		150.17

RESULTS AND DISCUSSION

The thermodynamic parameters such as ultrasonic velocity, density, molar volume, isentropic compressibility, etc., are found to be strongly affected by the changes of composition besides the type

of bonding present between the molecules of the constituent liquids. The experimental ultrasonic velocity and densities of the pure liquids i.e., Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol at a temperature 303.15K are presented in table 2 along with the literature values. Comparison of the experimental and literature values of ultrasonic velocity and density confirm the purity of the chemicals used in the present investigation.

The experimental ultrasonic velocity (U) and density (ρ) of the binary mixtures of Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol at temperature 303.15K over the entire composition are listed in table 3. Variations of speed of sound and density with the mole fraction of Furfuryl alcohol for all the systems are presented respectively in figures 1 and 2. For the smooth representation, the values of speeds of sound and density of the binary mixtures are fitted to suitable polynomial equations.

Table 2. Comparison of the experimental speeds of sound (U/ms^{-1}) and density (ρ/kgm^{-3}) of Furfuryl alcohol with ethylene glycol, diethylene glycol and tri ethylene glycol withthe literature data at 303.15K

Compound	U/ms^{-1}		ρ/kgm^{-3}	
	Exp.	Lit.	Exp.	Lit.
Furfuryl Alcohol	1432.51	--	1123.24	--
Ethylene Glycol	1643.75	1644.2[a]	1106.88	1106.6[a]
Diethylene Glycol	1568.73	1568.03[b]	1109.39	1109.4[b]
Triethylene Glycol	1597.30	--	1116.15	1116.4[a]

Ref. a[21], b[22]

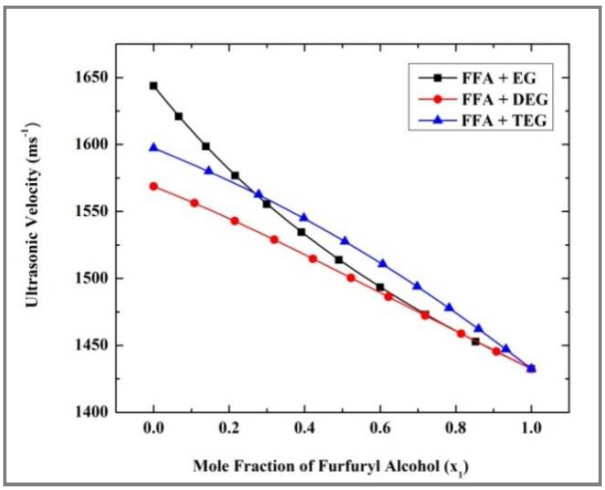


Figure 1. Variation of ultrasonic velocity (U/ms^{-1}) of (a) furfuryl alcohol + ethylene glycol, (b) furfuryl alcohol + diethylene glycol and (c) furfuryl alcohol + triethylene glycol at 303.15K with the mole fraction of furfuryl alcohol.

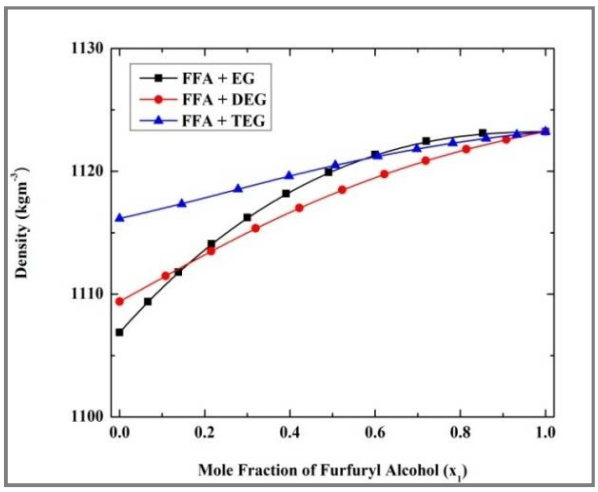


Figure 2. Figure 2. Variation of density (ρ/kgm^{-3}) of (a) furfuryl alcohol + ethylene glycol, (b) furfuryl alcohol+ diethylene glycol and (c) furfuryl alcohol+triethylene glycol at 303.15K with the mole fraction of furfuryl alcohol.

From figure 1, it can be concluded that the ultrasonic velocity decreases nonlinearly with the increase of mole fraction of furfuryl alcohol at 303.15 K indicating intermolecular interactions between the components of the liquid mixtures.

From figure 2, it is observed that the density for all the three liquid mixtures increases with the increase in concentration of furfuryl alcohol probably due to solvent-solvent interactions in the corresponding liquid mixtures.

The theoretical ultrasonic velocities determined from Nomoto, impedance, Van Dael and Vangeel, Junjie, Rao, collision factor theory and scaled particle theory along with the experimental values at 303.15 K in the binary mixtures (Furfuryl alcohol + ethylene glycol), (Furfuryl alcohol + diethylene glycol) and (Furfuryl alcohol + triethylene glycol) are presented in tables 3a, 3b and 3c respectively.The standard deviation in the computation of ultrasonic velocity (ΣdU and χ^2) values are also presented in tables 3a, 3b and 3c. Figure 3 represents the comparison plot of the χ^2 values obtained from different theories for the binary mixtures of Furfuryl alcohol + ethylene glycol (black bar), Furfuryl alcohol + diethylene glycol (red bar) and Furfuryl alcohol + triethylene glycol (blue bar). From table 3 and figure 3 it can be concluded that the χ^2 values are the least for scaled particle theory. Hence, it can be concluded that the scaled particle theory clearly predicts the ultrasonic velocities in the mixtures of furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol at 303.15 K.

Table 3a. Theoretical ultrasonic velocities (U/ms^{-1}) calculated by various theories along with experimental ultrasonic velocities in the binary mixtures of Furfuryl Alcohol+ ethylene glycol at 303.15 K

x_1	U_{EXP}	U_{NOM}	U_{IMP}	U_{VDV}	U_{JUN}	U_{CFT}	U_{RAO}	U_{SPT}
Furfuryl Alcohol+ Ethylene Glycol								
0.0000	1643.75	1643.75	1643.75	1643.75	1643.75	1643.75	1643.75	1643.75
0.0666	1620.89	1629.49	1621.75	1621.91	1618.64	1629.97	1629.08	1621.28
0.1383	1598.61	1614.16	1599.95	1600.07	1594.57	1615.07	1613.37	1599.12
0.2158	1576.83	1597.64	1578.34	1578.25	1571.49	1598.90	1596.52	1577.28
0.2997	1555.48	1579.78	1556.93	1556.50	1549.32	1581.31	1578.39	1555.73
0.3910	1534.50	1560.41	1535.71	1534.88	1528.01	1562.10	1558.84	1534.49
0.4906	1513.81	1539.34	1514.69	1513.47	1507.49	1541.07	1537.69	1513.53
0.5997	1493.35	1516.32	1493.85	1492.37	1487.73	1517.94	1514.75	1492.86
0.7198	1473.04	1491.09	1473.22	1471.71	1468.67	1492.41	1489.76	1472.47
0.8525	1452.79	1463.28	1452.77	1451.67	1450.28	1464.09	1462.46	1452.35
1.0000	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51
--	∑dU	0.1109	0.0051	0.0008	-0.0282	0.1182	0.1041	0.0002
--	χ^2	2.369470	0.005994	0.006766	0.148164	2.692894	2.084765	0.000980

Table 3b. Theoretical ultrasonic velocities (U/ms^{-1}) calculated by various theories along with experimental ultrasonic velocities in the binary mixtures of Furfuryl Alcohol+ diethylene glycol at 303.15 K

x_1	U_{EXP}	U_{NOM}	U_{IMP}	U_{VDV}	U_{JUN}	U_{CFT}	U_{RAO}	U_{SPT}
Furfuryl Alcohol+ Diethylene Glycol								
0.0000	1568.73	1568.73	1568.73	1568.73	1568.73	1568.73	1568.73	1568.73
0.1085	1556.29	1554.74	1553.79	1550.40	1553.49	1553.96	1553.55	1556.12
0.2150	1542.90	1540.82	1539.16	1533.40	1538.65	1539.46	1538.75	1543.06
0.3194	1528.95	1527.00	1524.85	1517.59	1524.20	1525.23	1524.32	1529.66
0.4220	1514.73	1513.25	1510.83	1502.88	1510.11	1511.25	1510.24	1516.02
0.5227	1500.47	1499.59	1497.10	1489.14	1496.38	1497.54	1496.49	1502.22
0.6216	1486.31	1486.01	1483.66	1476.31	1482.98	1484.06	1483.08	1488.32
0.7188	1472.37	1472.51	1470.48	1464.29	1469.91	1470.83	1469.99	1474.36
0.8142	1458.72	1459.10	1457.57	1453.03	1457.15	1457.83	1457.20	1460.39
0.9079	1445.43	1445.76	1444.92	1442.45	1444.69	1445.06	1444.71	1446.43
1.0000	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51
--	∑dU	-0.0048	-0.0158	-0.0513	-0.0190	-0.0139	-0.0185	0.0070
--	χ^2	0.0091	0.0500	0.4835	0.0703	0.0396	0.0667	0.0115

Theories of ultrasonic velocity: In the present work, the ultrasonic velocity in three binary liquid mixtures under investigation viz., Furfuryl alcohol +ethylene glycol, +diethylene glycol and + triethylene glycol is evaluated using semi-empirical formulations of Nomoto [**10**], Van Dael and Vangeel [**11**], impedance relation [**12**], Rao [**13**], Junjie [**14**], Schaaff's, collision factor theory [**19**] and scaled particle theory [**20**] and compared the relative merits of these theories. The applicability of the theoretical models is also checked by computing the standard deviation in ultrasonic velocity, Σ dU and by Chi-square fit (χ^2), which enables to find whether the deviations of the theoretical

values from the experimental ones are due to chance or really due to the inadequacy of the theory to fit the data.

Table 3c. Theoretical ultrasonic velocities (U/ms^{-1}) calculated by various theories along with experimental ultrasonic velocities in the binary mixtures of Furfuryl Alcohol+ Triethylene glycol at 303.15 K

x_1	U_{EXP}	U_{NOM}	U_{IMP}	U_{VDV}	U_{JUN}	U_{CFT}	U_{RAO}	U_{SPT}
Furfuryl Alcohol+ Triethylene Glycol								
0.0000	1597.30	1597.30	1597.30	1597.30	1597.30	1597.30	1597.30	1597.30
0.1462	1580.14	1580.28	1573.09	1540.83	1578.32	1573.93	1572.47	1581.27
0.2780	1562.62	1563.38	1551.27	1502.27	1559.98	1552.69	1550.28	1564.75
0.3977	1545.07	1546.60	1531.52	1475.59	1542.24	1533.28	1530.33	1547.99
0.5067	1527.70	1529.95	1513.55	1457.18	1525.07	1515.46	1512.31	1531.13
0.6064	1510.66	1513.41	1497.13	1444.77	1508.45	1499.02	1495.95	1514.30
0.6980	1494.04	1496.99	1482.06	1436.83	1492.33	1483.80	1481.03	1497.57
0.7823	1477.89	1480.69	1468.20	1432.29	1476.70	1469.65	1467.36	1480.99
0.8604	1462.25	1464.51	1455.39	1430.41	1461.54	1456.45	1454.80	1464.61
0.9327	1447.12	1448.45	1443.53	1430.62	1446.82	1444.10	1443.22	1448.44
1.0000	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51	1432.51
--	∑dU	0.0112	-0.0609	-0.3122	-0.0105	-0.0524	-0.0663	0.0156
--	χ^2	0.0261	0.6858	17.0408	0.0228	0.5105	0.8103	0.0456

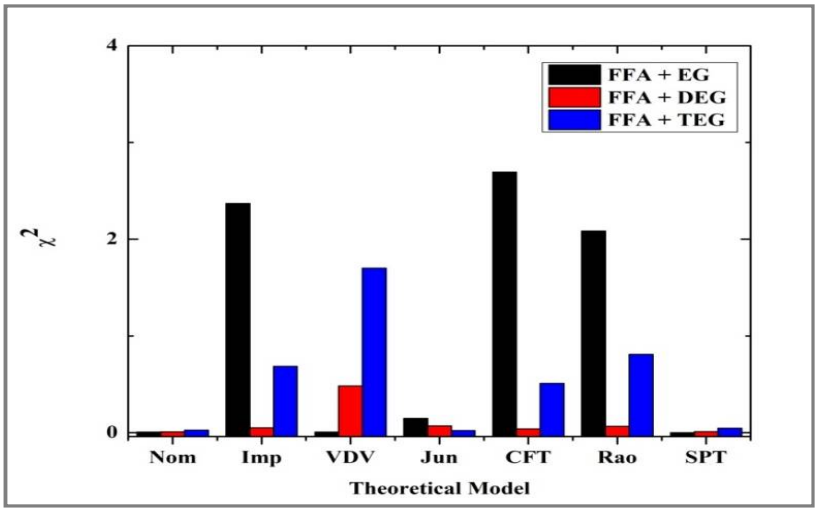


Figure 3. Comparison of various theories of ultrasonic velocities for the binary mixtures of furfuryl alcohol (FFA) + ethylene glycol (EG), + diethylene glycol (DEG) and + triethylene glycol (TEG) at 303.15 K.

Scaled particle theory (SPT): Generally the shapes of the molecules of a liquid are assumed to be spherical in pure state. When two liquids are mixed, the interaction between the component molecules affects the shapes of the participating liquid molecules. In scaled particle theory 7 shapes *viz*., sphere, cube, tetrahedron, disc A, disc B, disc C and disc D of the participating components are considered and when the participating components have the correct shapes the theoretical ultrasonic velocities are estimated based on this model which give values close to the experimental values. Scaled particle theory links the microscopic parameters *viz*., radius, surface area and hard core volume of a molecule with the macroscopic parameters like speed of sound [**20**].

According to the scaled particle theory, the equation of state of a fluid is

$$\frac{P}{\rho_N K_B T}\frac{1+\eta+\eta^2}{(1-\eta)^2}$$

Where, ρ_N is the number density, $\eta = V_H\rho_N$, V_H being hard core volume of the molecule and other quantities have usual meaning.

Scaled particle theory for mixtures of hard convex molecules gives the equation for the mixture as follows:

$$\frac{P}{\rho_N K_B T} = \frac{1}{(1-V\rho_N)^2} + \frac{AB\rho_N}{(1-V\rho_N)^2} + \frac{B^2C\rho_N^2}{(1-V\rho_N)^2}$$

Where, $A = \sum x_i R_i$, $B = \sum x_i S_i$ $C = \sum x_i R_i^2$, $V = \sum x_i V_H$

R_i, S_i and V_{Hi} are the mean radius of curvature, surface area and volume respectively of a molecule of species i, ρ_N is the number density of the mixture molecule, x_i is the mole fraction.

Relating this with the equation:

$$\gamma\left(\frac{dP}{d\rho}\right) = \text{, we get} \frac{MU^2}{\gamma RT} = \frac{1}{(1-V\rho_N)^2} + \frac{2AB\rho_N}{(1-V\rho_N)^2} + \frac{B^2C\rho_N^2}{3(1-V\rho_N)^2}$$

For pure liquids, the above equation becomes

$$\frac{MU^2}{\gamma RT} = \frac{(1+(X-1)\eta)^2}{(1-\eta)^2}$$

Where, X = RS/V is called the shape parameter.

The mean radius of the molecule is $R = Y\ (V_H)^{1/3}$ and the surface area of the molecule is $S = Z\ R^2$, where Y and Z are the parameters related to the shape of the liquid molecule. The characteristic parameters used in the computational aspects of scaled particle theory are summarized in table 4.

Table 4. Molecular assignment for different shapes and shape parameters

Shape	Size	R	S	V_H	X	Y	Z
Sphere	Radius=a	a	$4\pi a^2$	$4\pi a^3/3$	3.0000	0.6204	12.5664
Cube	Side = *l*	3/4	$6\,l^2$	l^3	4.5000	0.7500	10.6666
Tetrahedron	Side = *l*	(3 /arctanv2)/2π Radius=a and depth=*l*	$\sqrt{3}l^2$	$(\sqrt{2}/12)l^3$	6.7035	0.9303	8.3247
Disc A	*l* = a	(π+1)a/4	$4\pi a^2$	πa^3	4.1416	0.7070	11.7218
Disc B	*l* = a/4	(π+0.25)a/4	$5\pi a^2/2$	$\pi a^3/4$	8.4790	0.9190	10.9244
Disc C	*l* = a/2	(π+0.50)a/4	$3\pi a^2$	$\pi a^3/2$	5.4624	0.7832	11.3712
Disc D	*l* = a/10	(π+0.10)a/4	$11\pi a^2/5$	$\pi a^3/10$	17.8274	1.1920	10.5253

The microscopic dimensions of the pure liquid molecules (furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol) at 303.15 K obtained from the scaled particle theory are reported in table 5. To check the suitability of the scaled particle theory for the prediction of ultrasonic velocity in the binary mixtures of furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol, statistical analysis is carried out by determining ΣdU and χ^2 values for different shape combinations (7*7=49) and the corresponding ΣdU and χ^2 values are presented in tables 6a, 6b and 6c.

From Table 6a it is found that both ΣdU (0.0002) and χ^2 (0.001) values are minimum for shape combinations disc C (Furfuryl alcohol) + Te (Ethylene glycol) for (Furfuryl alcohol + Ethylene glycol) mixture. From Table 6b it is found that both ΣdU (0.007) and χ^2 (0.115) values are minimum

for shape combinations disc C (Furfuryl alcohol) + disc A (diethylene glycol) for (Furfuryl alcohol + diethylene glycol) mixture .Similarly, from Table 6c it is found that both ΣdU (0.0156) and χ^2 (0.0456) values are minimum for shape combinations disc C (Furfuryl alcohol) + Te (triethylene glycol) for (Furfuryl alcohol + triethylene glycol) mixture.

Table 5. Microscopic dimensions of pure liquid molecules at 303.15 K

Liquid	Shape	R(10^{10})	S(10^{18})	VH(10^{29})	η
Furfuryl Alcohol	sp	29.4431	108.8823	10686.1203	0.8964
	cu	35.3056	132.9584	10431.4972	0.8750
	te	43.3511	156.6262	10134.1959	0.8501
	disc A	33.3385	130.2829	10487.3564	0.8797
	disc B	42.5614	197.8925	9933.5065	0.8332
	disc C	36.7046	153.1810	10293.0058	0.8634
	disc D	53.7372	303.9558	9162.1377	0.7685
Ethylene glycol	sp	25.4169	81.1403	6874.4602	0.8932
	cu	30.4699	99.0311	6705.4910	0.8712
	te	37.4020	116.5879	6508.3778	0.8456
	disc A	28.7739	97.0494	6742.5476	0.8760
	disc B	36.7129	147.2428	6375.4310	0.8283
	disc C	31.6728	114.0610	6613.6458	0.8593
	disc D	46.3134	225.7741	5865.3269	0.7621
Diethylene glycol	sp	30.8339	119.4113	12273.0332	0.9039
	cu	36.9954	145.9904	12002.1677	0.8839
	te	45.4586	172.2251	11685.2382	0.8606
	disc A	34.9295	143.0147	12061.6341	0.8883
	disc B	44.6527	217.8171	11470.8800	0.8448
	disc C	38.4741	168.3069	11854.6235	0.8730
	disc D	56.4902	335.8966	10643.6255	0.7839
Triethylene glycol	sp	34.4970	149.4691	17187.4287	0.9121
	cu	41.4177	182.9787	16841.2312	0.8937
	te	50.9326	216.1998	16435.2328	0.8722
	disc A	39.0992	179.1970	16917.2977	0.8978
	disc B	50.0568	273.7301	16160.0459	0.8576
	disc C	43.0888	211.1026	16652.3481	0.8837
	disc D	63.4655	423.9709	15093.3381	0.8010

Table 6a. Standard deviation (ΣdU) and Chi-Square (χ^2) in the prediction of ultrasonic velocity with different shape combinations in the mixture furfuryl alcohol+ethylene glycol at 303.15 K using scaled particle theory.

Statistical parameter	Shape	Sp	Te	Cu	Disc A	Disc B	Disc C	Disc D
∑dU	Sp	0.0279	0.1221	0.2727	0.0959	0.3187	0.1711	0.6235
	Te	0.0173	0.0275	0.1275	0.0161	0.1764	0.0655	0.4357
	Cu	0.0037	0.0077	0.0271	0.0003	0.0913	0.0218	0.2945
	Disc A	0.0152	0.0450	0.1633	0.0275	0.2031	0.0833	0.4735
	Disc B	0.0248	0.0354	0.0137	0.0364	0.0269	0.0256	0.2025
	Disc C	0.0327	0.0002	0.0917	0.0112	0.1219	0.0273	0.3582
	Disc D	0.0758	0.0010	0.0177	0.0146	0.0371	0.0188	0.0263
				0.0002				
χ2	Sp	0.1482	2.8818	14.9520	1.7659	20.6965	5.7328	86.9501
	Te	0.0564	0.1444	3.1475	0.0505	6.0991	0.8193	40.0438
	Cu	0.0114	0.0120	0.1408	0.0024	1.5990	0.0915	17.5467
	Disc A	0.0433	0.3858	5.2048	0.1450	8.1457	1.3285	47.8194
	Disc B	0.1159	0.2324	0.0368	0.2451	0.1384	0.1221	8.0905
	Disc C	0.1984	0.0010	1.6139	0.0240	2.8752	0.1425	26.4538
	Disc D	1.2366	0.0130	0.0608	0.0642	0.2553	0.0687	0.1318
				0.0010				

Table 6a. Standard deviation (ΣdU) and Chi-Square (χ^2) in the prediction of ultrasonic velocity with different shape combinations in the mixture furfuryl alcohol+diethylene glycol at 303.15 K using scaled particle theory.

Statistical parameter	Shape	Sp	Te	Cu	Disc A	Disc B	Disc C	Disc D
∑dU	Sp	0.0126	0.0594	0.1680	0.0427	0.1906	0.0873	0.4364
	Te	0.0169	0.0127	0.0671	0.0115	0.0913	0.0285	0.2826
	Cu	0.0848	0.0253	0.0129	0.0433	0.0514	0.0321	0.1798
	Disc A	0.0087	0.0201	0.0936	0.0127	0.1088	0.0363	0.3129
	Disc B	0.0828	0.0243	0.0261	0.0334	0.0130	0.0115	0.1106
	Disc C	0.0244	0.0078	0.0534	0.0070	0.0581	0.0128	0.2228
	Disc D	0.2586	0.1414	0.0777	0.1641	0.0325	0.1005	0.0134
				0.0070				
χ^2	Sp	0.0318	0.6650	5.4467	0.3440	7.0524	1.4433	39.7700
	Te	0.0543	0.0325	0.8495	0.0268	1.5776	0.1541	15.9014
	Cu	1.3608	0.1200	0.0333	0.3496	0.4975	0.1931	6.2572
	Disc A	0.0165	0.0780	1.6594	0.0323	2.2506	0.2492	19.6720
	Disc B	1.2961	0.1110	0.1284	0.2081	0.0337	0.0265	2.3279
	Disc C	0.1112	0.0138	0.5362	0.0115	0.6353	0.0328	9.7223
	Disc D	13.5622	3.8693	1.1368	5.2549	0.1972	1.9214	0.0359
				0.0115				

Table 6a. Standard deviation (ΣdU) and Chi-Square (χ^2) in the prediction of ultrasonic velocity with different shape combinations in the mixture furfuryl alcohol+triethylene glycol at 303.15 K using scaled particle theory.

Statistical parameter	Shape	Sp	Te	Cu	Disc A	Disc B	Disc C	Disc D
∑dU	Sp	0.0158	0.0528	0.1536	0.0381	0.1721	0.0767	0.4109
	Te	0.0303	0.0160	0.0611	0.0169	0.0809	0.0274	0.2617
	Cu	0.1071	0.0382	0.0162	0.0582	0.0499	0.0405	0.1654
	Disc A	0.0200	0.0213	0.0858	0.0159	0.0966	0.0331	0.2908
	Disc B	0.1100	0.0422	0.0343	0.0533	0.0163	0.0249	0.0999
	Disc C	0.0422	0.0156	0.0517	0.0169	0.0517	0.0161	0.2047
	Disc D	0.2972	0.1732	0.1010	0.1974	0.0515	0.1286	0.0169
				0.0156				
χ^2	Sp	0.0470	0.5243	4.5365	0.2726	5.7263	1.1111	34.9195
	Te	0.1713	0.0480	0.7036	0.0534	1.2361	0.1403	13.5548
	Cu	2.2177	0.2734	0.0493	0.6396	0.4686	0.3073	5.2794
	Disc A	0.0750	0.0847	1.3923	0.0477	1.7694	0.2055	16.8857
	Disc B	2.3409	0.3340	0.2201	0.5364	0.0499	0.1156	1.8935
	Disc C	0.3346	0.0456	0.5016	0.0536	0.5020	0.0485	8.1662
	Disc D	18.4658	5.9598	1.9676	7.8201	0.5002	3.2258	0.0534
				0.0456				

APPLICATION

The thermodynamic properties of a binary mixture such as ultrasonic velocity and density are important for practical and theoretical points of view to understand liquid theory. Their properties are extremely useful in chemical industries.

CONCLUSION

The ultrasonic velocity and density are measured for binary mixtures of Furfuryl alcohol with ethylene glycol, diethylene glycol and triethylene glycol at a temperature of 303.15 K. The theoretical ultrasonic velocities are calculated by various theories along with experimental ultrasonic velocities in binary mixtures of FFA+EG, +DEG and +TEG. The combinations of different molecular shapes and thermodynamic states at 303.15 K are in close agreement between theoretically predicted speeds of

sound and the experimental values by using Nomoto and SPT theories. The deviations are less in SPT and more in CFT.

REFERENCES

[1]. G. V. Rama Rao, A. ViswanathaSarma, J. Sivarama Krishna, C. Rambabu, Theoretical evaluation of ultrasonic velocities in binary liquid mixtures of *o*-chlorophenol at different temperatures, *Indian J Pure Appl.Phys.*, **2005**, 43(5), 345-354.

[2]. P. Vasantharani, S. Muthu Shailaja, A. K. Kannappan, R. EzhilPavai, Theoretical evaluation of ultrasonic velocity in organic liquid mixtures , *J Appl Sci.,* **2008**, 8(12), 2329-2332.

[3]. S. L. Oswal, V. Pandiyan, B. Krishnakumar, P. Vasantharani, Thermodynamic and acoustic properties of binary mixtures of oxolane with aniline and substituted anilines at 303.15, 313.15 and 323.15 K, *Thermochim Acta*, **2010**, 507-508.

[4]. J. D. Pandey, RanjanDey, D. K. Dwivedi, Ultrasonic velocity of binary systems at elevated pressures, *Pramana J Phys*., **1999**, 52(2), 187.

[5]. T. Sumathi, Umamaheswari J, Ultrasonic and theoretical studies of some ternary liquid mixtures at Various temperatures,*Indian J Pure Appl Phys.*, **2009**, 47, 782.

[6]. D. Bala Karuna Kumar, K. Rayapa Reddy, G. Srinivasa Rao, G. V .Rama Rao, C. Rambabu, *Asian J Chem.,* **2012**, 24(5), 2239-2244.

[7]. A. Ali , A. Yasmin, A. K. Nain, Study of intermolecular interactions in binary liquid mixtures through ultrasonic speed measurement,*Indian J Pure Appl Phys.*, **2002**, 40, 315-322.

[8]. K. Rayapa Reddy, D. Bala Karuna Kumar, C. Rambabu, G. Srinivasa Rao, Theoretical evaluation of ultrasonic velocities in binary liquid mixtures of N-Methyl-2-pyrrolidone at different temperatures with Some cyclic compounds, *E-J Chem.*, **2012**,9(2), 553-562.

[9]. A. Ali , A. K. Nain, SoghraHyder, Ultrasonic study of molecular interaction in binary liquid mixtures at 308.15, *J Pure Appl Ultrasonics*, **2001**, 23, 73.

[10]. O. Nomoto, Empirical formula for sound velocity in liquid mixtures, *J. Phys. Soc. Jpn*, **1958**, 13, 1528.

[11]. Van Dael, Vangeel, *Proc. Int. Conf. on calorimetry and thermodynamics*, Warasa, **1955**, 555.

[12]. ShipraBaluja, P. H. Parsania, Studies on acoustical properties of diclofanac sodium methanol-water system at 30°C, *Asian Journal of Chemistry*,**1997**, 9(1), 149–152.

[13]. M. R. Rao, Velocity of sound in liquids and chemical constitution, *J. Chem. Phys*., **1941**, 9, 682.

[14]. Z. Junjie, *J. Chem. Univ. Sci. Technol*., **1984**, 14, 298.

[15]. K. Samal, S. C. Misra, Ultrasonic absorption in binary mixtures of carbon disulphide in comparison with Bauer's theory, *J Phys Soc Japan.*, **1972**, 32(6), 1615.

[16]. R. A. Aziz, D. H. Bowman, C. C. Lim, The law of corresponding states as applied to sound velocity in liquids consisting of elliptical molecules, *Can J Phys*., **1972**, 50(7), 721-727.

[17]. G. R. Poole, R. A. Aziz, C. C. Lim, An examination of the relationship between sound velocity and density in liquids, *Canadian Journal of Physics*, **1972**, 50, 646–654

[18]. B. A. Younglove, Speed of sound in fluid parahydrogen, *J AcoustSoc Am.*, **1965**, 38, 433.

[19]. W. Schaaff, Molekularakustic, The Problem of a Theoretical Calculation of the Velocity of Sound for Binary Liquid Mixtures, *Springer Berlin* , **1963**.

[20]. P.V.S. Sairam, G. Srinivasa Rao, M.V. Basaveswara Rao, K. Rayapa Reddy, Prediction of Speeds of Sound in the Binary Mixtures of Ethyl Lactate with Cyclohexanone, Cyclohexylamine and Cyclohexanol at 303.15 K, *J. Applicable Chem.*, **2019**, 8(2), 801-813.

[21]. Amalendu Pal, Wazir Singh, Speeds of Sound and Viscosities in Aqueous Poly(ethylene glycol) Solutions at 303.15 and 308.15 K, *J. Chem. Eng. Data*,**1997**, *42*, 234-237.

[22]. SL Krzysztof Klimaszewski, EwaStronka-Lewkowska, KatarzynaSoliwoda, Adam Bald Acoustic and volumetric studies on water + diethylene glycol mixtures in a wide temperature range. Comparison with mixtures of water withtri- and tetraethylene glycol,*Journal of Molecular Liquids,* **2016,** 215, 520–533.