

# Comparative Evaluation of Ultrasonic Velocity in Binary Liquid Mixtures Over Wide Range of Temperatures



## Engineering

**KEYWORDS :** Ultrasonic velocity, density, intermolecular interaction, binary mixtures, deviation

**S. R. Dandwate**

Engineering Science Department, SRES's Sanjivani College of Engineering, Kopergaon, (M.S.) India

**S. B. Deshmukh**

Department of Physics, J. E. S. College, Jalna

### ABSTRACT

Densities and ultrasonic velocities of the binary liquid mixtures of Dimethyl Sulfoxide with Methanol and Ethanol have been measured at five temperatures 295K, 300K, 305K, 310K and 315K. These measurements have been carried out for 15 concentrations of each binary system. Experimental results are compared with theoretical results using Junjie's method ( $U_j$ ), Ideal Mixture relation ( $U_{IMR}$ ) and Impedance dependence relation ( $U_{IDR}$ ). Deviation in ultrasonic velocity and standard percentage error has also been evaluated. Intermolecular interactions have been explained with the help of results

### INTRODUCTION

Ultrasonic studies of liquid mixtures have great importance in understanding intermolecular interaction. Derived thermodynamic parameters obtained from Ultrasonic velocity helps in elaborating the nature and strength of molecular interaction in liquids and liquid mixtures. Intermolecular interaction studies are further applicable in industrial and technological process [1].

Several theories and relations such as Nomoto's relation, Junjie's method, Ideal Mixture Relation, Rao's specific velocity methods relation, Impedance dependence relation provides theoretical calculation of Ultrasonic velocities in liquid mixtures [2]. Literature survey reveals that the study of intermolecular interactions in liquid and liquid mixtures have been carried out with the help of Ultrasonic velocity and density measurements [1-25]. The study of Dimethyl Sulfoxide (DMSO) is significant because of its application in medicinal area, as it easily penetrates biological membranes, eases chemical transport into biological tissue [5]. The distinctive properties of DMSO also give rise to its extensive use as a solvent.

In the present research work, Ultrasonic velocity and density have been measured for Dimethyl Sulfoxide (DMSO) with methanol, ethanol and propanol for pure liquids and binary liquid mixtures. These measurements are carried out at the temperatures of 295, 300, 305, 310 and 315 K. Experimentally obtained results are further compared with theoretical results. Intermolecular interactions are then discussed with the help of deviations found in the values.

### EXPERIMENTAL:

All the chemicals used for the study are highly pure Analytical grade (AR) and Spectroscopic reagent (SR). For all systems 15 mixtures were prepared in terms of mole fractions by changing their concentrations and kept in special air tight bottles. Samples were weighted with the help of a digital microbalance with accuracy of  $\pm 0.001$  gm. Ultrasonic velocity and density have been determined for fresh sample each time. Ultrasonic velocities are determined by Ultrasonic Interferometer of frequency 2 MHz (F-81 model, Mittal make, New Delhi) with accuracy of 0.05%. Densities were measured by a 25 ml specific gravity bottle. Constant temperature water bath with accuracy of  $\pm 0.01$  K have been used to maintain the temperature constant at desired values by circulating water using motor.

In the present paper two systems have been discussed for various temperatures from 295 K to 315 K with the interval

of 5K over wide range of mole fractions.

System 1: DMSO + Methanol

System 2: DMSO + Ethanol

### THEORETICAL CONSIDERATIONS

#### Junjie's method ( $U_j$ )

$$U_j = \frac{\frac{X_1 M_1}{\rho_1} + \frac{X_2 M_2}{2}}{\left[ \{X_1 M_1 + X_2 M_2\}^2 \left\{ \frac{X_1 M_1}{\rho_1 U_1^2} + \frac{X_2 M_2}{\rho_2 U_2^2} \right\}^{1/2} \right]}$$

Where  $M_1$  and  $M_2$  are weights and  $\rho_1$  and  $\rho_2$  are densities of constituent components respectively [2, 6].

#### Ideal Mixture Relation ( $U_{IMR}$ )

For the velocity of sound, following relation is suggested by

#### Van Deal and Vangeel:

$$\frac{1}{(X_1 M_1 + X_2 M_2) \times U_{mix}^2} = \frac{X_1}{M_1 U^2} + \frac{X_2}{M_2 U^2}$$

Where  $U_{mix}$  is the ideal mixing ultrasonic velocity in liquid mixture, and  $U_1$  and  $U_2$  are the velocities of the individual components [2, 6].

#### Impedance dependence relation ( $U_{IDR}$ )

$$U_{IDR} = \frac{\sum_{i=1}^n X_i Z_i}{\sum_{i=1}^n X_i \rho_i}$$

Where  $X_i$  is the mole fraction,  $Z_i$  is the acoustic impedance and  $\rho_i$  is the density of the components in the mixture [2.6]

#### Deviation in Ultrasonic velocity in %

The deviation between ultrasonic velocities obtained experimentally and computed theoretically is given by following relation

$$\left( \frac{\Delta U}{U} \right) \% = \left( \frac{U_{Exp} - U_{Theory}}{U_{Exp}} \right) \times 100$$

**Standard percentage error**

Standard percentage error e is given by following equation

$$e = \left[ \frac{\left( \sum \frac{\Delta U}{U} \right)^2 \%}{n} \right]^{1/2}$$

Where n is total number of readings.

**Molecular associations**

The degree of intermolecular interaction or molecular association is given by following equation

$$\alpha = \left( \frac{U_{Exp}^2}{U_{imix}^2} \right) - 1$$

**RESULTS AND DISCUSSIONS**

Table 1 and Table 2 summarizes experimentally acquired ultrasonic velocities and theoretically computed ultrasonic velocities and percentage deviation in ultrasonic velocity using Junjie’s method, Ideal mixture relation, Impedance dependence relation for system 1 and system 2 respectively.

From Table 1 and Table 2, it is observed that with increase in the mole fraction of DMSO, ultrasonic velocity increases in both systems. Also for every particular mole fraction, ultrasonic velocity decreases with increase in the temperature. This is probably due to the fact that the thermal energy activates the molecules, which

would boost the rate of association of unlike molecules [2].

It is observed from comparison of experimental values of ultrasonic velocities with theoretical models that there is deviation in the values. The inadequacy and approximation included in these theories are responsible for such deviation [15].

It has been observed that there is least deviation between experimental values and values predicted from Impedance dependence relation. Also the deviation is found less when the concentration of individual liquid is more and comparatively more deviation for middle concentrations in the mixture. This clearly indicates that the molecular interactions are taking place between unlike molecules in the liquid mixture [2, 6, and 15].

The values of percentage deviation of ultrasonic velocities are found positive as well as negative. This deviation indicates non-ideal behavior of liquid mixtures [2].

**CONCLUSION**

Experimentally obtained ultrasonic velocities compared with three theoretical models at 295 K, 300 K, 305 K, 310 K and 315 K in binary liquid mixtures of DMSO with Methanol and DMSO with Ethanol show excellent agreement with Impedance Dependence Relation,  $U_{IDR}$ . Positive values of degree of molecular interaction,  $\alpha$  confirms the strong interaction between the molecules of the liquid mixture [15].

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$X_2$	$U_{EXP}$ ms <sup>-1</sup>	$U_J$ ms <sup>-1</sup>	$U_{IMR}$ ms <sup>-1</sup>	$U_{IDR}$ ms <sup>-1</sup>	% $U_J$	% $U_{IMR}$	$U_{IDR}$	$\alpha$
295 K								
0.0000	1119.10	1119.10	1119.10	1119.10	0.0000	0.0000	0.0000	0.00000
0.0306	1130.45	1132.17	1130.44	1130.54	-0.1520	0.0007	-0.0083	0.00005
0.064	1171.63	1146.27	1142.82	1182.71	2.1651	2.4595	-0.9457	0.05106
0.1006	1188.41	1161.52	1156.38	1212.85	2.2623	2.6952	-2.0567	0.05616
0.1409	1195.76	1202.46	1171.31	1227.38	-0.5604	2.0440	-2.6444	0.04217
0.1856	1214.63	1196.23	1187.87	1256.28	1.5150	2.2029	-3.4291	0.04555
0.2353	1289.06	1214.24	1228.78	1228.05	5.8042	4.6760	4.7327	0.10051
0.2908	1303.64	1237.88	1226.85	1260.34	5.0442	5.8901	3.3216	0.12909
0.3535	1336.91	1262.07	1250.09	1303.78	5.5976	6.4943	2.4781	0.14373
0.4247	1402.26	1289.02	1276.47	1379.56	8.0757	8.9707	1.6185	0.20680
0.5062	1437.89	1319.21	1306.67	1422.21	8.2536	9.1260	1.0899	0.21093
0.6006	1469.22	1353.37	1341.64	1465.61	7.8853	8.6836	0.2457	0.19923
0.7110	1476.57	1392.31	1382.55	1422.36	5.7067	6.3675	3.6717	0.14063
0.8421	1480.92	1437.49	1430.12	1455.68	2.9325	3.4302	1.7040	0.07230
1.0000	1489.63	1489.63	1489.63	1489.63	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					5.9314	5.6575	2.1502	
300 K								
0.0000	1101.14	1101.14	1101.14	1101.14	0.0000	0.0000	0.0000	0.00000
0.0306	1119.59	1113.89	1112.21	1126.06	1.9077	1.6134	-1.5614	0.01331
0.064	1149.57	1127.63	1124.30	1167.52	2.2911	4.0398	-2.5429	0.04544
0.1006	1169.31	1142.52	1137.54	1199.04	-0.9536	4.2803	-3.2706	0.05663
0.1409	1171.47	1182.64	1152.12	1209.78	1.5197	3.6491	-3.8789	0.03387
0.1856	1194.53	1176.38	1168.29	1240.87	5.6391	3.8151	4.7348	0.04542
0.2353	1265.31	1193.95	1208.41	1205.40	2.6092	6.2564	3.5107	0.09638
0.2908	1249.63	1217.03	1206.35	1205.76	5.6266	7.4628	2.4036	0.07304
0.3535	1314.61	1240.64	1229.04	1283.01	5.0891	8.0684	1.4106	0.14409
0.4247	1334.88	1266.95	1254.80	1316.05	8.1529	10.515	0.8322	0.13171
0.5062	1411.51	1296.43	1284.28	1399.76	8.4587	10.682	0.2467	0.20794
0.6006	1452.67	1329.80	1318.44	1449.09	5.9996	10.262	3.5485	0.21399
0.7110	1455.13	1367.83	1358.37	1403.50	3.2228	8.0051	1.6119	0.14754
0.8421	1459.00	1411.98	1404.82	1435.48	0.5097	5.1385	-0.5773	0.07862
1	1462.94	1462.94	1462.94	1462.94	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					5.9884	5.6575	2.1502	
305 K								
0	1081.63	1081.63	1081.63	1081.63	0.0000	0.0000	0.0000	0.00000
0.0306	1100.48	1094.35	1092.97	1121.19	3.1933	3.3154	0.8190	0.01378
0.064	1128.71	1108.10	1105.34	1160.79	5.4225	5.6581	0.9254	0.04274

0.1006	1147.83	1123.00	1118.90	1191.17	5.5038	5.8488	-0.2324	0.05237
0.1409	1152.57	1162.12	1133.83	1203.04	2.8128	5.1787	-0.6092	0.03333
0.1856	1172.73	1157.04	1150.39	1232.73	4.7409	5.2888	-1.4901	0.03922
0.2353	1242.29	1174.77	1190.54	1184.20	8.8654	7.6426	8.1345	0.08881
0.2908	1238.04	1198.12	1189.36	1181.03	8.0937	8.7661	9.4050	0.08353
0.3535	1293.35	1222.10	1212.59	1261.84	8.5872	9.2989	5.6150	0.13763
0.4247	1313.57	1248.91	1238.96	1294.36	10.935	11.645	7.6946	0.12405
0.5062	1389.24	1279.07	1269.15	1379.95	11.044	11.735	4.0292	0.19820
0.6006	1436.92	1313.38	1304.12	1436.36	10.606	11.237	2.2368	0.21404
0.711	1439.08	1352.70	1345.02	1391.47	8.3886	8.9092	5.7634	0.14476
0.8421	1447.10	1398.64	1392.61	1422.12	5.5555	5.9630	3.9703	0.07979
1.0000	1452.08	1452.08	1452.08	1452.08	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					8.2376	7.6268	1.3258	
310 K								
0.0000	1074.70	1074.70	1074.70	1074.70	0.0000	0.0000	0.0000	0.00000
0.0306	1077.88	1087.36	1086.03	1097.60	3.8116	3.9293	2.9058	-0.01495
0.064	1113.35	1101.06	1098.391	1141.07	6.0234	6.2512	2.6085	0.02741
0.1006	1125.63	1115.92	1111.94	1163.94	6.0996	6.4345	2.0589	0.02478
0.1409	1138.53	1154.75	1126.86	1185.66	3.4292	5.7616	0.8442	0.02082
0.1856	1151.92	1149.85	1143.41	1208.75	5.3332	5.8635	0.4840	0.01493
0.2353	1226.82	1167.54	1183.42	1168.16	9.4269	8.1950	9.3788	0.07468
0.2908	1231.92	1190.84	1182.36	1188.79	8.6525	9.3030	8.8098	0.08558
0.3535	1284.57	1214.78	1205.58	1253.54	9.1351	9.8232	6.2358	0.13533
0.4247	1302.12	1241.55	1231.94	1281.26	11.460	12.146	8.6289	0.11718
0.5062	1368.65	1271.70	1262.11	1359.19	11.557	12.224	5.4730	0.17595
0.6006	1418.78	1306.00	1297.06	1415.71	11.109	11.718	3.6423	0.19648
0.711	1421.91	1345.35	1337.94	1370.87	8.8869	9.3887	7.1585	0.12945
0.8421	1438.76	1391.36	1385.51	1410.51	6.0474	6.4425	4.7543	0.07834
1.0000	1444.94	1444.94	1444.94	1444.94	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					7.7583	7.1112	1.4727	
315 K								
0.0000	1048.00	1048.00	1048.00	1048.00	0.0000	0.0000	0.0000	0.00000
0.0306	1058	1060.98	1059.98	1078.80	6.1452	6.2337	4.5688	-0.00373
0.064	1098.16	1075.05	1073.06	1129.25	8.2434	8.4132	3.6174	0.04730
0.1006	1106.69	1090.35	1087.40	1151.30	8.2512	8.4994	3.1225	0.03580
0.1409	1118	1128.34	1103.18	1163.18	5.6378	7.7419	2.7242	0.02704
0.1856	1137.22	1125.43	1120.69	1196.32	7.3437	7.7340	1.5074	0.02972
0.2353	1200.97	1143.79	1161.22	1144.10	11.269	9.9172	11.245	0.06962
0.2908	1222.20	1168.06	1161.89	1179.19	10.399	10.873	9.5462	0.10651
0.3535	1269.71	1193.09	1186.44	1238.80	10.757	11.254	7.3384	0.14530
0.4247	1281.47	1221.22	1214.33	1264.38	12.910	13.401	9.8326	0.11363
0.5062	1341.27	1253.06	1246.24	1332.27	12.854	13.328	7.3452	0.15831
0.6006	1403.35	1289.50	1283.22	1403.28	12.232	12.660	4.4883	0.19599
0.711	1416.09	1331.60	1326.45	1367.95	9.8181	10.166	7.3563	0.13972
0.8421	1425.44	1381.24	1376.85	1400.35	6.7308	7.0272	5.4404	0.07182
1.0000	1439.63	1439.63	1439.63	1439.63	0.0000	0.0000	0.0000	0.0000
Average absolute percentage deviation					8.4666	7.6135	1.3217	

**Table 1: Experimental and theoretical velocities of ultrasonic waves for binary liquid mixture of DMSO and Methanol**

$X_2$	$U_{ms}^{EXP}$	$U_{ms}^I$	$U_{ms}^{IMR}$	$U_{ms}^{IDR}$	$\%U_J$	$\%U_{IMR}$	$U_{IDR}$	A
295 K								
0.0000	1145.10	1145.10	1145.10	1145.10	0.0000	0.0000	0.0000	0.00000
0.0434	1170.44	1157.61	1160.05	1167.44	1.0965	0.8880	0.2567	0.01800
0.0895	1191.63	1171.09	1175.93	1191.60	1.7237	1.3171	0.0024	0.02687
0.1385	1236.40	1185.63	1192.81	1222.37	4.1064	3.5254	1.1350	0.07442
0.1908	1285.75	1226.12	1210.83	1274.59	4.6376	5.8266	0.8681	0.12757
0.2468	1344.63	1218.61	1230.13	1355.00	9.3714	8.5152	-0.7716	0.19481
0.3067	1392.05	1237.38	1250.77	1301.10	11.110	10.149	6.5334	0.23868
0.3709	1403.63	1257.94	1272.88	1330.04	10.379	9.3150	5.2432	0.21599
0.4402	1436.90	1280.68	1296.76	1371.37	10.872	9.7531	4.5610	0.22782
0.4574	1452.26	1295.79	1236.84	1407.01	10.773	14.832	3.1158	0.37865
0.5958	1467.88	1333.95	1350.37	1425.26	9.1242	8.0055	2.9035	0.18161
0.6838	1476.45	1365.56	1380.69	1446.52	7.5106	6.4861	2.0274	0.14353
0.7796	1480.99	1401.32	1413.69	1416.89	5.3793	4.5440	4.3281	0.09747
0.8915	1485.45	1442.59	1460.15	1455.00	2.8852	1.7035	2.0498	0.03496
1.0000	1489.63	1489.63	1489.63	1489.63	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					3.6353	4.2027	0.6518	
300 K								
0.0000	1138.14	1138.14	1138.14	1138.14	0.0000	0.0000	0.0000	0.00000
0.0434	1159.59	1150.09	1152.23	1166.91	0.8188	0.6340	-0.6313	0.01280
0.0895	1189.56	1162.95	1167.21	1198.87	2.2367	1.8791	-0.7826	0.03866
0.1385	1233.30	1176.82	1183.12	1246.98	4.5797	4.0686	-1.1094	0.08662
0.1908	1281.46	1216.81	1200.11	1294.76	5.0456	6.3486	-1.0377	0.14017
0.2468	1334.53	1208.21	1218.30	1351.11	9.4650	8.7093	-1.2426	0.19990
0.3067	1385.30	1226.04	1237.75	1295.05	11.496	10.650	6.5147	0.25262
0.3709	1389.63	1245.54	1258.61	1317.23	10.368	9.4285	5.2098	0.21903
0.4402	1414.61	1267.06	1281.11	1350.65	10.429	9.4368	4.5212	0.21926
0.4574	1444.88	1281.35	1221.26	1400.93	11.317	15.476	3.0415	0.39974

0.5958	1447.19	1317.34	1331.65	1408.27	8.9723	7.9834	2.6888	0.18106
0.6838	1451.51	1347.07	1360.23	1423.20	7.1950	6.2880	1.9499	0.13870
0.7796	1455.89	1380.60	1391.35	1382.37	5.1713	4.4331	5.0501	0.09492
0.8915	1458.98	1419.17	1435.55	1430.32	2.7292	1.6064	1.9646	0.03292
1.0000	1462.93	1462.93	1462.93	1462.93	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					3.3382	3.9005	0.4312	
305 K								
0.0000	1081.63	1081.63	1081.63	1081.63	0.0000	0.0000	0.0000	0.00000
0.0434	1135.02	1094.31	1097.71	1155.97	3.5866	3.2872	-1.8458	0.06913
0.0895	1181.71	1108.02	1114.78	1202.25	6.2357	5.6634	-1.7381	0.12367
0.1385	1220.00	1122.89	1132.94	1241.28	7.9597	7.1360	-1.7446	0.15959
0.1908	1272.57	1160.94	1152.31	1300.56	8.7716	9.4499	-2.1993	0.21961
0.2468	1332.73	1156.87	1173.05	1364.22	13.195	11.981	-2.3628	0.29076
0.3067	1362.28	1176.38	1195.24	1275.24	13.645	12.265	6.3895	0.29903
0.3709	1378.04	1197.90	1219.03	1303.54	13.071	11.538	5.4062	0.27789
0.4402	1403.34	1221.88	1244.70	1338.97	12.930	11.304	4.5870	0.27115
0.4574	1433.56	1237.93	1188.88	1401.39	13.646	17.068	2.2441	0.45397
0.5958	1440.24	1278.83	1302.34	1400.68	11.207	9.5746	2.7465	0.22298
0.6838	1445.34	1313.16	1334.94	1416.91	9.1453	7.6383	1.9668	0.17224
0.7796	1447.54	1352.50	1370.43	1381.75	6.5655	5.3268	4.5451	0.11569
0.8915	1450.85	1398.59	1419.35	1423.38	3.6019	2.1715	1.8934	0.04488
1.0000	1452.08	1452.08	1452.08	1452.08	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					3.3349	3.8010	0.0619	
310 K								
0.0000	1074.69	1074.69	1074.69	1074.69	0.0000	0.0000	0.0000	0.00000
0.0434	1117.87	1087.28	1090.76	1144.39	2.7369	2.4254	-2.3716	0.05033
0.0895	1163.34	1100.90	1107.83	1186.85	5.3676	4.7720	-2.0203	0.10273
0.1385	1205.63	1115.67	1125.97	1233.86	7.4611	6.6072	-2.3413	0.14649
0.1908	1258.53	1153.35	1145.33	1288.04	8.3574	8.9940	-2.3449	0.20742
0.2468	1311.91	1149.48	1166.07	1345.06	12.381	11.117	-2.5265	0.26579
0.3067	1356.81	1168.90	1188.24	1268.46	13.849	12.423	6.5114	0.30384
0.3709	1359.91	1190.34	1212.01	1283.39	12.469	10.875	5.6267	0.25894
0.4402	1384.57	1214.25	1237.67	1320.37	12.300	10.609	4.6367	0.25145
0.4574	1410.12	1230.27	1182.25	1366.92	12.754	16.159	3.0635	0.42264
0.5958	1418.65	1271.13	1295.28	1376.89	10.398	8.6959	2.9433	0.19955
0.6838	1428.65	1305.48	1327.86	1399.03	8.6212	7.0545	2.0733	0.15756
0.7796	1432.47	1344.90	1363.33	1358.48	6.1135	4.8265	5.1653	0.10399
0.8915	1442.57	1391.15	1412.18	1389.55	3.5644	2.1070	3.6754	0.04351
1.0000	1444.93	1444.93	1444.93	1444.93	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					2.7869	3.2423	0.1309	
315 K								
0.0000	1048.00	1048.00	1048.00	1048.00	0.0000	0.0000	0.0000	0.00000
0.0434	1108.00	1060.94	1064.99	1137.29	4.2470	3.8811	-2.6442	0.08238
0.0895	1148.16	1074.97	1083.05	1175.67	6.3740	5.6707	-2.3961	0.12384
0.1385	1186.69	1090.22	1102.24	1217.47	8.1286	7.1163	-2.5939	0.15910
0.1908	1244.00	1127.21	1122.72	1275.89	9.3875	9.7488	-2.5642	0.22770
0.2468	1297.22	1125.24	1144.65	1330.34	13.256	11.760	-2.5536	0.28433
0.3067	1340.00	1145.45	1168.11	1254.37	14.518	12.827	6.3902	0.31594
0.3709	1342.20	1167.81	1193.25	1272.28	12.992	11.096	5.2087	0.26522
0.4402	1369.71	1192.84	1220.39	1310.08	12.912	10.901	4.3528	0.25966
0.4574	1401.46	1209.66	1166.87	1360.01	13.685	16.738	2.9570	0.44249
0.5958	1411.26	1252.78	1281.33	1373.46	11.229	9.2063	2.6783	0.21307
0.6838	1424.65	1289.25	1315.79	1396.55	9.5039	7.6406	1.9721	0.17229
0.7796	1430.09	1331.36	1353.31	1357.17	6.9032	5.3684	5.0989	0.11667
0.8915	1436.65	1381.17	1404.37	1380.33	3.8612	2.2467	3.9198	0.04649
1.0000	1439.63	1439.63	1439.63	1439.63	0.0000	0.0000	0.0000	0.00000
Average absolute percentage deviation					3.1396	3.4698	0.0138	

**Table 2: Experimental and theoretical velocities of ultrasonic waves for binary liquid mixture of DMSO and Ethanol**

SPE for DMSO( $X_2$ ) with Methanol ( $X_1$ )				SPE for DMSO( $X_2$ ) with Ethanol ( $X_1$ )			
$X_2$	$U_t$	$U_{exp}$	$U_{app}$	$X_2$	$U_t$	$U_{exp}$	$U_{app}$
295 K							
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0306	0.0039	0.0002	0.0001	0.0434	0.0283	0.0066	0.0229
0.064	0.0559	0.0244	0.0635	0.0895	0.0445	0.0006	0.0340
0.1006	0.0584	0.0531	0.0695	0.1385	0.1060	0.0293	0.0910
0.1409	0.0144	0.0682	0.0527	0.1908	0.1197	0.0224	0.1504
0.1856	0.0391	0.0885	0.0568	0.2468	0.2419	0.0199	0.2198
0.2353	0.1498	0.1221	0.1207	0.3067	0.2868	0.1686	0.2620
0.2908	0.1302	0.0857	0.1520	0.3709	0.2679	0.135	0.2400
0.3535	0.1445	0.0639	0.1676	0.4402	0.2807	0.1177	0.2510
0.4247	0.2085	0.0417	0.2316	0.4574	0.2781	0.0804	0.3829
0.5062	0.2131	0.0281	0.2356	0.5958	0.2355	0.0749	0.2067
0.6006	0.2035	0.0063	0.2242	0.6838	0.1939	0.0523	0.1674
0.7110	0.1473	0.0948	0.1644	0.7796	0.1388	0.1117	0.1173
0.8421	0.0757	0.0439	0.0885	0.8915	0.0744	0.0529	0.0439

1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Avg.	0.0963	0.0481	0.1085	Avg.	0.1531	0.0581	0.1460
300 K							
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0306	0.0132	0.0149	0.0170	0.0434	0.0211	0.0163	0.0163
0.064	0.0492	0.0403	0.0567	0.0895	0.0577	0.0202	0.0485
0.1006	0.0591	0.0656	0.0701	0.1385	0.1182	0.0286	0.1050
0.1409	0.0246	0.0844	0.0426	0.1908	0.1302	0.0267	0.1639
0.1856	0.0392	0.1001	0.0567	0.2468	0.2443	0.0320	0.2248
0.2353	0.1456	0.1225	0.1161	0.3067	0.2968	0.1682	0.2750
0.2908	0.0673	0.0906	0.0894	0.3709	0.2677	0.1345	0.2434
0.3535	0.1452	0.0620	0.1680	0.4402	0.2693	0.1167	0.2436
0.4247	0.1314	0.0364	0.1548	0.4574	0.2922	0.0785	0.3996
0.5062	0.2105	0.0214	0.2327	0.5958	0.2316	0.0694	0.2061
0.6006	0.2184	0.0063	0.2385	0.6838	0.1857	0.0503	0.1623
0.7110	0.1549	0.0916	0.1716	0.7796	0.1335	0.1303	0.1144
0.8421	0.0832	0.0412	0.0958	0.8915	0.0704	0.0507	0.0414
1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Avg.	0.0894	0.0518	0.1007	Avg.	0.1546	0.0615	0.1496
305 K							
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0306	0.0143	0.0485	0.0176	0.0434	0.0926	0.0476	0.0848
0.064	0.0471	0.0733	0.0534	0.0895	0.1610	0.0448	0.1462
0.1006	0.0558	0.0974	0.0650	0.1385	0.2050	0.0450	0.1842
0.1409	0.0213	0.1130	0.0419	0.1908	0.2264	0.0567	0.2439
0.1856	0.0345	0.1320	0.0491	0.2468	0.3406	0.0610	0.3093
0.2353	0.1403	0.1207	0.1075	0.3067	0.3523	0.1649	0.3165
0.2908	0.0832	0.1188	0.1015	0.3709	0.3375	0.1395	0.2979
0.3535	0.1422	0.0628	0.1612	0.4402	0.3338	0.1184	0.2918
0.4247	0.1270	0.0377	0.1466	0.4574	0.3523	0.0579	0.4406
0.5062	0.2047	0.0172	0.2232	0.5958	0.2893	0.0709	0.2472
0.6006	0.2219	0.0010	0.2386	0.6838	0.2361	0.0507	0.1972
0.7110	0.1549	0.0854	0.1687	0.7796	0.1695	0.1173	0.1375
0.8421	0.0864	0.0445	0.0972	0.8915	0.0930	0.0488	0.0560
1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Avg.	0.0889	0.0635	0.0981	Avg.	0.2126	0.0682	0.1969
310 K							
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0306	0.0227	0.0472	0.0195	0.0434	0.0706	0.0612	0.0626
0.064	0.0284	0.0642	0.0346	0.0895	0.1385	0.0521	0.1232
0.1006	0.0222	0.0878	0.0314	0.1385	0.1926	0.0604	0.1705
0.1409	0.0367	0.1068	0.0264	0.1908	0.2157	0.0605	0.2322
0.1856	0.0046	0.1273	0.0190	0.2468	0.3196	0.0652	0.2870
0.2353	0.1247	0.1234	0.0913	0.3067	0.3575	0.1681	0.3207
0.2908	0.0860	0.0903	0.1038	0.3709	0.3219	0.1452	0.2808
0.3535	0.1402	0.0623	0.1587	0.4402	0.3176	0.1197	0.2739
0.4247	0.1201	0.0413	0.1391	0.4574	0.3293	0.0791	0.4172
0.5062	0.1829	0.0178	0.2009	0.5958	0.2684	0.0759	0.2245
0.6006	0.2052	0.0055	0.2215	0.6838	0.2226	0.0535	0.1821
0.7110	0.1390	0.0926	0.1524	0.7796	0.1578	0.1333	0.1246
0.8421	0.0850	0.0506	0.0955	0.8915	0.0920	0.0944	0.0544
1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Avg.	0.0798	0.0612	0.0863	Avg.	0.2003	0.0779	0.1836
315 K							
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0306	0.0072	0.0507	0.0048	0.0434	0.1096	0.068274	0.100211
0.064	0.0543	0.0730	0.0590	0.0895	0.1645	0.061869	0.146417
0.1006	0.0381	0.1040	0.0450	0.1385	0.2098	0.066975	0.183743
0.1409	0.0238	0.1043	0.0342	0.1908	0.2423	0.066208	0.251715
0.1856	0.0267	0.1341	0.0375	0.2468	0.3422	0.065936	0.303666
0.2353	0.1229	0.1222	0.0854	0.3067	0.3748	0.164997	0.3312
0.2908	0.1143	0.0908	0.1274	0.3709	0.3354	0.13449	0.286522
0.3535	0.1558	0.0628	0.1693	0.4402	0.3333	0.112389	0.281464
0.4247	0.1213	0.0344	0.1352	0.4574	0.3533	0.076351	0.432193
0.5062	0.1697	0.0173	0.1829	0.5958	0.2899	0.069154	0.237706
0.6006	0.2094	0.0001	0.2210	0.6838	0.2453	0.05092	0.19728
0.7110	0.1540	0.0877	0.1634	0.7796	0.1782	0.131655	0.138612
0.8421	0.0800	0.0454	0.0880	0.8915	0.0996	0.101209	0.058011
1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Avg.	0.0852	0.0618	0.0902	Avg.	0.2186	0.0780	0.1965

**Table 3: Standard percentage error for binary liquid mixtures of DMSO with Methanol and DMSO with Ethanol and their average values**

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