

Theoretical Evaluation of Ultrasonic Velocity in Binary Liquid Mixtures of Alcohols [S] + Benzene

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ABSTRACT

Ultrasonic velocities and densities of the binary liquid mixtures of benzene with 1-propanol, 2-propanol, 1-butanol, 2-butanol and 3-butanol at 303.15 to 318.15 K, over the entire composition range were measured. The theoretical values of ultrasonic velocity were evaluated using the Nomoto's Relation (NR), Ideal Mixture Relation (IMR), Free Length Theory (FLT) and Collision Factor Theory (CFT). The validity of these relations and theories were tested by comparing the computed sound velocities with experimental values. Further, the molecular interaction parameter (α) was computed by using the experimental and the theoretical ultrasonic velocity values. The variation of this parameter with composition of the mixtures has been discussed in terms of molecular interaction in these mixtures.

Keywords: alcohols; benzene; sound; mixtures; NR; IMR; FLT; CFT

1. INTRODUCTION

Among the non-spectroscopic methods in the study of molecular interactions, the ultrasonic velocity measurement finds extensive applications owing to its ability of characterising the physico-chemical behavior of liquid systems from speed data. The ultrasonic velocity of liquid is fundamentally related to the binding forces between the atoms or the molecules. According to physical concept of liquid model¹⁻³, molecules in the liquid state are so loosely packed as to leave some free space in between them. The intermolecular free space and its dependent properties are related to intermolecular interactions and may reveal the some information regarding the interaction, which may be occurring when the liquids are mixed together.

Acoustical and thermodynamic properties are of great significance in studying the physico-chemical behavior and molecular interactions in pure liquid components and their mixtures. Literature survey shows that ultrasonic study of liquid mixture is highly useful in understanding the nature of molecular interactions^{4,5} and physico-chemical behavior of the liquid mixtures⁶⁻⁸ further, these ultrasonic velocities and other related properties of liquid mixtures are valuable in testing the various theories of liquid state.

The theoretical evaluation of sound velocity in liquids and liquid mixtures as a function of composition is of considerable interest. Also a comparison of theoretically obtained sound velocities with those of experimental is found to be useful in knowing the thermodynamics of liquid and liquid mixtures and provides a better means to test the validity of the various empirical relations and theories. In recent years various theories⁹⁻¹² have been in use for computing ultrasonic velocity in liquid mixtures and the deviation in theoretical sound velocity from that of the experimental has been attributed mainly to the molecular interactions prevailing in liquid mixtures.

The measurements of ultrasonic velocity in solutions formed by liquid components reveals the degree of deviation from ideality whenever there are interactions among the component molecules. The deviations have been used to gain insight into nature and degree of interactions among the interacting systems. In the case of liquid mixtures the data on composition dependency of ultrasonic velocity help to understand the nature of molecular interactions in terms of some physical parameters. A departure from linearity in the ultrasonic velocity versus composition behavior in liquid mixtures is an indication of the existence of interaction between different species¹³. Various theories which were originally proposed for binary mixtures¹⁴ Ramasamy and Anbanathan¹⁵ carried out the ultrasonic investigations on some binary and ternary liquid mixtures and correlated the experimental findings of ultrasonic velocity with the theoretical relations suggested by Nomoto¹⁶ and Van Deal and Van Geel^{17,18} and interpreted the results in terms of molecular interactions.

In the present investigation, the ultrasonic velocity of binary liquid mixtures of benzene with alcohols have been theoretically evaluated by using various theories at 303.15 – 318.15 K and these theoretical values are compared with experimental values. Further, the intermolecular interaction parameter (α) has been discussed in the light of deviations observed by plotting the experimental and the theoretical values of ultrasonic velocity against the mole fraction of alcohols.

2. EXPERIMENTAL

Ultrasonic velocity of pure liquids and liquid mixtures were measured at 3MHz with variable path single beam interferometer having gold plated quartz crystal at the bottom and double walled gold plated cell having grooves at inside walls to check the overlapping of stationary waves to produce clarity nodes and internodes. The accuracy of velocity measurements is $\pm 0.1 \text{ ms}^{-1}$. The temperature during the experiment was controlled by circulating water around the liquid cell from the thermostatically controlled adequately stirred water bath (accurately $\pm 0.1 \text{ }^\circ\text{C}$).

The densities of pure liquids and liquid mixtures were determined from the weight measurements on using the specific gravity bottle immersed in the thermostat at the experimental temperature and the accuracy in the measurements is $\pm 0.1 \text{ Kg m}^{-3}$.

The liquids used in the present work were of AR grade and were purified according to the standard procedure in the literature¹⁹. The liquid mixtures were prepared by mixing calculated amount of pure liquids.

3. THEORETICAL ASPECTS

Nomoto¹⁶ established an empirical formula for ultrasonic velocity in binary liquid mixture

$$U_{NR} = [(X_1 R_1 + X_2 R_2) / (X_1 V_1 + X_2 V_2)]^3 \quad (1)$$

Where U_{NR} = ultrasonic velocity as per Nomoto,

R = Rao constant, is related to molecular weight M and density ρ by,

$$R = (M / \rho) U^{1/3} = V_M U^{1/3} \quad (2)$$

Where V_M = molar volume, obey the additivity, $V_M = X_1 V_1 + X_2 V_2$

Van Deal and Van Geel^{17,18} proposed the following expression for the estimation of sound velocity u_{IMR} in an ideal mixture using the sound velocities in the pure components According to Jacobson's theory¹¹ of free length, the ultrasonic velocity is given by

$$U_{IMR} = [1 / (X_1 M_1 + X_2 M_2)]^{1/2} \{1 / [X_1 / M_1 U_1^2] + (X_2 / M_2 U_2^2)]^{1/2}\} \quad (3)$$

According to Jacobson's theory¹¹ of free length, the ultrasonic velocity is given by

$$U = K / (L_F \rho^{1/2}) = KY / (2V_A \rho^{1/2}) \quad (4)$$

For the Binary liquid mixture Eq. (4) is

$$U = K(X_1 Y_1 + X_2 Y_2) / 2[V_M - (X_1 V_{0,1} + X_2 V_{0,2})] \rho^{1/2} \quad (5)$$

Y is an adjustable parameter in the evaluation of velocity in liquid mixtures. Y is obtained from velocity in pure liquids using equation Eq.(4):

$$Y = 2V_A U \rho^{1/2} / K \quad (6)$$

Where K is the temperature – dependent Jacobson's constant¹¹, V_a is the available molar volume, which is the difference between the molar volumes at T(K) and 0(K), is a direct measure of the compactness and the strength of bonding between the molecules of a liquid in mixture. V_a is given by

$$V_a = V_M - V_0 \quad (7)$$

When Y in Eq. (5) is replaced according to Eq. (6) and when the resulting expression is rearranged, one gets

$$U_{(FLT)} = \{ [X_1 (V_{M1} - V_{0,1}) U_1 \rho_1^{1/2}] + [X_2 (V_{M2} - V_{0,2}) U_2 \rho_2^{1/2}] \} / [V_M - (X_1 V_{0,1} + X_2 V_{0,2})] \rho^{1/2} \quad (8)$$

Eq. (8) says that according to the free length theory the square root of the inverse of the adiabatic compressibility of liquid mixture ($\rho^{1/2}$) is the sum of the available volume fraction average of the square root of the inverse of adiabatic compressibilities of the individual components.

Collision Factor Theory (CFT)

According to Schaaffs¹² the sound velocity in pure liquid is given by

$$U = U_\infty s B / V_M \quad (9)$$

where $u_\infty = 1600 \text{ m/s}$; s = collision factor and B/V_M = space filling factor, B is the actual volume of molecules per mole.

For binary liquid mixtures this formula was modified by Nutsch – Kuhnekies²⁰ as:

$$u_{(CFT)} = (u_\infty / V) [(x_1 s_1 + x_2 s_2) (x_1 B_1 + x_2 B_2)] \quad (10)$$

$B = b/4$, where b is the vander Waals parameter given by

$$B = (M/\rho) [1 - (RT/Mu^2)] \{ (1 + Mu^2/3RT)^{1/2} - 1 \} \quad (11)$$

s as an adjustable parameter, obtained from velocities in pure components.

$$s = (V / B) (u / u_{\infty}) \quad (12)$$

The degree of intermolecular interaction (molecular association) is given by,

$$\alpha = (u_{\text{exp}}^2 / u_{\text{im}}^2) - 1 \quad (13)$$

4. RESULT AND DISCUSSION

The experimental and computed ultrasonic velocity using NR – Eq. (1), IMR – Eq. (3), FLT – Eq. (8) and CFT – Eq. (10) and also the percentage relative deviation between experimental predicted ultrasonic velocity values for the alcohols + benzene systems at 303.15 K – 318.15 K are given in Table 1. Molecular interaction parameters (α) are also given in Table 1. The variations of experimental and theoretical ultrasonic velocities with the concentration of alcohols are represented in Fig.1.

The predictive abilities of various ultrasonic theories depend upon the strength of the interaction prevailing in a system; these theories generally fail to predict accurately the ultrasonic velocities where strong interactions supposed to exist and the average absolute percentage relative deviation is small in systems where the interactions are less or nil. The theoretically found ultrasonic velocities of liquid mixtures reveal that CFT shows better agreement than the other relations.

Compared to FLT, CFT succeeds in making accurate predictions of ultrasonic velocities, the error range being only 0.04% (benzene + 2-butyl alcohol at 318.15 K) to 0.70% (benzene + 2-propyl alcohol at 318.15K) compared to 1.72% (benzene + 1-butyl alcohol at 303.15K, benzene + 3-butyl alcohol at 318.15 K) to 2.16% (benzene + 1-propyl alcohol at 308.15 and 313.15 K) of the former. Agnihotri and Adgaonkar²¹ also arrived at the same conclusion for ethylbenzene + n-alkanol (s) systems. Both the NR and the IMR give satisfactory estimates of ultrasonic velocities for all the mixtures²². However, there is a better agreement between the estimated ultrasonic velocity values through the IMR and the experimental results. The average absolute percentage deviation for the IMR varies from 0.06% (benzene + 2-propyl alcohol at 313.15 K) to 0.66% (benzene + 3-butyl alcohol at 313.15 K) to 1.83% (benzene + 2-propyl alcohol).

The CFT consider that the elastic nature of spherical molecules is responsible for the molecular interaction. It is more valid in these mixtures. On the other hand, The FLT assumes that molecules are rigid spheres with no interaction between them and it is not valid in the present cases. Hence the deviation from the experimental ultrasonic velocity values is maximum in the CFT. Though both the IMR and NR fit the data reasonably well, the gives a better fit.

The deviation of the ratio $U_{\text{exp}}^2 / U_{\text{im}}^2$ from unity (degree of interaction, α) and its variation as a function of mole fraction of alcohols is a direct measure of the nonideality of the system as a consequence of association or other type of interactions.

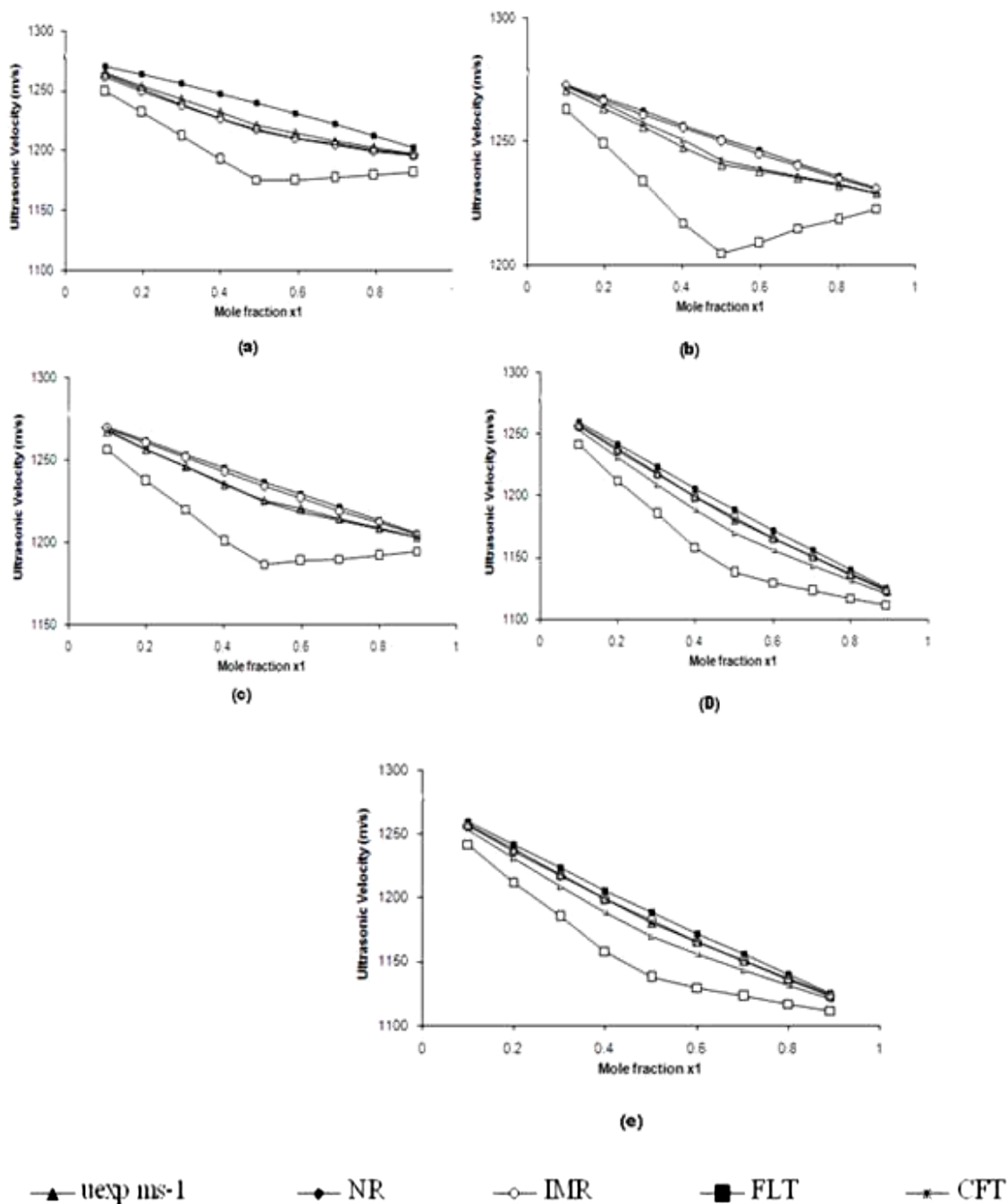


Fig. 1. Mole Fraction (x_1) Vs Ultrasonic Velocity for the temperature 303.15 K (a) n-Propyl alcohol (1) – Benzene (2) system (b) iso-Propyl alcohol (1) – Benzene (2) system (c) n-Butyl alcohol (1) – Benzene (2) system (d) sec-Butyl alcohol (1) – Benzene (2) system (e) tert-Butyl alcohol (1) – Benzene (2) system

Table 1. Experimental and predicted ultrasonic velocities and their percentage derivation and molecular interaction parameter for the n-Propyl alcohol (1) – Benzene (2) system at different temperatures.

Mole fraction x_1	$U_{\text{exp}} \text{ ms}^{-1}$	Predicted Ultrasonic Velocity				Absolute Percentage Deviation				$\alpha\alpha$
		NR	IMR	FLT	CFT	NR	IMR	FLT	CFT	
1	2	3	4	5	6	7	8	9	10	11
303.15 K										
0.0000	1278.2									
0.1051	1263.4	1270.4	1261.7	1249.0	1264.4	0.55	0.13	1.14	0.08	0.0026
0.1980	1251.3	1263.3	1248.9	1231.3	1254.0	0.96	0.19	1.60	0.22	0.0038
0.2998	1238.5	1255.3	1236.7	1212.0	1242.6	1.36	0.14	2.14	0.33	0.0029
0.3990	1226.5	1247.2	1226.3	1192.5	1231.3	1.69	0.02	2.77	0.39	0.0003
0.4944	1216.1	1239.3	1217.8	1175.4	1220.7	1.90	0.14	3.35	0.38	0.0027
0.5939	1210.3	1230.7	1210.2	1174.4	1214.1	1.69	0.1	2.96	0.31	0.001
0.6961	1205.2	1221.6	1203.9	1176.8	1208.1	1.36	0.11	2.35	0.24	0.0022
0.7974	1200.2	1212.3	1198.9	1178.7	1202.2	1.01	0.11	1.79	0.16	0.0021
0.8985	1196.6	1202.27	1195.2	1181.5	1196.4	0.51	0.11	1.26	0.01	0.0023
1.0000	1192.8									
Average Absolute Percentage Deviation						1.23	0.11	2.15	0.24	
308.15 K										
0.0000	1253.2									
0.1051	1239.1	1245.7	1237.4	1224.6	1239.8	0.54	0.14	1.17	0.05	0.0028
0.1980	1226.8	1239.0	1225.1	1207.2	1229.7	0.99	0.14	1.60	0.23	0.0028
0.2998	1214.8	1231.3	1213.4	1188.7	1218.7	1.36	0.12	2.15	0.32	0.0023
0.3990	1203.2	1223.6	1203.4	1170.2	1207.8	1.07	0.02	2.74	0.38	0.0004
0.4944	1193.4	1216.0	1195.2	1152.2	1197.2	1.89	0.15	3.45	0.32	0.0031
0.5939	1188.1	1207.8	1188.0	1153.1	1191.4	1.66	0.01	2.95	0.28	0.0001
0.6961	1183.1	1199.1	1182.0	1155.6	1185.8	1.36	0.09	2.32	0.23	0.0019
0.7974	1178.3	1190.3	1177.3	1157.0	1180.1	1.01	0.08	1.80	0.15	0.0017
0.8985	1175.2	1181.1	1173.9	1160.5	1174.9	0.50	0.11	1.25	0.03	0.0023
1.0000	1171.6									
Average Absolute Percentage Deviation						1.22	0.10	2.16	0.22	

1	2	3	4	5	6	7	8	9	10	11
313.15 K										
0.0000	1227.4									
0.1051	1214.4	1220.6	1212.7	1199.6	1214.6	0.51	0.14	1.21	0.02	0.0028
0.1980	1203.1	1214.3	1201.3	1182.9	1205.1	0.93	0.15	1.68	0.17	0.0030
0.2998	1191.2	1207.4	1190.5	1165.4	1194.9	1.36	0.06	2.16	0.31	0.0012
0.3990	1180.4	120.3	1181.2	1148.3	1184.8	1.68	0.07	2.72	0.37	-0.0014
0.4944	1171.6	1193.3	1173.7	1131.8	1175.0	1.85	0.18	3.40	0.29	-0.0036
0.5939	1166.3	1185.8	1167.1	1132.9	1169.7	1.67	0.07	2.87	0.30	-0.0014
0.6961	1161.8	1177.8	1161.7	1135.0	1164.7	1.38	0.01	2.30	0.25	0.0003
0.7974	1158.1	1169.7	1157.5	1137.3	1159.7	1.00	0.06	1.80	0.14	0.0011
0.8985	1155.8	1161.3	1154.5	1141.0	1155.1	0.48	0.12	1.28	0.06	0.0023
1.0000	1152.6									
Average Absolute Percentage Deviation						1.21	0.10	2.16	0.21	
318.15 K										
0.0000	1205.6									
0.1051	1193.0	1199.2	1191.7	1178.6	1193.2	0.52	0.11	1.21	0.02	0.0023
0.1980	1181.8	1193.4	1180.8	1162.7	1184.2	0.98	0.08	1.62	0.20	0.0016
0.2998	1171.0	1186.8	1170.5	1146.1	1174.5	1.35	0.04	2.21	0.30	0.0008
0.3990	1160.8	1180.1	1161.8	1129.4	1164.7	1.66	0.09	2.71	0.34	-0.0017
0.4944	1152.1	1173.5	1154.7	1113.2	1155.3	1.86	0.23	3.38	0.28	-0.0045
0.5939	1147.5	1166.5	1148.5	1115.1	1150.7	1.65	0.09	2.83	0.27	-0.0018
0.6961	1143.4	1159.0	1143.4	1117.0	1145.9	1.36	0.00	2.31	0.22	0.0000
0.7974	1140.0	1151.3	1139.5	1120.1	1141.5	0.99	0.04	1.75	0.1	0.0008
0.8985	1138.1	1143.4	1136.8	1123.0	1137.1	0.47	0.11	1.33	0.08	0.0023
1.0000	1135.2									
Average Absolute Percentage Deviation						1.21	0.09	2.14	0.20	

Table 2. Experimental and predicted ultrasonic velocities and their percentage derivation and molecular interaction parameter for the iso-Propyl alcohol (1) – Benzene (2) system at different temperatures.

Mole fraction x_1	$U_{\text{exp}} \text{ ms}^{-1}$	Predicted Ultrasonic Velocity				Absolute Percentage Deviation				α
		NR	IMR	FLT	CFT	NR	IMR	FLT	CFT	
1	2	3	4	5	6	7	8	9	10	11
303.15 K										
0.0000	1278.2									
0.1005	1253.9	1265.1	1252.8	1239.5	1258	0.89	0.09	1.15	0.32	0.0017
0.1999	1232.1	1251.8	1230.8	1214.4	1240.9	1.6	0.1	1.44	0.71	0.002
0.3015	1212.4	1237.9	1211.2	1188.5	1223.2	2.1	0.1	1.97	0.89	0.002
0.4002	1194.8	1224.1	1194.6	1165.2	1206.4	2.45	0.02	2.47	0.97	0.0004
0.5002	1178.3	1209.8	1179.9	1143.2	1189.7	2.68	0.13	2.98	0.97	-0.0027
0.5996	1167.4	1195.3	1167.2	1135.8	1177.0	2.39	0.01	2.71	0.82	0.0003
0.6992	1157.3	1180.5	1156.4	1132.5	1165.3	2.00	0.08	2.14	0.7	0.0016
0.8002	1148.1	1165	1147.1	1128.5	1153.5	1.47	0.09	1.71	0.46	0.0017
0.9012	1140.4	1149.2	1139.4	1125	1141.6	0.77	0.08	1.35	0.11	0.0017
1.0000	1133.4									
Average Absolute Percentage Deviation						1.82	0.08	1.99	0.66	
308.15 K										
0.0000	1253.2									
0.1005	1229.4	1240.2	1228.1	1215.9	1233.3	0.88	0.10	1.1	0.32	0.0021
0.1999	1207.5	1227.1	1206.4	1191.1	1216.4	1.63	0.09	1.36	0.74	0.0018
0.3015	1188.5	1213.4	1187.1	1166.6	1199.2	2.1	0.12	1.84	0.90	0.0024
0.4002	1171.1	1199.8	1170.6	1144.7	1182.8	2.45	0.04	2.26	1.00	0.0008
0.5002	1155.2	1185.7	1156.1	1122.3	1166.1	2.66	0.10	2.83	0.96	-0.0019
0.5996	1144.2	1171.4	1143.7	1115.1	1153.6	2.38	0.05	2.55	0.82	0.0010
0.6992	1134.1	1156.7	1132.9	1113.8	1142.8	1.99	0.10	1.79	0.76	0.0020
0.8002	1124.4	1141.4	1123.8	1109.9	1131	1.52	0.06	1.29	0.59	0.0011
0.9012	1117.3	1125.8	1116.2	1106.3	1119.5	0.76	0.10	0.98	0.19	0.0020
1.0000	1110.2									
Average Absolute Percentage Deviation						1.82	0.08	1.78	0.70	

1	2	3	4	5	6	7	8	9	10	11
313.15 K										
0.0000	1227.4									
0.1005	1204.8	1215	1203.5	1190.8	1208.1	0.85	0.11	1.16	0.27	0.0022
0.1999	1183.5	1202.6	1182.8	1166.2	1191.6	1.61	0.06	1.46	0.69	0.0012
0.3015	1165.2	1189.5	1164.3	1142	1174.9	2.09	0.08	1.99	0.84	0.0016
0.4002	1148.9	1176.5	1148.6	1120.8	1159.2	2.4	0.03	2.45	0.89	0.0005
0.5002	1133.8	1163.1	1134.8	1098.1	1142.8	2.58	0.08	3.14	0.79	-0.0017
0.5996	1123.4	1149.4	112.9	1091.1	1130.8	2.32	0.05	2.88	0.66	0.0010
0.6992	1113.2	1135.4	1112.7	1090.2	1120.7	2.00	0.05	2.07	0.67	0.0010
0.8002	1104.4	1120.9	1103.9	1086.2	1109.5	1.49	0.04	1.65	0.46	0.0008
0.9012	1098.0	1106	1096.7	1082.7	1098.4	0.73	0.11	1.4	0.04	0.0023
1.0000	1091.1									
Average Absolute Percentage Deviation						1.79	0.07	2.02	0.59	
318.15 K										
0.0000	1205.6									
0.1005	1182.9	1193.3	1181.7	1169.1	1186.1	88	0.10	1.16	0.27	0.0021
0.1999	1161.8	1180.8	1161	1144.8	1169.7	1.63	0.07	1.46	0.68	0.0014
0.3015	1143.4	1167.7	1142.5	1121.4	1153.1	12.2	0.08	1.93	0.85	0.0016
0.4002	1126.6	1154.7	1126.8	1100.3	1137.4	2.49	0.02	2.34	0.95	-0.0004
0.5002	1112.1	1141.2	1113	1076.9	1120.7	2.62	0.08	3.16	0.77	-0.0016
0.5996	1101.3	1127.5	1101.1	1070.4	1108.9	2.38	0.02	2.80	0.69	0.0004
0.6992	1091.0	1113.5	1090.9	1069.4	1098.8	2.06	0.01	1.98	0.72	0.0003
0.8002	1082.5	1099	1082.1	1065.4	1087.7	1.52	0.04	1.58	0.48	0.0007
0.9012	1076.2	1084.1	1074.9	1061.3	1076.6	0.73	0.12	1.39	0.04	0.0024
1.0000	1069.2									
Average Absolute Percentage Deviation						1.83	0.06	1.98	0.61	

Table 3. Experimental and predicted ultrasonic velocities and their percentage derivation and molecular interaction parameter for the n-Butyl alcohol (1) – Benzene (2) system at different temperatures.

Mole fraction x_1	$U_{\text{exp}} \text{ ms}^{-1}$	Predicted Ultrasonic Velocity				Absolute Percentage Deviation				α
		NR	IMR	FLT	CFT	NR	IMR	FLT	CFT	
1	2	3	4	5	6	7	8	9	10	11
303.15 K										
0.0000	1278.2									
0.0998	1272.3	1272.8	1272.2	1262.6	1270.5	0.04	0.00	0.77	0.14	0.0001
0.1983	1265.1	1267.5	1266.5	1248.8	1263.3	0.19	0.11	1.29	0.14	-0.0023
0.3002	1257.3	1262.0	1260.8	1233.5	1255.6	0.38	0.28	1.89	0.14	-0.0056
0.4021	1250.3	1256.6	1255.2	1216.9	1247.5	0.51	0.40	2.67	0.22	-0.0079
0.5026	1242.3	1251.3	1249.9	1204.6	1240.5	0.73	0.61	3.04	0.14	-0.0122
0.6003	1238.8	1246.2	1244.9	1208.7	1237.7	0.60	0.49	2.43	0.09	-0.0098
0.6993	1235.5	1241.1	1240.0	1214.7	1235.2	0.45	0.36	1.69	0.03	-0.0072
0.8042	1232.4	1235.7	1234.9	1218.1	1231.8	0.27	0.20	1.16	0.05	-0.0040
0.9015	1229.1	1230.8	1230.3	1222.7	1229.1	0.14	0.10	0.52	0.00	-0.0020
1.0000	1225.8									
Average Absolute Percentage Deviation						0.37	0.28	1.72	0.11	
308.15 K										
0.0000	1253.2									
0.0998	1247.4	1247.9	1247.4	1237.4	1245.6	0.04	0.00	0.08	0.15	0.0000
0.1983	1240.6	1242.8	1241.9	1224.1	1238.5	0.18	0.10	1.33	0.17	-0.0021
0.3002	1232.5	1237.5	1236.3	1209.3	1231.0	0.40	0.31	1.88	0.13	-0.0062
0.4021	1225.2	1232.2	1230.9	1193.2	1223.0	0.57	0.47	2.16	0.18	-0.0093
0.5026	1217.9	1227.1	1225.7	1181.2	1216.2	0.76	0.64	3.01	0.14	-0.0128
0.6003	1215.3	1222.1	1220.9	1185.7	1213.6	0.56	0.46	2.44	0.14	-0.0091
0.6993	1212.1	1217.2	1216.1	1191.2	1211.2	0.42	0.33	1.72	0.08	-0.0065
0.8042	1209.1	1211.9	1211.1	1194.5	1208.0	0.23	0.17	1.21	0.09	-0.0033
0.9015	1205.6	1207.1	1206.7	1198.8	1205.3	0.13	0.09	0.56	0.03	-0.0018
1.0000	1202.3									
Average Absolute Percentage Deviation						0.37	0.28	1.73	0.12	

1	2	3	4	5	6	7	8	9	10	11
313.15 K										
0.0000	1227.4									
0.0998	1222.2	1222.6	1222.2	1211.8	1220.1	0.04	0.00	0.85	0.17	0.0000
0.1983	1216.0	1218.0	1217.2	1199.6	1213.7	0.16	0.10	1.35	0.19	-0.0020
0.3002	1208.7	1213.2	1212.2	1185.5	1206.6	0.37	0.29	1.92	0.17	-0.0058
0.4021	1201.4	1208.5	1207.3	1170.0	1199.2	0.59	0.49	2.61	0.18	-0.0098
0.5026	1194.9	1203.8	1202.7	1159.1	1192.9	0.75	0.65	3.00	0.17	-0.0129
0.6003	1192.6	1199.4	1198.3	1163.3	1190.7	0.57	0.47	2.46	0.16	-0.0094
0.6993	1190.2	1194.9	1193.9	1169.2	1188.8	0.39	0.31	1.77	0.12	-0.0062
0.8042	1187.6	1190.2	1189.5	1172.4	1186.0	0.22	0.16	1.28	0.13	-0.0031
0.9015	1184.4	1185.9	1185.4	1177.0	1183.8	0.12	0.09	0.62	0.05	-0.0018
1.0000	1181.5									
Average Absolute Percentage Deviation						0.36	0.28	1.76	0.15	
318.15 K										
0.0000	1205.6									
0.0998	1200.2	1201.0	1200.5	1189.5	1198.2	0.07	0.02	0.89	0.17	-0.0005
0.1983	1193.5	1196.4	1195.6	1177.8	1191.9	0.24	0.17	1.31	0.14	-0.0035
0.3002	1186.6	1191.7	1190.7	1164.3	1185.0	0.43	0.34	1.88	0.14	-0.0068
0.4021	1179.1	1187.0	1185.9	1149.4	1177.7	0.67	0.57	2.52	0.12	-0.0114
0.5026	1173.1	1182.5	1181.3	1138.3	1171.4	0.80	0.70	2.97	0.15	-0.0138
0.6003	1171.5	1178.1	1177.0	1142.8	1169.4	0.56	0.47	2.45	0.18	-0.0093
0.6993	1169.0	1173.7	1172.7	1148.4	1167.5	0.40	0.32	1.76	0.13	-0.0063
0.8042	1166.1	1169.0	1168.3	1151.4	1164.8	0.25	0.19	1.26	0.11	-0.0038
0.9015	1163.3	1164.8	1164.4	1155.7	1162.6	0.13	0.09	0.65	0.06	-0.0019
1.0000	1160.5									
Average Absolute Percentage Deviation						0.39	0.32	1.74	0.13	

Table 4. Experimental and predicted ultrasonic velocities and their percentage derivation and molecular interaction parameter for the sec-Butyl alcohol (1) – Benzene (2) alcohol system at different temperatures.

Mole fraction x_1	$U_{\text{exp}} \text{ ms}^{-1}$	Predicted Ultrasonic Velocity				Absolute Percentage Deviation				α
		NR	IMR	FLT	CFT	NR	IMR	FLT	CFT	
1	2	3	4	5	6	7	8	9	10	11
303.15 K										
0.0000	1278.2									
0.1013	1267.6	1269.6	1268.7	1256.3	1266.9	0.16	0.09	0.89	0.05	-0.0017
0.2018	1256.2	1261.2	1259.6	1236.9	1256.2	0.40	0.27	1.54	0.00	-0.0054
0.3029	1245.5	1252.9	1250.8	1219.6	1245.8	1.59	0.42	2.08	0.03	-0.0084
0.4024	1235.1	1244.7	1242.4	1200.2	1234.9	0.78	0.59	2.82	0.01	-0.0117
0.5045	1223.9	1236.5	1234.1	1186.5	1225.2	1.03	0.83	3.06	0.11	-0.0165
0.5998	1218.1	1228.8	1226.6	1188.4	1219.9	0.88	0.70	2.44	0.15	-0.0138
0.7001	1212.8	1220.9	1219.0	1189.5	1214.1	0.67	0.51	1.92	0.10	-0.0101
0.8011	1207.9	1213.0	1211.5	1191.4	1208.3	0.42	0.30	1.37	0.04	-0.0060
0.8981	1202.8	1205.4	1204.6	1194.3	1203.1	0.22	0.15	0.71	0.02	-0.0030
1.0000	1197.6									
Average Absolute Percentage Deviation						0.57	0.43	1.87	0.06	
308.15 K										
0.0000	1253.2									
0.1013	1243.3	1245.1	1244.3	1231.4	1242.3	0.15	0.08	0.96	0.08	-0.0015
0.2018	1232.5	1237.2	1235.7	1213.2	1232.1	0.38	0.26	1.56	0.03	-0.0052
0.3029	1221.5	1229.3	1227.4	1196.0	1222.0	0.64	0.48	2.09	0.04	-0.0095
0.4024	1211.9	1221.6	1219.5	1177.9	1211.7	0.80	0.62	2.81	0.02	-0.0124
0.5045	1201.7	1213.8	1211.6	1164.6	1202.4	1.01	0.83	3.09	0.06	-0.0163
0.5998	1196.1	1206.6	1204.5	1166.5	1197.5	0.88	0.70	2.48	0.11	-0.0139
0.7001	1191.3	1199.1	1197.3	1168.1	1192.1	0.66	0.50	1.95	0.07	-0.0100
0.8011	1186.5	1191.6	1190.3	1169.9	1186.8	0.43	0.32	1.40	0.03	-0.0063
0.8981	1181.5	1184.5	1183.7	1173.3	1182.1	0.22	0.16	0.72	0.01	-0.0031
1.0000	1177.1									
Average Absolute Percentage Deviation						0.58	0.44	1.89	0.05	

1	2	3	4	5	6	7	8	9	10	11
313.15 K										
0.0000	1227.4									
0.1013	1218.6	1220.2	12194	1206.2	1217.1	0.13	0.07	1.20	0.12	-0.0013
0.2018	1208.8	1213.1	1211.8	1188.9	1207.7	0.35	0.25	1.64	0.09	-0.0049
0.3029	1198.2	1206.0	1204.3	1173.2	1198.5	0.65	0.51	2.09	0.03	-0.0101
0.4024	1189.2	1199.1	1197.2	1156.5	1189.1	0.83	0.67	2.75	0.01	-0.0134
0.5045	1180.0	1192.1	1190.2	1144.5	1180.7	1.02	0.86	3.01	0.06	-0.0170
0.5998	1175.5	1185.6	1183.8	1146.4	1176.4	0.86	0.71	2.47	0.07	-0.0140
0.7001	1171.1	1178.9	1171.3	1148.2	1171.7	0.66	0.53	1.96	0.05	-0.1050
0.8011	1167.0	1172.1	1171.0	1150.7	1167.2	0.44	0.34	1.40	0.02	-0.0068
0.8981	1163.3	1165.8	1165.1	1154.7	1163.2	0.21	0.15	0.75	0.01	-0.0031
1.0000	1159.1									
Average Absolute Percentage Deviation						0.57	0.45	1.90	0.05	
318.15 K										
0.0000	1205.6									
0.1013	1196.8	1198.6	1197.8	1184.4	1195.3	0.15	0.09	1.04	0.12	-0.0017
0.2018	1186.9	1191.7	1190.4	1168.1	1186.2	0.40	0.25	1.58	0.05	-0.0058
0.3029	1176.8	1184.8	1183.1	1152.7	1177.2	0.68	0.54	2.05	0.04	-0.0107
0.4024	1168.0	1178.1	1176.2	1136.4	1168.0	0.86	0.70	2.71	0.00	-0.0139
0.5045	1159.1	1171.2	1169.4	1124.5	1159.7	1.05	0.89	2.98	0.05	-0.0175
0.5998	1154.7	1164.9	1163.2	1126.6	1155.6	0.89	0.73	2.43	0.08	-0.0145
0.7001	1150.8	1158.4	1156.8	1128.5	1151.2	0.66	0.53	1.93	0.03	-0.0104
0.8011	1146.8	1151.8	1150.7	1130.6	1146.8	0.44	0.34	1.41	0.00	-0.0067
0.8981	1143.1	1145.6	1144.9	1134.7	1143.0	0.22	0.16	0.74	0.01	-0.0032
1.0000	1139.1									
Average Absolute Percentage Deviation						0.59	0.47	1.87	0.04	

Table 5. Experimental and predicted ultrasonic velocities and their percentage derivation and molecular interaction parameter for the tert-Butyl alcohol (1) – Benzene (2) system at different temperatures.

Mole fraction x_1	$U_{\text{exp}} \text{ ms}^{-1}$	Predicted Ultrasonic Velocity				Absolute Percentage Deviation				$\alpha\alpha$
		NR	IMR	FLT	CFT	NR	IMR	FLT	CFT	
1	2	3	4	5	6	7	8	9	10	11
303.15 K										
0.0000	1278.2									
0.1012	1253.1	1259.5	1256.3	1241.5	1257.1	0.50	0.26	0.93	0.32	-0.0051
0.1998	1230.2	1241.4	1236.3	1212.1	1237.6	0.91	0.50	1.47	0.60	-0.0098
0.3024	1208.3	1223.1	1216.7	1184.9	1218.0	1.22	0.69	1.94	0.80	-0.0137
0.4014	1188.2	1205.8	1198.8	1158.1	1198.6	1.48	0.89	2.53	0.88	-0.0176
0.5017	1169.1	1188.7	1181.7	1137.2	1180.4	1.68	1.08	2.73	0.97	-0.0212
0.6029	1155.3	1171.8	1165.4	1129.5	1165.5	1.43	0.87	2.23	0.89	-0.0172
0.7048	1142.4	1155.2	1149.8	1122.4	1150.6	1.12	0.64	1.75	0.72	-0.0128
0.8024	1130.9	1139.5	1135.6	1116.9	1136.6	0.76	0.41	1.24	0.51	-0.0082
0.8942	1120.6	1125.1	1122.9	1111.5	1123.3	0.41	0.20	0.81	0.25	-0.0040
1.0000	1108.9									
Average Absolute Percentage Deviation						1.06	0.62	1.74	0.66	
308.15 K										
0.0000	1253.2									
0.1012	1228.5	1234.7	1231.7	1216.4	1232.2	0.50	0.26	0.99	0.30	-0.0052
0.1998	1206.1	1217.0	1212.0	1187.8	1213.1	0.90	0.49	1.51	0.58	-0.0097
0.3024	1183.9	1199.0	1192.7	1161.4	1193.8	1.28	0.74	1.90	0.83	-0.0146
0.4014	1164.2	1182.0	1175.1	1135.5	1174.8	1.53	0.94	2.47	0.91	-0.0185
0.5017	1146.1	1165.2	1158.3	1114.7	1156.7	1.67	1.06	2.74	0.93	-0.0209
0.6029	1132.8	1148.6	1142.2	1107.0	1142.2	1.39	0.83	2.27	0.83	-0.0164
0.7048	1119.4	1132.2	1126.9	1100.5	1127.7	1.14	0.67	1.69	0.74	-0.0132
0.8024	1108.2	1116.8	1112.9	1094.6	1113.9	0.78	0.43	1.23	0.51	-0.0085
0.8942	1098.2	1102.7	1100.4	1088.8	1100.7	0.41	0.20	0.85	0.23	-0.0040
1.0000	1086.7									
Average Absolute Percentage Deviation						1.07	0.62	1.74	0.65	

1	2	3	4	5	6	7	8	9	10	11
313.15 K										
0.0000	1227.4									
0.1012	1203.7	1209.4	1206.6	1190.7	1206.7	0.47	0.24	1.08	0.25	-0.0047
0.1998	1182.0	1192.2	1187.5	1163.1	1188.1	0.87	0.46	1.60	0.52	-0.0092
0.3024	1160.2	1174.8	1168.8	1138.1	1169.5	1.26	0.74	1.90	0.80	-0.0146
0.4014	1140.9	1158.3	1151.7	1113.0	1151.0	1.53	0.95	2.45	0.89	-0.0187
0.5017	1123.5	1142.0	1135.4	1092.8	1133.5	1.64	1.06	2.73	0.89	-0.0209
0.6029	1110.0	1125.9	1119.8	1085.3	1119.4	1.43	0.88	2.23	0.84	-0.0174
0.7048	1097.5	1110.0	1104.9	1078.8	1105.4	1.14	0.68	1.70	0.72	-0.0134
0.8024	1086.5	1095.1	1091.4	1073.0	1091.9	0.79	0.45	1.25	0.50	-0.0089
0.8942	1077.1	1081.4	1079.2	1067.7	1079.3	0.40	0.20	0.88	0.20	-0.0040
1.0000	1065.9									
Average Absolute Percentage Deviation						1.06	0.63	1.76	0.62	
318.15 K										
0.0000	1205.6									
0.1012	1182.0	1187.9	1185.0	1169.2	1184.9	0.49	0.25	1.08	0.25	-0.0050
0.1998	1160.0	1170.9	1166.1	1142.1	1166.6	0.90	0.49	1.58	0.53	-0.0097
0.3024	1138.9	1153.6	1147.6	1117.5	1148.2	1.29	0.76	1.88	0.82	-0.0150
0.4014	1119.3	1137.3	1130.7	1092.8	1129.3	1.60	1.02	2.37	0.95	-0.0201
0.5017	1102.3	1121.1	1114.6	1073.3	1112.7	1.71	1.11	2.63	0.94	-0.0219
0.6029	1089.1	1105.2	1099.2	1065.6	1098.7	1.47	0.92	2.16	0.88	-0.0182
0.7048	1077.0	1089.5	1084.4	1058.9	1084.8	1.16	0.69	1.68	0.73	-0.0137
0.8024	1066.1	1074.8	1071.1	1052.7	1071.5	0.81	0.47	1.25	0.51	-0.0093
0.8942	1056.8	1061.2	1059.1	1047.6	1059.1	0.42	0.21	0.87	0.22	-0.0043
1.0000	1045.9									
Average Absolute Percentage Deviation						1.09	0.66	1.72	0.65	

While molecular interaction parameter values are positive as well as negative in the benzene + propanol [s] systems, they are only negative in the benzene + butanol [s] systems at all temperatures. This indicates the presence of somewhat stronger interaction in the propanol [s] systems compared to butanol [s] systems.

5. CONCLUSION

Comparison of the theoretically estimated ultrasonic velocities using NR, IMR, CFT and FLT with the experimental values shows that the CFT is preferable than the FLT and the IMR more satisfactorily proclaims for the observed values, than that of the NR.

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