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Research Article

Computation of Ultrasonic Speed in Ternary Liquid Mixtures using Empirical Theories

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ABSTRACT
The most powerful four empirical theories of sound speed, proposed for binary liquid mixtures successfully are applied in the present work, for five ternary liquid mixtures, namely chlorobenzene + cyclohexane + n-heptane, chlorobenzene + cyclohexane + n-hexadecane, chlorobenzene + cyclohexane + isooctane, chlorobezene + isooctane + n-heptane and 1-chloronaphthalene + isooctane + n-heptane at 298.15K. These theories are: Nomoto relation, ideal mixing relation of Van Dael, Eyring-Jacobson free length theory and Schaaffs collision factor theory. The experimental values of sound speed in the aforesaid ternary mixture were measured in our lab. In the present works these four empirical theories were applied to the aforesaid ternary mixtures. A comparative study of these theories is also made and excellent results were obtained. These theories have also been employed, in the present work, to study the interactions occurring in the system.

KEYWORDS: Ultrasonic speed; density; heat capacity; ternary liquid mixture

INTRODUCTION

For the first time in the year 1994, Patterson and co-workers [1] measured accurately and precisely the density and heat capacity of five ternary systems at 298.15K. These systems include chlorobenzene + cyclohexane + n-heptane, chlorobenzene + cyclohexane + n-hexadecane, chlorobenzene + cyclohexane + isooctane, chlorobezene + isooctane + n-heptane and 1-chloronaphthalene + isooctane + n-heptane. Subsequently, Sharma and others [2, 3] measured the density and ultrasonic speed of the aforesaid ternary mixtures. Nomoto [4], Van Dael [5], free length [8] and Schaaffs collision factor theories [7] have been applied to few ternary systems [8, 9]. In all these papers the experimental data of sound speed and density have been taken from literature. In the present work, an attempt has been made to test the validity of aforesaid theories for five ternary mixtures for which velocity and density were measured at 25°C [2, 3]. The importance of these systems has been outlined by Patterson and co-workers [1].

FORMULATION

Assuming the linearity of molecular sound velocity and no volume change on mixing

Nomoto [4] established the relation for the sound speed (u) in binary mixtures which can be extended for ternary liquid mixture as

$$u_{mix} = \left(\frac{R_{mix}}{V_{mix}}\right)^3 = \left(\frac{x_1R_1 + x_2R_2 + x_3R_3}{x_1V_1 + x_2V_2 + x_3V_3}\right)^3 \quad (1)$$

where R_{mix} and V_{mix} are the additive molar sound speed and molar volume of the mixture respectively and are represented as follows

$$R_{mix} = x_1R_1 + x_2R_2 + x_3R_3 \quad (2)$$

$$V_{mix} = x_1V_1 + x_2V_2 + x_3V_3 \quad (3)$$

Molar sound speed (u) is related to the molecular weight (M) and density (ρ) by the relation

$$R_{mix} = \frac{M_{mix}}{\rho_{mix}}.u_{mix}^{1/3} = \left[\frac{x_1M_1 + x_2M_2 + x_3M_3}{\rho_{mix}}\right]u_{mix}^{1/3} \quad (4)$$

or,

$$R_{mix} = V_{mix}u_{mix}^{1/3} \quad (5)$$

According to the theory of ideal mixing relation, Van Dael [5] obtained the following relation:-

$$\frac{1}{x_1M_1 + x_2M_2 + x_3M_3}.\frac{1}{u_{mix}^2} = \frac{x_1}{M_1u_1^2} + \frac{x_2}{M_2u_2^2} + \frac{x_3}{M_3u_3^2} \quad (6)$$

According to the Eyring and Hirschfelder [10] the intermolecular free length (L_f) of a pure liquid is given by

$$L_f = 2\frac{V_a}{Y} \quad (7)$$

where V_a is the available volume and is equal to

$$V_a = V_T - V_O$$

where V_T and V_O stand for molar volume at temperature T and at absolute zero respectively at particular pressure, Y is the surface area per mole. V_O and Y can be expressed as

$$V_0 = V_T\left(1 - \frac{T}{T_c}\right)^{0.3} \quad (8)$$

$$Y = (36\pi NvV_0^2)^{1/3} \quad (9)$$

where T_C and N stand for critical temperature and Avogadro number. Assuming the additive of surface area, L_f of a ternary mixture is given by

$$L_{f(123)} = 2\frac{\left[V_{T(123)} - \{x_1V_1 + x_2V_2 + x_3V_3\}\right]}{\left(x_1Y_1 + x_2Y_2 + x_3Y_3\right)} \quad (10)$$

The value of $L_{f(123)}$, so obtained is known as thermodynamic L_f. On the above basis, Jacobson [6] obtained the following expression for the sound velocity in the liquid mixture which for the ternary mixture can be written as

$$u_{123} = \frac{K}{L_{f(123)}\rho_{123}^{1/2}} \quad (11)$$

where K is the temperature dependent Jacobson constant. The value of K at 25°C is 623.34.

In the Collision factor theory, Schaaffs [7] gave the following relation for the available volume and sound speed in pure liquids:

$$V_a = V_T\left[\left(1 - \frac{u}{u_\infty}\right)\right] \quad (12)$$

$$u = u_\infty Sr_j = u_\infty S\frac{B}{V_B} \quad (13)$$

where u_∞ =1600ms^{-1}, S is the collision factor, r_j =B/V_M =space filling factor, where in turn B=actual volume of the molecule per mole an V_M is the molar volume. This concept was in turn extended to binary liquid mixture by Kuhnkies and Schaaffs [11], which can further be extended to ternary mixture as

$$u_{123} = u_\infty\left[x_1S_1 + x_2S_2 + x_3S_3\right]\left(x_1B_1 + x_2B_2 + x_3B_3\right) \quad (14)$$

The actual value of the molecule per mole can be obtained from the relation

$$B = \frac{4\pi}{3}r_m^3N$$

where r_m stands for the molecular radius and N the Avogadro number. In the computation of B, the average value of r_m can be obtained from relations of Schaaffs or Gopala Rao et al. The values of B, thus obtained, has been used to compute S by the relation

$$S = \frac{uV}{Bu_\infty} \quad (15)$$

The values of S obtained by the above equation have been employed to calculate the ultrasonic velocity in ternary mixtures by eq (15).

RESULTS & DISCUSSION

In the present work, various theories namely Nomoto [4], Ideal mixing [12], Collision factor [9] and Free length [8] have been extended for ternary liquid mixtures. Their validity has been tested by evaluating the ultrasonic velocity in ternary liquid mixtures:

(I) chlorobenzene(1) +cyclohexane (2)+ n-heptane (3)

(II) chlorobenzene(1) + cyclohexane(2) + n-hexadecane(3)

(III) chlorobenzene(1) + cyclohexane(2) + isooctane(3)

(IV) chlorobezene(1) + isooctane(2) + n-heptane(3)

(V) 1-chloronaphthalene(1) + isooctane(2) + n-heptane(3)

The ultrasonic speeds in the above mixtures were measured accurately and precisely at 298.15K in our lab [3]. The density values were

taken from the paper of Patterson et al [1]. The values of ultrasonic speed obtained from various theories for ternary liquid mixtures have been recorded in the Tables 1 to 5, for all the systems (I to V) undertaken in the present study at 298.15 K. We have used our own experimental data [3] for the comparison of theoretical ultrasonic velocity obtained from various theories as reported earlier. A close perusal of Tables 1 to 5, reveals that the computed ultrasonic speed using Nomoto's relation, theory of ideal mixing and collision mixing theory (CFT) compares well with our own experimental data, whereas free length theory (FLT) shows relatively larger deviations than other theories. The percentage deviations between experimental values and theoretical predictions have also been reported in Tables 1 to 5.

Table 1: Comparison between observed and theoretical values of ultrasonic velocity of system – I

Chlorobenzene (X_1) + Cyclohexane (X_2) + n-Heptane (X_3)										
x_1	x_2	u_{exp} (ms^{-1})	u_{nomoto}	$u_{vandael}$	u_f	u_{df}	% Δu_{nomoto}	% $u_{vandael}$	% Δu_f	% Δu_f
X_2 (Cyclohexane) = 0.1883										
0.0773	0.1737	1169.3	1169.3	1156.3	1181.4	1161.2	0	1.1	1.0	0.7
0.1375	0.1624	1173.6	1173.6	1160.0	1184.5	1167.5	0	1.2	0.9	0.5
0.1954	0.1515	1178.3	1178.3	1163.9	1189.1	1173.0	0	1.2	0.9	0.4
0.2975	0.1323	1187.1	1187.1	1171.2	1198.1	1182.6	0	1.3	0.9	0.4
0.4062	0.1118	1197.3	1197.3	1179.6	1208.1	1192.7	0	1.5	0.9	0.4
0.5038	0.0934	1207.2	1207.2	1187.9	1220.5	1201.5	0	1.6	1.1	0.5
0.5918	0.0769	1216.7	1216.7	1196.0	1233.3	1209.2	0	1.7	1.4	0.6
0.6974	0.0570	1229.0	1229.0	1206.4	1250.4	1218.2	0	1.8	1.7	0.9
0.7969	0.0382	1241.4	1241.4	1217.1	1269.0	1226.3	0	2.0	2.2	1.2
0.8660	0.0252	1250.5	1250.5	1224.9	1282.8	1231.7	0	2.0	2.6	1.5
0.9380	0.0117	1260.4	1260.4	1233.6	1298.4	1237.0	0	2.1	3.3	1.9
%Average							**0**	**1.6**	**1.5**	**0.8**
X_2 (Cyclohexane) = 0.3138										
0.7660	0.2898	1178.4	1178.4	1169.4	188.4	1175.7	0	0.8	0.8	0.2
0.1233	0.2751	1181.6	1181.6	1171.6	1192.3	1179.5	0	0.8	0.9	0.2
0.2040	0.2498	1187.4	1187.4	1175.8	1197.4	1185.8	0	1.0	0.8	0.1
0.3078	0.2172	1195.5	1195.5	1181.7	1206.1	1193.9	0	1.2	0.9	0.1
0.4009	0.1880	1203.5	1203.5	1187.7	1214.1	1201.1	0	1.3	0.9	0.2
0.5028	0.1560	1212.9	1212.9	1194.8	1226.1	1208.7	0	1.5	1.1	0.4
0.5868	0.1297	1221.3	1221.3	1201.3	1238.8	1214.8	0	1.6	1.4	0.5
0.6983	0.0947	1233.1	1233.1	1210.8	1254.0	1226.6	0	1.8	1.7	0.9
0.7952	0.0643	1244.1	1244.1	1219.8	1271.1	1229.0	0	2.0	2.2	1.2
0.8683	0.0413	1252.8	1252.8	1227.1	1285.0	1233.7	0	2.1	2.6	1.5
0.9379	0.0195	1261.3	1261.3	1234.5	1299.2	1237.9	0	2.1	3.0	1.9
%Average							**0**	**1.5**	**1.5**	**0.7**
X_2 (Cyclohexane) = 0.3997										
0.0756	0.3695	1185.2	1185.2	1178.6	1195.6	1185.3	0	0.6	0.9	0.0
0.1258	0.3494	1188.2	1188.2	1180.4	1198.1	1188.7	0	0.7	0.8	0.0
0.1939	0.3222	1192.7	1192.7	1183.2	1201.6	1193.4	0	8.0	0.7	0.1

0.2912	0.2833	1199.6	1199.6	1187.7	1208.9	1999.9	0	1.0	0.8	0.0
0.4011	0.2394	1208.3	1208.3	1193.5	1218.1	1207.1	0	1.2	0.8	0.1
0.7118	0.1152	1237.3	1237.3	1214.8	1259.5	1226.3	0	1.8	1.8	0.9
0.8119	0.0752	1247.9	1247.9	1223.2	1275.0	1231.9	0	2.0	2.2	1.3
0.8687	0.0525	1254.2	1254.2	1228.4		1235.0	0	2.1		1.5
0.9395	0.0242	1262.2	1262.2	1235.3	1300.2	1238.6	0	2.1	3.0	1.9
%Average							**0**	**1.5**		**0.7**
X_2 (Cyclohexane) = 0.5410										
0.0692	0.5036	1196.8	1196.8	1194.1	1206.7	1200.8	0	0.2	0.8	0.3
0.1217	0.4752	1199.4	1199.4	1195.0	1208.3	1203.4	0	0.4	0.7	0.3
0.2004	0.4326	1203.6	1203.6	1196.8	1210.2	1207.3	0	0.6	0.5	0.3
0.2864	0.3861	1208.8	1208.8	1199.2	1215.9	1211.5	0	0.8	0.6	0.2
0.3960	0.3268	1216.2	1216.2	1203.1	1224.6	1216.8	0	1.1	0.7	0.0
0.5059	0.2673	1224.5	1224.5	1207.9	1234.9	1221.9	0	1.4	0.9	0.2
0.6077	0.2122	1232.8	1232.8	1213.2	1246.9	1226.5	0	1.6	1.1	0.5
0.6996	0.1625	1240.8	1240.8	1218.6	1260.0	1230.4	0	1.8	1.6	0.8
0.8030	0.1066	1250.3	1250.3	1225.6	1276.3	1234.6	0	2.0	2.1	1.3
0.8756	0.0673	1257.1	1257.1	1231.0	1288.5	1237.3	0	2.1	2.5	1.6
0.9378	0.0337	1263.1	1263.1	1236.1	1300.1	1239.5	0	2.1	2.9	1.9
%Average							**0**	**1.3**	**1.3**	**0.7**
X_2 (Cyclohexane) = 0.6776										
0.0734	0.6279	1209.9	1209.9	1209.8	1219.2	1216.3	0	0.0	0.8	0.6
0.1289	0.5903	1211.5	1211.5	1209.7	1219.8	1218.1	0	0.2	0.7	0.5
0.3074	0.4693	1219.9	1219.9	1211.2	1226.9	1223.8	0	0.7	0.6	0.3
0.4018	0.4053	1225.3	1225.3	1213.0	1232.5	1226.7	0	1.0	0.6	0.1
0.5099	0.3321	1232.1	1232.1	1215.9	1242.6	1229.9	0	1.3	0.9	0.2
0.6047	0.2679	1238.6	1238.6	1219.3	1251.8	1232.6	0	1.6	1.1	0.5
0.7047	0.2001	1246.0	1246.0	1223.6	1264.4	1235.2	0	1.8	1.5	0.9
0.7995	0.1359	1253.3	1253.3	1228.5	1278.1	1237.5	0	2.0	2.0	1.9
0.8697	0.0883	1258.8	1258.8	1232.6	1289.6	1239.1	0	2.1	2.4	1.6
0.9398	0.0408	1264.4	1264.4	1237.2	1301.7	1240.4	0	2.2	2.9	1.9
%Average							**0**	**1.3**	**1.3**	**0.8**
X_2 (Cyclohexane) = 0.8502										
0.0784	0.7835	1227.0	1227.0	1230.1	1234.4	1235.6	0	0.3	0.6	0.7
0.1316	0.7383	1228.1	1228.1	1228.7	1232.7	1236.1	0	0.1	0.4	0.7
0.2182	0.6647	1203.3	1203.3	1226.9	1233.5	1237.0	0	0.3	0.3	0.5
0.4115	0.5003	1237.4	1237.4	1225.5	1239.1	1238.9	0	1.0	0.1	0.1
0.5136	0.4135	1242.2	1242.2	1226.0	1247.0	1239.8	0	1.3	0.4	0.2
0.5967	0.3429	1246.4	1246.4	1227.1	1254.9	1240.4	0	1.5	0.7	0.5
0.6944	0.2598	1251.7	1251.7	1229.2	1265.3	1241.0	0	1.8	1.1	0.9
0.7987	0.1711	1257.6	1257.6	1232.4	1279.3	1241.4	0	2.0	1.7	1.3
0.8676	0.1126	1261.6	1261.6	1235.1	1289.9	1241.6	0	2.1	2.2	1.6
0.9414	0.0498	1265.9	1265.9	1238.4	1302.0	1241.6		2.2	2.9	1.9
%Average							**0**	**1.2**	**1.0**	**0.8**

Table 2: Comparison between observed and theoretical values of ultrasonic velocity of system – II

Chlorobenzene (X_1) + Cyclohexane (X_2) + n-hexadecane (X_3)										
x_1	x_2	u_{exp} (ms^{-1})	u_{nomoto}	$u_{vandael}$	u_f	u_{df}	% Δu_{nomoto}	% $u_{vandael}$	% Δu_f	% Δu_{df}
X_2 (Cyclohexane) = 0.5049										
0.0546	0.4773	1051.3	1051.3	1088.3	951.4	1193.8	0	3.5	9.5	13.6
0.0696	0.4697	1052.7	1052.7	1090.2	953.2	778.4	0	3.6	9.4	26.1
0.0794	0.4648	1053.6	1053.6	1091.4	954.4	781.1	0	3.6	9.4	25.9
0.0897	0.4596	1054.6	1054.6	1092.8	955.7	783.9	0	3.6	9.4	25.7
0.0993	0.4547	1055.5	1055.5	1094.0	956.9	786.5	0	3.7	9.3	25.5
0.1090	0.4498	1056.4	1056.4	1095.3	958.1	789.2	0	3.7	9.3	25.3
0.1243	0.4421	1057.9	1057.9	1097.3	960.1	793.5	0	3.7	9.2	25.0
0.1341	0.4371	1058.9	1058.9	1098.6	961.3	796.3	0	3.7	9.2	24.8
0.1448	0.4317	1059.9	1059.9	1100.0	962.7	799.4	0	3.8	9.2	24.6
%Average							**0**	**3.7**	**9.3**	**24.0**

Table 3: Comparison between observed and theoretical values of ultrasonic velocity of system – III

Chlorobenzene (X_1) + Cyclohexane (X_2) + Isooctane (X_3)										
x_1	x_2	u_{exp} (ms^{-1})	u_{nomoto}	$u_{vandael}$	u_f	u_{df}	% Δu_{nomoto}	% $u_{vandael}$	% Δu_f	% Δu_{df}
X_2 (Cyclohexane) = 0.1500										
0.0537	0.1419	1056.9	1056.9	1114.6	2046.9	1243.2	0	5.5	93.7	17.6
0.0693	0.1396	1061.5	1061.5	1116.6	1969.8	1122.4	0	5.2	85.6	5.7
0.0789	0.1382	1064.4	1064.4	1117.4	1924.8	1123.4	0	5.0	80.8	5.6
0.0886	0.1367	1067.4	1067.4	1118.5	1881.3	1125.1	0	4.8	76.3	5.4
0.1075	0.1339	1073.2	1073.2	1120.7	1801.3	1127.6	0	4.4	67.8	5.1
0.1080	0.1338	1073.3	1073.3	1120.7	1799.3	1127.7	0	4.4	67.6	5.1
0.1225	0.1316	1077.9	1077.9	1122.4	1742.0	1129.6	0	4.1	61.6	4.8
0.1332	0.1300	1081.2	1081.2	1123.6	1701.8	1131.1	0	3.9	57.4	4.6
0.1422	0.1287	1081.1	1081.1	1124.6	1669.2	1132.3	0	3.7	54.0	4.5
0.1526	0.1271	1087.4	1087.4	1125.8	1633.0	1133.7	0	3.5	50.2	4.3
%Average							**0**	**4.5**	**69.5**	**6.3**
X_2 (Cyclohexane) = 0.2758										
0.0539	0.2609	1119.1	1119.1	1133.1	5887.7	1248.1	0	1.3	426.1	11.5
0.0693	0.2567	1123.6	1123.6	1134.2	5162.7	1248.7	0	0.9	359.5	11.1
0.0787	0.2541	1126.4	1126.4	1134.9	4001.1	1249.1	0	0.8	326.2	10.9
0.0884	0.2514	1129.2	1129.2	1135.6	4474.5	1249.4	0	0.6	296.2	10.6
0.0981	0.2487	1132.1	1132.1	1136.4	4189.2	1294.8	0	0.4	270.0	10.4
0.1074	0.2462	1134.9	1134.9	1137.1	3946.9	1250.1	0	0.2	247.8	10.2
0.1227	0.2420	1139.5	1139.5	1138.2	3902.4	1250.7	0	0.1	216.1	9.8
0.1325	0.2393	1142.5	1142.5	1139.0	3410.7	1251.0	0	0.3	198.5	9.5

0.1426	0.2365	1145.6	1145.6	1139.8	3232.7	1251.4	0	0.5	182.2	9.2
0.1591	0.2319	1150.7	1150.7	1141.1	2977.4	1251.9	0	0.8	158.7	8.8
0.1615	0.2313	1151.4	1151.4	1141.3	2943.4	1252.0	0	0.6	268.1	10.2
%Average							**0**	**0.6**	**268.1**	**10.2**
X_2 (Cyclohexane) = 0.4689										
0.0479	0.4464	1145.5	1145.5	1161.7	3266.8	1255.8	0	1.4	185.2	9.6
0.0573	0.4420	1148.2	1148.2	1162.1	3123.3	1256.0	0	1.2	172.0	9.4
0.0667	0.4376	1150.8	1150.8	1162.5	2991.4	1256.1	0	1.0	159.9	9.2
0.0767	0.4329	1153.6	1153.6	1163.0	2862.5	1256.3	0	0.8	148.1	8.9
0.0858	0.4287	1156.2	1156.2	1163.4	2754.1	1256.4	0	0.6	138.2	8.7
0.0957	0.4240	1159.1	1159.1	1163.8	2644.8	1256.5	0	0.4	128.2	8.4
0.1049	0.4197	1161.7	1161.7	1164.3	2550.5	1256.7	0	0.2	119.6	8.2
0.1146	0.4152	1164.5	1164.5	1164.7	2457.8	1256.8	0	0.0	111.1	7.9
0.1241	0.4107	1167.2	1167.2	1165.2	2373.1	1256.9	0	0.2	103.3	7.7
%Average							**0**	**0.7**	**140.6**	**8.7**
X_2 (Cyclohexane) = 0.7007										
0.0475	0.6674	1183.9	1183.9	1198.7	1995.9	1259.5	0	1.2	68.6	6.4
0.0571	0.6607	1186.4	1186.4	1198.7	1943.2	1259.5	0	1.0	63.8	6.2
0.0665	0.6541	1188.9	1188.9	1198.8	1894.2	1259.4	0	0.8	59.3	5.9
0.0762	0.6473	1191.5	1191.5	1198.8	1846.0	1259.4	0	0.6	54.9	5.7
0.0858	0.6406	1194.0	1194.0	1198.9	1800.6	1259.3	0	0.4	50.8	5.5
0.0956	0.6337	1196.8	1196.6	1198.9	1756.4	1259.3	0	0.2	46.8	5.2
0.1044	0.6275	1198.9	1198.9	1199.0	1718.5	1259.2	0	0.0	43.3	5.0
0.1139	0.6209	1201.5	1201.5	1199.1	1679.3	1259.2	0	0.2	39.8	4.8
0.1238	0.6140	1204.2	1204.2	1199.1	1640.2	1259.1	0	0.4	36.2	4.6
0.1337	0.6070	1206.8	1206.8	1199.1	1602.8	1259.1	0	0.6	32.8	4.3
0.1429	0.6006	1209.3	1209.3	1193.3	1569.5	1259.0	0	0.8	29.8	4.1
%Average							**0**	**0.6**	**47.8**	**5.2**
X_2 (Cyclohexane) = 0.850										
0.0541	0.8040	1213.7	1213.7	1223.7	1538.8	1257.8	0	0.8	26.8	3.6
0.0688	0.7915	1217.3	1217.3	1223.3	1493.4	1257.6	0	0.5	22.7	3.3
0.0784	0.7834	1219.7	1219.7	1223.1	1465.1	1257.4	0	0.3	20.1	3.1
0.0884	0.7749	122.2	122.2	1222.8	1436.8	1257.3	0	0.1	17.6	2.9
0.0978	0.7669	1224.5	1224.5	1222.6	1411.1	1257.3	0	0.2	15.2	2.7
0.1077	0.7585	1227.0	1227.0	1222.4	1385.0	1257.2	0	0.4	12.9	2.5
0.1226	0.7458	1230.7	1230.7	1222.2	1347.4	1257.1	0	0.7	9.5	2.1
0.1324	0.7375	1233.2	1233.2	1222.0	1323.8	1257.0	0	0.9	7.3	1.9
0.1421	0.7292	1235.7	1235.7	1221.8	1301.2	1256.8	0	1.1	5.3	1.7
0.1517	0.7211	1238.1	1238.1	1221.6	1279.5	1256.7	0	1.3	3.3	1.5
0.1613	0.7129	1240.6	1240.6	1221.5	1258.5	1256.6	0	1.5	1.4	1.3
%Average							**0**	**0.7**	**12.9**	**2.4**

Table 4: Comparison between observed and theoretical values of ultrasonic velocity of System – V

Chlorobenzene (X_1) + Isooctane (X_2) + n-heptane (X_3)										
x_1	x_2	u_{exp} (ms^{-1})	u_{nomoto}	$u_{vandael}$	u_f	u_{df}	% Δu_{nomoto}	% $u_{vandael}$	% Δu_f	% Δu_{df}
X_2 (Isooctane) = 0.1856										
0.0478	0.1767	1101.2	1101.2	1080.8	1653.1	1212.3	0	1.9	50.1	10.1
0.0569	0.1750	1104.0	1104.0	1082.0	1620.8	1130.1	0	2.0	46.8	2.4
0.0666	0.1732	1106.9	1106.9	1083.1	1587.6	1131.4	0	2.1	43.4	2.2
0.0758	0.1715	1109.7	1109.7	1084.3	1557.3	1132.5	0	2.3	40.3	2.1
0.0855	0.1697	1112.7	1112.7	1085.5	1526.4	133.8	0	2.4	37.2	1.9
0.9580	0.1678	1115.9	1115.9	1086.8	1494.7	1135.1	0	2.6	34.0	1.7
0.1042	0.1663	1118.5	1118.5	1087.8	1469.8	1136.2	0	2.7	31.4	1.6
0.1144	0.1644	1121.7	1121.7	1089.1	1440.5	1137.5	0	2.9	28.4	1.4
0.1232	0.1627	1124.5	1124.5	1090.3	1415.5	1138.6	0	3.0	25.8	1.3
0.1336	0.1608	1127.7	1127.7	1091.6	1388.1	1129.9	0	3.2	23.1	1.1
0.1430	0.1591	1130.7	1130.7	1092.8	1363.6	1141.1	0	3.4	20.6	0.9
%Average							**0**	**2.6**	**34.7**	**2.4**
X_2 (Isooctane) = 0.3062										
0.0539	0.2897	1068.9	1068.9	1049.6	2906.0	1124.8	0	1.8	115.7	5.2
0.0690	0.2851	1073.3	1073.3	1051.8	2207.0	1126.8	0	2.0	105.6	5.0
0.0785	0.2822	1076.1	1076.1	1053.2	2148.6	1128.0	0	2.1	99.7	4.8
0.0887	0.2790	1079.1	1079.1	1054.7	2089.0	1129.3	0	2.3	93.3	4.7
0.0980	0.2762	1081.9	1081.9	1056.1	2033.3	1130.6	0	2.4	88.3	4.5
0.1082	0.2731	1084.9	1084.9	1057.6	1983.2	1131.9	0	2.5	82.8	4.3
0.1235	0.2684	1089.6	1089.6	1059.9	1906.8	1133.9	0	2.7	75.0	4.1
0.1330	0.2654	1022.6	1022.6	1061.4	1860.6	1135.2	0	2.9	70.3	3.9
0.1424	0.2626	1025.4	1025.4	1062.8	1819.5	1136.4	0	3.0	66.1	3.7
0.1523	0.2596	1028.5	1028.5	1064.3	1776.6	1137.7	0	3.1	61.7	3.6
0.1623	0.2565	1101.6	1101.6	1055.9	1735.1	1193.0	0	3.2	57.5	3.4
%Average							**0**	**2.5**	**83.3**	**4.3**
X_2 (Isooctane) = 0.5015										
0.0575	0.4727	1020.1	1020.1	1002.7	6137.7	1117.4	0	1.7	501.7	9.5
0.0575	0.4727	1020.1	1020.1	1002.7	6137.7	1117.4	0	1.7	501.7	9.5
0.0666	0.4681	1022.6	1022.6	1004.7	5730.3	1118.6	0	1.8	460.4	9.4
0.0763	0.4632	1025.3	1025.3	1006.1	5351.2	1119.9	0	1.9	421.9	9.2
0.0861	0.4582	1028.8	1028.8	1007.8	5014.0	1121.3	0	2.0	487.7	9.1
0.0956	0.4536	1030.9	1030.9	1009.5	4724.1	1122.6	0	2.1	458.3	8.9
0.1075	0.4476	1034.3	1034.3	1011.7	4403.5	1124.2	0	2.2	425.7	8.7
0.1173	0.4427	1037.1	1037.1	1013.5	4169.3	1125.5	0	2.3	302.0	8.5
0.1241	0.4393	1039.1	1039.1	1014.7	4020.3	1126.5	0	2.4	286.9	8.4
0.1866	0.4079	1058.0	1058.0	1026.4	3013.7	1136.0	0	3.0	184.8	8.3
%Average							**0**	**2.1**	**373.1**	**8.9**

X_2 (Isooctane) = 0.7111										
0.0552	0.7718	965.7	965.7	956.4	-5990	1108.6	0	1.0	720.3	14.8
0.0692	0.6619	969.4	969.4	959.2	-6690	1110.7	0	1.1	790.2	14.6
0.0796	0.5545	972.2	972.2	961.3	-7330	1112.2	0	1.1	854.0	14.4
0.0879	0.6486	974.5	974.5	963.1	-7940	1113.3	0	1.2	914.8	14.2
0.0992	0.6406	977.6	977.6	965.4	-8959	1115.0	0	1.2	1016	14.1
0.1089	0.6337	918.3	918.3	967.4	-10074	1116.4	0	1.3	1127	13.9
0.1241	0.6229	984.6	984.6	917.6	-12536	1118.5	0	1.4	1373	13.6
0.1337	0.6160	987.3	987.3	972.6	-14841	1119.9	0	1.5	1603	13.4
0.1429	0.6095	919.0	919.0	974.6	-18034	1121.3	0	1.6	1921	13.3
0.1522	0.6029	992.6	992.6	976.6	-23077	1122.6	0	1.6	2424	13.1
0.1625	0.5955	995.7	995.7	978.6	-33503	1124.1	0	1.7	3464	13.9
%Average							**0**	**1.3**	**1473**	**13.8**
X_2 (Isooctane) = 0.7959										
0.0541	0.7528	944.4	944.4	938.9	-3299.0	1105.1	0	0.6	449.4	17.0
0.0693	0.4407	948.4	948.4	942.1	-3519.0	1107.3	0	0.7	471.1	16.8
0.7890	0.7331	950.9	950.9	944.1	-3674.0	1108.7	0	0.7	486.4	16.6
0.0887	0.7253	953.6	953.6	946.2	-3848.0	1110.2	0	0.7	503.6	16.4
0.0980	0.7179	956.1	956.1	948.2	-4031.0	1111.5	0	0.8	521.1	16.3
0.1074	0.7104	958.7	958.7	953.3	-4235.0	1112.9	0	0.9	541.8	16.1
0.1233	0.6978	963.1	963.1	953.8	-4634.0	1115.2	0	0.0	581.2	15.8
0.1328	0.6902	965.7	965.7	955.9	-4112.0	1116.6	0	0.0	608.7	15.6
0.1424	0.6826	968.4	968.4	958.0	-5231.0	1118.0	0	0.1	640.2	15.4
0.1522	0.6748	971.2	971.2	960.2	-5605.0	1119.5	0	0.1	677.2	15.3
0.1626	0.6665	974.2	974.2	962.6	-6067.0	1121.0	0	0.2	722.8	15.1
%Average							**0**	**0.9**	**564.0**	**16.0**

Table 5: Comparison between observed and theoretical values of ultrasonic velocity of system – V

Chloronaphthalene (X_1) + Isooctane (X_2) + n-heptane (X_3)										
x_1	**x_2**	**u_{exp} (ms^{-1})**	**u_{nomoto}**	**$u_{vandael}$**	**u_f**	**u_{df}**	**% Δu_{nomoto}**	**% $u_{vandael}$**	**% Δu_f**	**% Δu_{df}**
	X_2(Isooctane) = 0.2710									
0.0234	0.2647	1074.7	1074.7	1117.2	1228.0	1264.7	0	4.0	14.3	17.7
0.0301	0.2628	1078.9	1078.9	1117.0	1211.9	1129.1	0	3.5	12.3	4.7
0.0343	0.2617	1081.6	1081.6	1116.8	1202.1	1130.5	0	3.3	11.3	4.5
0.0386	0.2605	1084.3	1084.3	1116.8	1129.1	1131.9	0	3.0	9.9	4.4
0.0426	0.2595	1086.8	1086.8	1116.5	1183.0	1133.2	0	2.7	8.9	4.3
0.0470	0.2583	1089.6	1089.6	1116.4	1173.2	1134.7	0	2.5	7.7	4.1
0.0535	0.2565	1093.7	1093.7	1116.2	1158.9	1136.8	0	2.1	6.0	3.9
0.0577	0.2554	1096.4	1096.4	1116.1	1149.9	1138.2	0	1.8	4.9	3.8
0.0616	0.2543	1098.9	1098.9	1116.0	1141.7	1139.5	0	1.6	3.9	3.7
%Average							**0**	**2.7**	**8.8**	**5.7**
X_2 (Isooctane) = 0.4715										

0.0401	0.4565	1024.3	1024.3	1175.0	1829.9	1123.9	0	14.7	78.6	9.7
0.0512	0.4474	1030.6	1030.6	1174.4	1718.1	1127.5	0	14.0	72.7	9.4
0.0589	0.4437	1034.9	1034.9	1174.0	1747.5	1130.1	0	13.4	68.9	9.2
0.0661	0.4403	1039.0	1039.0	1173.6	1718.1	1132.4	0	13.0	65.4	9.0
0.0728	0.4373	1042.9	1042.9	1173.3	1691.1	1134.6	0	12.5	62.2	8.8
0.0802	0.4337	1047.1	1047.1	1173.0	1663.3	1137.0	0	12.0	58.9	8.6
0.0916	0.4283	1053.7	1053.7	1172.5	1621.1	1140.8	0	11.3	53.9	8.3
0.0986	0.4250	1057.7	1057.7	1172.2	1597.0	1143.1	0	10.8	51.0	8.1
0.1054	0.4218	1061.7	1061.7	1171.9	1573.8	1145.3	0	10.4	48.2	8.9
%Average							**0**	**12.8**	**63.2**	**9.4**
X_2 (Isooctane) = 0.7310										
0.0404	0.7015	957.8	957.8	1208.1	4953.9	1113.1	0	26.2	417.6	16.3
0.0521	0.6929	962.9	962.9	1207.4	4631.9	1117.0	0	25.4	381.0	16.0
0.0595	0.6875	966.7	966.7	1207.0	4448.9	1119.4	0	24.9	360.2	15.8
0.0664	0.6825	970.3	970.3	1206.6	4290.8	1121.7	0	24.4	342.2	15.0
0.0734	0.6773	973.9	973.9	1206.2	4141.6	1124.0	0	23.9	325.3	15.4
0.0810	0.6718	977.8	977.8	1205.8	3990.8	1126.5	0	23.3	308.1	15.2
0.0929	0.6631	984.0	984.0	1205.8	3775.6	1130.4	0	22.5	283.7	14.9
0.0999	0.6580	987.7	987.7	1204.8	3659.5	1132.7	0	22.0	270.8	14.7
0.1074	0.6525	991.7	991.7	1204.4	3542.7	1135.0	0	21.4	257.2	14.5
%Average							**0**	**25.2**	**334.3**	**16.4**

In Nomoto relation [4], linearity of sound velocity and additivity of molar volume has been assumed. The percentage deviations of sound speed obtained by Nomoto relations are positive for all the five systems studied by us. The limitation of this method is that it assumes no volume change on mixing and no account has been taken for interaction between the components of the liquid mixture. The ideal mixing relation of Van Dael [5] also provides good agreement with the experimental data, but however this theory has some limitation. During its formulation, it has been assumed that the ratio of specific heats of components is equal to the ratio of specific heat of ideal mixture i.e. $\Upsilon_1 = \Upsilon_2 = \Upsilon_3 = \Upsilon_{(id)}$ and also $V_1=V_2=V_3$. So the deviation observed in case of ideal mixing relation can be attributed to the above stated reasons. In the n-alkanes, the dipole is shielded more, and this leads to a lowering of cohesive forces between molecules. The main effect of addition of n-alkane is a change in the free volume in the mixture compared with that in the pure components. Disruption of structure and restriction of the rotational motion has been described as the condensation effect. Thus interstitial accommodation and orientation order lead to a more compact structure. Deviations are the result of molecular interactions in ternary liquid systems which involve active collisions among their molecules. Size of the ring, molecular configuration orientations and concept of charge transfer provide better information for molecular interaction studies. It appears that the strength of interactions between two components is weakened by the addition of third component in ternary liquid systems. It appears that collision factor theory [7] provides best results while free length theory [8] gives comparatively poor performance in comparison to other theories studied.

In CFT the molecules of the liquid components are treated as a real non elastic substance whereas in case of FLT [8] they are supposed to be rigid hard spheres, concept of which is not possible in practice. Deviations between theoretical sound speeds obtained from CFT and experimental sound velocity may be only due to some short of elasticity in the nature of molecules of the components i.e. due to uncertainties in actual molecular volume per mole and collision factors [8]. The collision factor is directly related to molecular radii [13]. There may be some errors in the calculation for

molecular radii for which an exact precise measurement is required. In case of FLT, molecules are regarded as stated above as hard sphere. The large deviations and not good agreement may also be due to certain reasons such as uncertainty in the value of free length (L_f), there is uncertainty in its exact applicability to particular liquid. It is evident on recalling eq (10), error in L_f can be due to an error in V_a [14] (caused by an computing error of V_0), and to an error in estimating the surface area of the molecule per mole (Y) or due to both. However, Jacobson [6] observed that V_0 cannot be computed with accuracy better than 0.5 percent by means of eq (8), even when the correct value of T_C is known. As far as the error in Y is considered in eq (9) itself, it is theoretically valid for spherical molecules only.

CONCLUSION

The most powerful empirical theories of sound speed (Nomoto relation, ideal mixing relation of Van Dael, Eyring-Jacobson free length theory and Schaaffs collision theory), originally found successfully for binary liquid mixtures, and have been extended to five ternary liquid mixtures mentioned. A comparative study of four different theories of sound speed has been made and excellent results were found. A quantitative study of molecular interactions occurring in the system has been presented.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest in this research article.

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