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Physicochemical study of a binary liquid mixture by ultrasonic speed, isentropic compressibility and acoustic impedance from 288.15-318.15K

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Abstract

Ultrasonic study of intermolecular interactions between the solvents of different nature have been performed by ultrasonic speed (U), isentropic compressibility (βs) and acoustic impedance (Z). Ultrasonic speed and aforesaid acoustical parameters for binary liquid mixture of 2-butanol and dodecane were computed from 288.15-318.15K over the entire range of concentration and atmospheric pressure and compared with the literature values Paterson-Flory-Prigogine (PFP), Ramaswamy- Anbananthan (RS) and Glinski model (GLI) were used to study the intermolecular interactions between the poor interacting liquids at different temperatures. Standard deviations and numerical coefficients of mixing properties were estimated by Redlich Kister polynomial. McAllister multibody correlation model was used to correlate the experimental findings. Ramaswamy model deals a fair agreement with experimental values in comparison to statistical liquid state PFP model.

Keywords: Isentropic compressibility, Acoustic impedance, Ultrasonic speed, PFP.

Introduction

Ultrasonic studies play a significant role to analyse various thermodynamic properties and to predict the molecular interactions between like and unlike components of liquid mixtures at varying concentration. In the continuation of previously published work[1]. This paper is concerned with the study of intermolecular interaction in weakly interacting liquid mixture of 2-butanol and long chain saturated hydrocarbon dodecane. Theoretical interpretation of various physicochemical properties and intermolecular interactions by ultrasonic speed and other acoustical parameters such as isentropic compressibility and acoustic impedance have become a subject of deep interest in past few years. several researchers[2-6] have made a successful attempt to evaluate theoretical ultrasonic speed and other acoustical parameters of different binary liquid mixtures at different temperatures using various liquid state models. PFP[7-12] model based on non-associated process, Ramaswamy[13] and Glinski model [14] based on associated process with association constantan as adjustable parameter were used to study the extent of interaction between the binary components. McAllister multibody interaction model[15] based on Eyring's theory were used to correlate the theoretical values with experimental findings. Redlich Kister[16] equation was used to determine the binary coefficient and standard deviation using deviation in ultrasonic speed and other acoustical parameters. In this paper an attempt has been made to evaluate the ultrasonic speed, isentropic compressibility and acoustic impedance of binary liquid mixture using different liquid state models from 288.15-318.15K and compared with experimental analysis of Peleteiro[17]. The aim of this work to understand the extent of intermolecular interactions and to estimate the associated and non-associated liquid state models at different temperatures.

Modelling

Prigogine-Flory- Patterson: PFP [7-12] is a statistical liquid state model based on non-associated process. Ultrasonic speed can be calculated using surface tension of binary liquid mixture from Auerbach relation

$$U = \left(\frac{\sigma}{6.3\times10^{-4}\rho_{Mix}}\right)^{2/3} \quad (1)$$

Where σ is surface tension can be calculated in terms of characteristic surface tensionσ^* and reduce surface tension $\tilde{\sigma}(v)$ by the following equation:

$$\sigma = \sigma^*\tilde{\sigma}(v) \quad (2)$$

characteristic surface tension σ^* can be calculated by proposed concept of Patterson and Rastogi of extension of corresponding state theory

$$\sigma^* = K^{1/3}P^{*2/3}T^{*1/3} \quad (3)$$

Where: K, T^* and P^* Boltzmann constant, characteristic temperature and characteristic pressure respectively.

Reduced surface tension $\tilde{\sigma}(v)$ can be calculated by the following equation:

$$\tilde{\sigma}(v) = M\tilde{v}^{5/3} - \frac{(\tilde{v}^{1/3}-1)}{(\tilde{v}^2)}\ln\frac{(\tilde{v}^{1/3}-0.5)}{(\tilde{v}^{1/3}-1)} \quad (4)$$

Where, $\tilde{v}$ is reduced volume which can be calculated from equation (5) by isothermal expansion coefficient (α) and M is adjustable parameter and its values lies in the range 0.25 < M < 0.29.

$$\tilde{v} = \left[\frac{\alpha T}{3(1+\alpha T)} + 1\right]^3 \quad (5)$$

Characteristic temperature (T*) and characteristic pressure (P*) can be calculated from equation 6 and 7 respectively.

$$T^* = \left[\frac{T\{\tilde{V}\}^{4/3}}{\{(\tilde{V}^{1/3})-1\}}\right] \quad (6)$$

$$P^* = \left[\frac{\alpha}{\beta_T}\right] T\tilde{V}^2 \quad (7)$$

Where β_T is isothermal compressibility.

Ramaswamy-Anbananthan model: Ramaswamy[13] model (associated process) deals with a linear relation between acoustic impedance with the mole fraction. In order to extend the proposed model ultrasonic speed can be calculated by the following equation:

$$U_{RS} = X_1U_1 + X_2U_2 + X_{12}U_{12} \quad (8)$$

Where: U1, U2 are ultrasonic speeds of pure component 1 and 2 respectively. U12 is ultrasonic speed of associated molecules.

Glinski Model: Glinski[14] proposed a relation, based on an assumption of additivity with volume fraction (Φ) of pure components and associate.

$$U_{GLI} = \frac{U_1U_2U_{12}}{U_1U_{12}\phi_2 + U_2U_{12}\phi_1 + U_1U_2\phi_{12}} \quad (9)$$

Where: ϕ_1 and ϕ_2 are volume fraction of pure components andϕ_{12} is volume fraction of associate.

Isentropic compressibility: Isentropic compressibility (βs) can be calculated by Newton – Laplace's equation,

$$\beta_S = \left[\frac{1}{u^2\rho_{Mix}}\right] \quad (10)$$

ρ_{Mix} is density of binary mixture.

Acoustic impedance: Acoustic impedance of binary liquid mixture is calculated from the following equation

$$Z = U \times \rho_{Mix} \quad (11)$$

McAllister multibody interaction model: McAllister model[15] based on the assumption of Eyring's theory of absolute rate. Which is used to correlate the ultrasonic speed and other acoustical parameter with mole fraction.

McAllister-3- body

$$\ln U = x_1^3 \ln U_1 + 3x_1^2x_2 \ln U_{A_0} + 3x_1{x_2}^2 \ln U_{A_1} + x_2^3 \ln U_2 - \ln[x_1 + x_2M_2/M_1] + 3x_1^2x_2 \ln[(2 + M_2/M_1)/3] + 3x_1x_2^2 \ln[(1 + 2\,M_2/M_1)/3] + x_2^3 \ln[M_2/M_1] \quad (12)$$

McAllister-4-body

$$\ln U = x_1^4 \ln U_1 + 4x_1^3x_2 \ln U_{A_0} + 6x_1^2x_2^2 \ln U_{A_1} + 4x_1x_2^2 \ln U_{A_2} + x_2^4 \ln U_2 - \ln[(x_1 + x_2M_2/M_1)] + 4x_1^3x_2 \ln[(3 + M_2/M_1)/4] + 6x_1^2x_2^2 \ln[(1 + M_2/M_1)/2] + 4x_1x_2^3 \ln[(1 + 3M_2/M_1)/4] + x_2^4 \ln(M_2/M_1) \quad (13)$$

Where: A_0, A_1 and A_2 are adjustable parameters. Which were calculated by least square method.M1 and M2 are molecular weight of pure liquids.

Results and discussion

Table-1 represents experimental and theoretical ultrasonic speed (U) calculated from various liquid state models for aforesaid liquid mixture along with their percentage deviation from 288.15-318.15K. Theoretical and experimental isentropic compressibility (βs) along with their percentage deviation is reported in Table-2. Table-3 represents the experimental and theoretical acoustic impedance (Z) along with their percentage deviation at different temperatures. Standard deviation and numerical coefficients calculated from Redlich Kister polynomial are reported in Table-4. Average absolute percentage deviation (AAPD) of ultrasonic speed, isentropic compressibility and acoustic impedance calculated for PFP, Ramaswamy, Glinski, McAllister-3 body model and McAllister-4 body model along with association constant (Kas) and adjustable parameters at different temperatures are reported in Table-5, Table-6 and Table-7 respectively.

$$\Delta U = X_I(1 - X_1)\sum_{i=0}^{n} A_i(1 - X_1)^i \quad (14)$$

Experimental data can be correlated by above Redlich Kister polynomial[16] in terms of mixing function (ΔU). Where A_i is numerical coefficient, which were calculated by multiple regression analysis based least square method and respective ultrasonic properties are represented in term of standard deviations (δU) at different temperatures.

$$\delta U = \left[\sqrt{\sum_{i=1}^{k} \left(U_{exp_i} - U_{cal_i}\right)^2 \Big/ (N - P)}\right] \quad (15)$$

Where: N is number of experimental points and P is number of adjustable parameters.

A very careful observation of Table-1 reveals that with increase of mole fraction the values of ultrasonic speed calculated from different models decreases and density of binary liquid mixture increases at all temperatures.

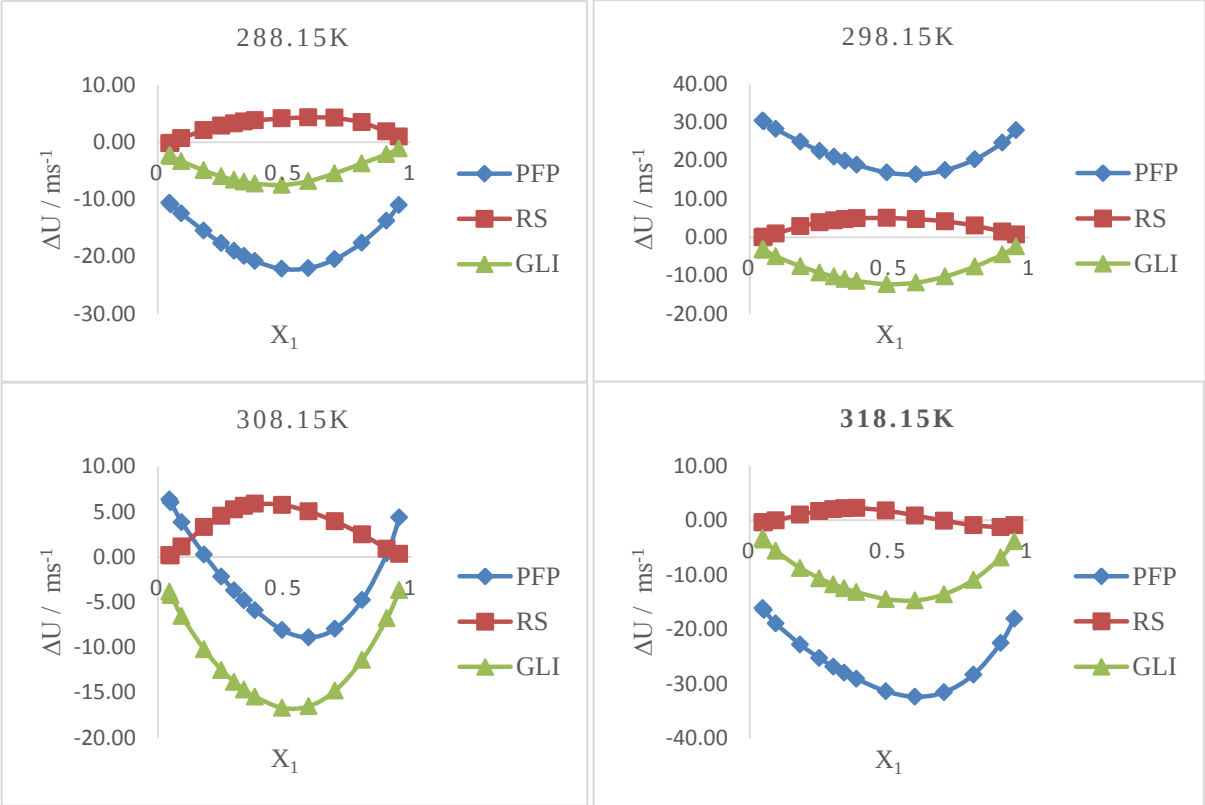

Figure-1: Graphical representation of deviation in ultrasonic speed.

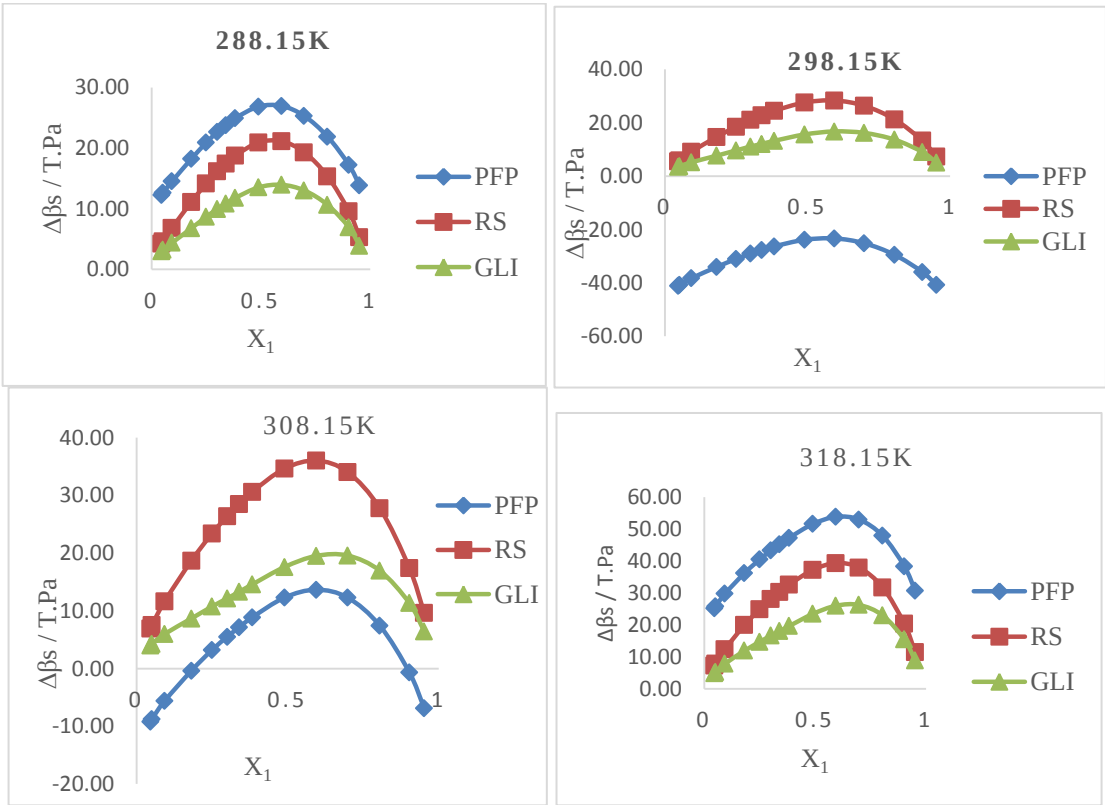

Figure-2: Graphical representation of deviation in isentropic compressibility.

The relative strength of their molecular interactions depends upon the magnitude of percentage deviation and their actual sign. Percentage deviation calculated from Ramaswamy model was very less for entire range of mole fraction in comparison to Glinski and PFP model. Positive deviation in ultrasonic speed show weak molecular interaction[18] between the components of binary system. Magnitude of percentage deviation of concerning models clearly indicate that Ramaswamy model based on association process was found to be more consistent with experimental findings in comparison to Glinski and PFP model. PFP model show more percentage deviation for entire range of mole fraction because the model was developed for γ-meric spherical chain of non-electrolytes[19]. Increasing order of percentage deviation in ultrasonic speed is as follows: Ramaswamy < Glinski < PFP. Values of thermal expansion coefficient (α) and isothermal compressibility (βT) required for PFP model can be calculated in absence of experimental data by the following empirical equation which are already tested by us[19,20].

$$\alpha = \frac{75.6\times10^{-3}}{T^{1/9}U^{1/2}\rho^{1/3}}\,K^{-1} \quad (16)$$

$$\beta_T = \frac{1.17\times10^{-3}}{T^{4/9}\rho^{4/3}U^{2}}\,cm^2dyne^{-1} \quad (17)$$

Increase in density and non-linear variation of ultrasonic speed with mole fraction as shown in Figure-(1) confirm the solvent-solvent interactions[21]. A perusal of Table-2 reveals that is entropic compressibility (βs) increases with increase in mole fraction for all the models at different temperatures. Which clearly confirm the inverse relation of ultrasonic speed and isentropic compressibility. Deviation in isentropic compressibility as shown in Figure-2 positively increases with increase in mole fraction of 2-butanol up to a certain limit than decreases. Which indicate that system is very less compact due to the breakup of hydrogen bonds present between alcoholic components[22].

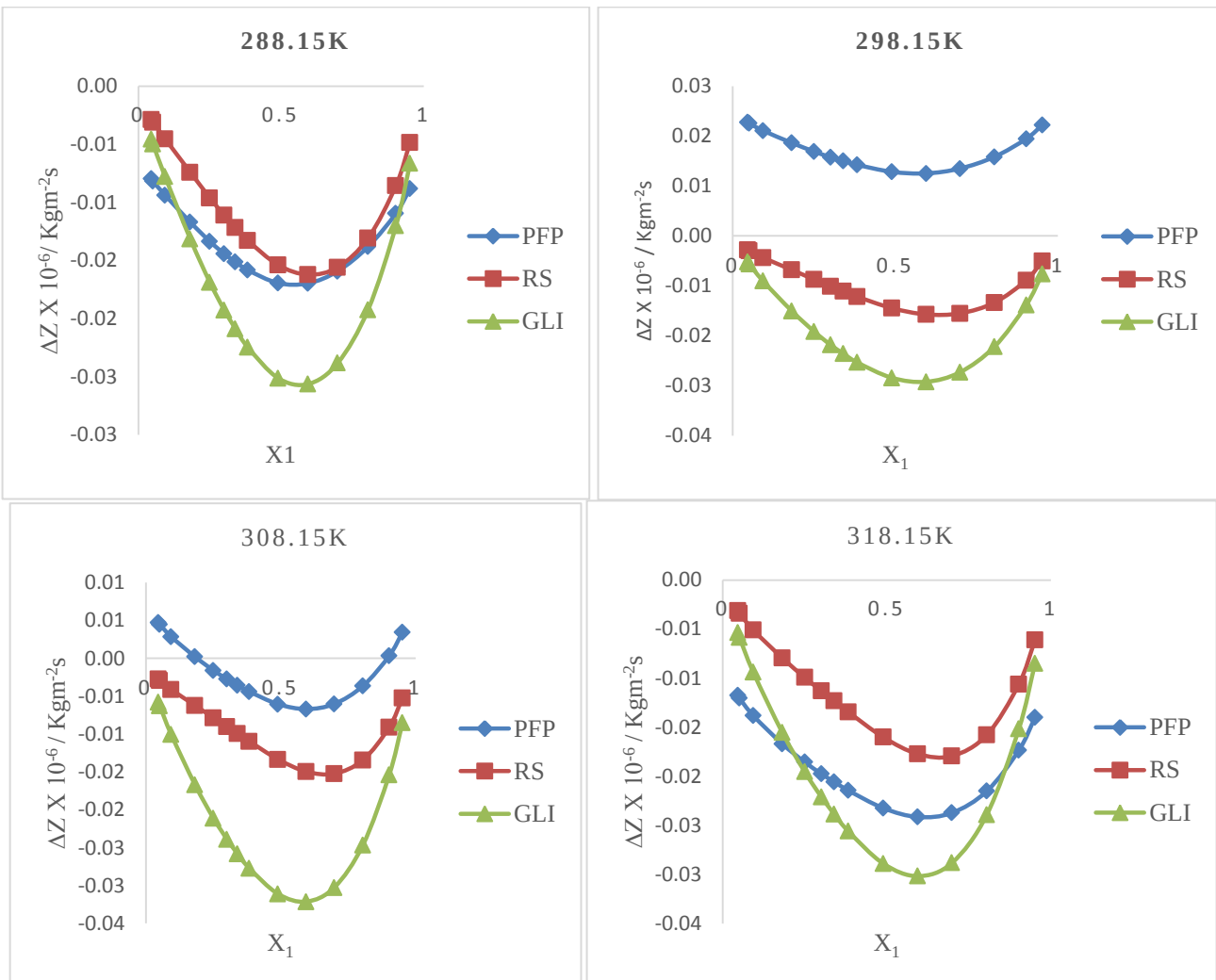

Figure-3: Graphical representation of deviation in acoustic impedance.

Increasing order of percentage deviation in isentropic compressibility is as follows: Glinski < Ramaswamy < PFP. Deviation in acoustic impedance decreases negatively than increases with increase in mole fraction of 2-butanol as shown in Figure-3 for all models at different temperatures. Which indicate the molecular interaction formed by dissociation of hydrogen bonds[23]. The result obtained from the discussion of graphical representation support each other. At 298.15K deviation in acoustic impedance calculated by PFP model based on non-association process show positive variation in entire range of mole fraction while other two associated models show negative deviation. Increasing order of percentage deviation in acoustic impedance is as follows: Ramaswamy < Glinski < PFP. Standard deviations (δU) calculated from Redlich Kister polynomial for mixing function (ΔU) reported in Table-4 varies from 0.24<δ<0.32 which indicate the excellent correlation between experimental and theoretical findings. AAPD of ultrasonic speed, isentropic compressibility, acoustic impedance calculated for PFP, Ramaswamy and Glinski model reported in Table-5, Table-6 and Table-7 clearly explain Ramaswamy model based on association process gave an excellent result in comparison to Glinski and PFP model based on non-association model, whereas in case of correlation model McAllister-4 body deal a fair agreement with experimental results in comparison to McAllister-3 body model for all the acoustical properties at different temperatures.

Table-1: Experimental, theoretical ultrasonic speed and their % deviation from 288.15-318.15K.

X_1	ρ^{MIX}	U^{EXP}	U^{PFP}	U^{RS}	U^{GLI}	$\%\Delta^{PFP}$	$\%\Delta^{RS}$	$\%\Delta^{GLI}$
T=288.15K								
0.04602	0.7528	1312.74	1323.31	1312.91	1315.00	-0.81	-0.01	-0.17
0.0507	0.7529	1312.32	1323.18	1312.47	1314.76	-0.83	-0.01	-0.19
0.09287	0.7536	1309.26	1321.71	1308.58	1312.58	-0.95	0.05	-0.25
0.18128	0.7555	1302.82	1318.31	1300.71	1307.73	-1.19	0.16	-0.38
0.24985	0.7572	1297.76	1315.41	1294.89	1303.73	-1.36	0.22	-0.46
0.30044	0.7586	1294.05	1313.07	1290.75	1300.64	-1.47	0.25	-0.51
0.33974	0.7598	1291.23	1311.13	1287.63	1298.15	-1.54	0.28	-0.54
0.38271	0.7612	1288.14	1308.93	1284.30	1295.36	-1.61	0.30	-0.56
0.48939	0.7654	1280.62	1302.76	1276.46	1288.09	-1.73	0.33	-0.58
0.59429	0.7707	1273.68	1295.69	1269.31	1280.48	-1.73	0.34	-0.53
0.69831	0.7773	1267.06	1287.54	1262.79	1272.49	-1.62	0.34	-0.43
0.80469	0.7860	1260.19	1277.76	1256.70	1263.89	-1.39	0.28	-0.29
0.90245	0.7964	1253.50	1267.23	1251.61	1255.62	-1.10	0.15	-0.17
0.95177	0.8028	1250.22	1261.21	1249.23	1251.32	-0.88	0.08	-0.09
T=298.15K								
0.04602	0.7455	1273.46	1242.97	1273.49	1276.59	2.39	0.00	-0.25
0.0507	0.7455	1273.10	1242.85	1273.02	1276.42	2.38	0.01	-0.26
0.09287	0.7462	1269.82	1241.56	1268.86	1274.80	2.23	0.08	-0.39
0.18128	0.7480	1263.38	1238.47	1260.55	1270.97	1.97	0.22	-0.60

0.24985	0.7496	1258.36	1235.81	1254.50	1267.63	1.79	0.31	-0.74
0.30044	0.7509	1254.67	1233.69	1250.27	1264.94	1.67	0.35	-0.82
0.33974	0.7522	1251.84	1231.88	1247.10	1262.74	1.59	0.38	-0.87
0.38271	0.7535	1248.76	1229.87	1243.78	1260.21	1.51	0.40	-0.92
0.48939	0.7576	1241.13	1224.20	1236.10	1253.39	1.36	0.41	-0.99
0.59429	0.7627	1234.11	1217.70	1229.37	1245.96	1.33	0.38	-0.96
0.69831	0.7692	1227.66	1210.13	1223.50	1237.91	1.43	0.34	-0.83
0.80469	0.7778	1221.36	1201.00	1218.32	1229.00	1.67	0.25	-0.63
0.90245	0.7882	1215.73	1191.05	1214.30	1220.24	2.03	0.12	-0.37
0.95177	0.7947	1213.24	1185.31	1212.53	1215.62	2.30	0.06	-0.20
T=308.15K								
0.04602	0.7381	1234.92	1228.56	1234.74	1238.76	0.52	0.01	-0.31
0.0507	0.7381	1234.48	1228.44	1234.31	1238.72	0.49	0.01	-0.34
0.09287	0.7387	1231.07	1227.22	1229.90	1237.62	0.31	0.09	-0.53
0.18128	0.7404	1224.51	1224.25	1221.19	1234.74	0.02	0.27	-0.84
0.24985	0.7419	1219.48	1221.66	1214.93	1231.98	-0.18	0.37	-1.03
0.30044	0.7432	1215.85	1219.55	1210.59	1229.66	-0.30	0.43	-1.14
0.33974	0.7444	1213.01	1217.80	1207.38	1227.69	-0.40	0.46	-1.21
0.38271	0.7457	1209.91	1215.81	1204.02	1225.38	-0.49	0.49	-1.28
0.48939	0.7496	1202.20	1210.29	1196.43	1218.89	-0.67	0.48	-1.39
0.59429	0.7546	1195.02	1203.91	1189.99	1211.53	-0.74	0.42	-1.38
0.69831	0.7609	1188.52	1196.45	1184.59	1203.29	-0.67	0.33	-1.24
0.80469	0.7694	1182.58	1187.34	1180.09	1193.95	-0.40	0.21	-0.96
0.90245	0.7797	1177.79	1177.37	1176.87	1184.58	0.04	0.08	-0.58
0.95177	0.7863	1175.92	1171.57	1175.58	1179.59	0.37	0.03	-0.31
T=318.15K								
0.04602	0.7306	1197.08	1213.19	1197.45	1200.36	-1.35	-0.03	-0.27
0.0507	0.7306	1196.62	1213.10	1197.00	1200.20	-1.38	-0.03	-0.30
0.09287	0.7312	1193.03	1211.93	1193.08	1198.66	-1.58	0.00	-0.47

0.18128	0.7326	1186.25	1209.04	1185.24	1195.03	-1.92	0.09	-0.74
0.24985	0.7341	1181.20	1206.47	1179.52	1191.84	-2.14	0.14	-0.90
0.30044	0.7353	1177.53	1204.38	1175.50	1189.28	-2.28	0.17	-1.00
0.33974	0.7364	1174.71	1202.64	1172.50	1187.18	-2.38	0.19	-1.06
0.38271	0.7377	1171.59	1200.65	1169.34	1184.76	-2.48	0.19	-1.12
0.48939	0.7415	1163.80	1195.14	1162.02	1178.25	-2.69	0.15	-1.24
0.59429	0.7462	1156.43	1188.78	1155.58	1171.13	-2.80	0.07	-1.27
0.69831	0.7523	1149.84	1181.37	1149.92	1163.42	-2.74	-0.01	-1.18
0.80469	0.7606	1143.97	1172.25	1144.88	1154.89	-2.47	-0.08	-0.95
0.90245	0.7709	1139.65	1162.16	1140.92	1146.49	-1.97	-0.11	-0.60
0.95177	0.7774	1138.24	1156.26	1139.17	1142.06	-1.58	-0.08	-0.34

Table-2: Experimental, theoretical isentropic compressibility and their % deviation from 288.15-318.15K.

X_1	βs^{EXP}	βs^{PFP}	βs^{RS}	βs^{GLI}	$\%\Delta^{PFP}_{(\beta s)}$	$\%\Delta^{RS}_{(\beta s)}$	$\%\Delta^{GLI}_{(\beta s)}$
T=288.15K							
0.04602	770.85	758.58	766.59	767.87	1.59	0.55	0.39
0.0507	771.28	758.67	766.66	768.06	1.63	0.60	0.42
0.09287	774.11	759.60	767.27	769.73	1.87	0.88	0.57
0.18128	779.86	761.63	768.73	773.08	2.34	1.43	0.87
0.24985	784.20	763.30	770.03	775.54	2.67	1.81	1.10
0.30044	787.23	764.59	771.08	777.27	2.88	2.05	1.26
0.33974	789.40	765.62	771.95	778.57	3.01	2.21	1.37
0.38271	791.72	766.77	772.96	779.94	3.15	2.37	1.49
0.48939	796.63	769.78	775.70	783.11	3.37	2.63	1.70
0.59429	799.84	772.90	778.73	785.91	3.37	2.64	1.74
0.69831	801.37	776.08	782.08	788.37	3.16	2.41	1.62
0.80469	801.18	779.29	785.84	790.55	2.73	1.91	1.33
0.90245	799.17	781.95	789.60	792.25	2.16	1.20	0.87
0.95177	796.89	783.07	791.61	792.99	1.73	0.66	0.49

T=298.15K							
0.04602	827.19	868.27	821.64	823.70	-4.97	0.67	0.42
0.0507	827.60	868.38	821.67	823.93	-4.93	0.72	0.44
0.09287	831.12	869.39	822.00	825.97	-4.60	1.10	0.62
0.18128	837.62	871.66	822.97	829.99	-4.06	1.75	0.91
0.24985	842.49	873.52	823.99	832.88	-3.68	2.20	1.14
0.30044	845.93	874.95	824.88	834.87	-3.43	2.49	1.31
0.33974	848.39	876.11	825.67	836.34	-3.27	2.68	1.42
0.38271	851.05	877.38	826.61	837.87	-3.09	2.87	1.55
0.48939	856.87	880.74	829.33	841.30	-2.79	3.21	1.82
0.59429	860.85	884.21	832.55	844.14	-2.71	3.29	1.94
0.69831	862.59	887.76	836.28	846.43	-2.92	3.05	1.87
0.80469	861.88	891.34	840.63	848.23	-3.42	2.46	1.58
0.90245	858.39	894.33	845.12	849.38	-4.19	1.55	1.05
0.95177	854.83	895.60	847.56	849.78	-4.77	0.85	0.59
T=308.15K							
0.04602	888.45	897.67	881.50	884.43	-1.04	0.78	0.45
0.0507	889.02	897.78	881.50	884.72	-0.99	0.85	0.48
0.09287	893.21	898.83	881.58	887.23	-0.63	1.30	0.67
0.18128	900.81	901.19	882.14	892.14	-0.04	2.07	0.96
0.24985	906.37	903.14	882.95	895.62	0.36	2.58	1.19
0.30044	910.17	904.65	883.76	898.00	0.61	2.90	1.34
0.33974	913.04	905.86	884.51	899.73	0.79	3.12	1.46
0.38271	916.08	907.21	885.46	901.52	0.97	3.34	1.59
0.48939	923.01	910.72	888.36	905.42	1.33	3.75	1.91
0.59429	928.02	914.36	891.99	908.50	1.47	3.88	2.10
0.69831	930.40	918.11	896.35	910.82	1.32	3.66	2.10

0.80469	929.38	921.94	901.58	912.41	0.80	2.99	1.83
0.90245	924.53	925.18	907.09	913.17	-0.07	1.89	1.23
0.95177	919.76	926.61	910.12	913.29	-0.74	1.05	0.70
T=318.15K							
0.04602	955.14	929.94	947.90	950.27	2.64	0.76	0.51
0.0507	955.84	930.05	947.96	950.56	2.70	0.82	0.55
0.09287	960.93	931.19	948.51	953.07	3.10	1.29	0.82
0.18128	969.98	933.76	950.00	958.06	3.73	2.06	1.23
0.24985	976.37	935.90	951.45	961.66	4.15	2.55	1.51
0.30044	980.80	937.56	952.69	964.17	4.41	2.87	1.70
0.33974	984.07	938.88	953.76	966.03	4.59	3.08	1.83
0.38271	987.60	940.37	955.02	967.96	4.78	3.30	1.99
0.48939	995.78	944.23	958.59	972.35	5.18	3.73	2.35
0.59429	1002.05	948.26	962.73	976.05	5.37	3.92	2.59
0.69831	1005.35	952.40	967.44	979.12	5.27	3.77	2.61
0.80469	1004.60	956.71	972.88	981.62	4.77	3.16	2.29
0.90245	998.78	960.47	978.43	983.35	3.84	2.04	1.55
0.95177	992.89	962.18	981.44	984.01	3.09	1.15	0.89

Table-3: Experimental, theoretical acoustic Impedance and their % deviation from 288.15-318.15K.

X_1	$Z^{exp}X\ 10^{-6}$	$Z^{PFP}X\ 10^{-6}$	$Z^{RS}X\ 10^{-6}$	$Z^{GLI}X\ 10^{-6}$	$\%\Delta^{PFP}$	$\%\Delta^{RS}$	$\%\Delta^{GLI}$
T=288.15K							
0.04602	0.9882	0.9962	0.9911	0.9928	-0.81	-0.29	-0.46
0.0507	0.9880	0.9962	0.9911	0.9930	-0.83	-0.32	-0.50
0.09287	0.9867	0.9961	0.9912	0.9945	-0.95	-0.46	-0.79
0.18128	0.9842	0.9959	0.9916	0.9974	-1.19	-0.75	-1.34
0.24985	0.9826	0.9960	0.9922	0.9995	-1.36	-0.98	-1.72
0.30044	0.9816	0.9961	0.9927	1.0009	-1.47	-1.13	-1.96

0.33974	0.9811	0.9962	0.9932	1.0019	-1.54	-1.24	-2.13
0.38271	0.9805	0.9964	0.9938	1.0030	-1.61	-1.35	-2.29
0.48939	0.9802	0.9972	0.9956	1.0054	-1.73	-1.57	-2.56
0.59429	0.9816	0.9986	0.9978	1.0072	-1.73	-1.65	-2.61
0.69831	0.9848	1.0008	1.0004	1.0087	-1.62	-1.58	-2.42
0.80469	0.9905	1.0043	1.0035	1.0097	-1.39	-1.32	-1.94
0.90245	0.9982	1.0092	1.0068	1.0102	-1.10	-0.86	-1.20
0.95177	1.0037	1.0125	1.0086	1.0104	-0.88	-0.48	-0.66
T=298.15K							
0.04602	0.9493	0.9266	0.9521	0.9545	2.39	-0.30	-0.55
0.0507	0.9491	0.9266	0.9521	0.9548	2.38	-0.31	-0.59
0.09287	0.9475	0.9264	0.9519	0.9565	2.23	-0.46	-0.95
0.18128	0.9450	0.9263	0.9518	0.9600	1.97	-0.72	-1.59
0.24985	0.9433	0.9264	0.9520	0.9624	1.79	-0.92	-2.03
0.30044	0.9422	0.9264	0.9523	0.9640	1.67	-1.07	-2.31
0.33974	0.9416	0.9266	0.9526	0.9651	1.59	-1.18	-2.50
0.38271	0.9410	0.9267	0.9531	0.9663	1.51	-1.29	-2.69
0.48939	0.9403	0.9275	0.9548	0.9687	1.36	-1.54	-3.02
0.59429	0.9413	0.9288	0.9570	0.9705	1.33	-1.67	-3.10
0.69831	0.9443	0.9308	0.9598	0.9716	1.43	-1.64	-2.89
0.80469	0.9500	0.9341	0.9633	0.9722	1.67	-1.41	-2.34
0.90245	0.9583	0.9388	0.9671	0.9721	2.03	-0.93	-1.44
0.95177	0.9642	0.9420	0.9692	0.9718	2.30	-0.52	-0.79
T=308.15K							
0.04602	0.9114	0.9068	0.9142	0.9172	0.52	-0.30	-0.64
0.0507	0.9112	0.9067	0.9141	0.9175	0.49	-0.32	-0.69
0.09287	0.9094	0.9066	0.9135	0.9195	0.31	-0.45	-1.11

0.18128	0.9066	0.9064	0.9128	0.9233	0.02	-0.69	-1.84
0.24985	0.9047	0.9063	0.9126	0.9258	-0.18	-0.87	-2.33
0.30044	0.9036	0.9064	0.9127	0.9275	-0.30	-1.00	-2.64
0.33974	0.9029	0.9065	0.9129	0.9287	-0.40	-1.10	-2.86
0.38271	0.9022	0.9066	0.9132	0.9299	-0.49	-1.21	-3.07
0.48939	0.9012	0.9073	0.9145	0.9323	-0.67	-1.48	-3.45
0.59429	0.9017	0.9084	0.9167	0.9338	-0.74	-1.66	-3.56
0.69831	0.9043	0.9104	0.9196	0.9346	-0.67	-1.69	-3.35
0.80469	0.9099	0.9135	0.9233	0.9345	-0.40	-1.48	-2.71
0.90245	0.9184	0.9180	0.9275	0.9337	0.04	-0.99	-1.68
0.95177	0.9246	0.9212	0.9298	0.9331	0.37	-0.57	-0.92
T=318.15K							
0.04602	0.8746	0.8864	0.8777	0.8800	-1.35	-0.36	-0.62
0.0507	0.8743	0.8863	0.8777	0.8802	-1.38	-0.39	-0.67
0.09287	0.8723	0.8861	0.8774	0.8817	-1.58	-0.58	-1.08
0.18128	0.8691	0.8858	0.8770	0.8846	-1.92	-0.91	-1.79
0.24985	0.8671	0.8856	0.8770	0.8866	-2.14	-1.15	-2.25
0.30044	0.8659	0.8856	0.8772	0.8880	-2.28	-1.31	-2.55
0.33974	0.8651	0.8856	0.8774	0.8889	-2.38	-1.42	-2.76
0.38271	0.8643	0.8857	0.8777	0.8899	-2.48	-1.56	-2.96
0.48939	0.8629	0.8861	0.8789	0.8918	-2.69	-1.86	-3.35
0.59429	0.8630	0.8871	0.8807	0.8931	-2.80	-2.05	-3.50
0.69831	0.8651	0.8888	0.8830	0.8939	-2.74	-2.07	-3.33
0.80469	0.8701	0.8917	0.8859	0.8941	-2.47	-1.81	-2.75
0.90245	0.8785	0.8959	0.8892	0.8937	-1.97	-1.21	-1.73
0.95177	0.8848	0.8989	0.8910	0.8933	-1.58	-0.69	-0.96

Table-4: Coefficients and standard deviation of Redlich Kister polynomial.

T/K	A_0	A_1	A_2	A_3	δU
288.15	-6.7840	0.8589	-9.5917	15.2087	0.38
298.15	-14.6155	-6.6252	-15.1473	17.7979	0.36
308.15	-20.9362	-12.5154	-21.7222	18.1055	0.32
318.15	-25.2409	-15.1511	-25.8856	10.6701	0.24

Table-5: Average absolute % deviation of ultrasonic speed along with association constant (K_{as}) and adjustable parameter (U_{AB}) from 288.15-318.15K.

T/K	K_{as}	U_{AB}	AAPD				
			U^{PFP}	U^{RS}	U^{GLI}	U^{Mc-3}	U^{Mc-4}
288.15	0.02	1250.25	1.30	0.20	0.37	0.07	0.03
298.15	0.03	1225.25	1.83	0.24	0.63	0.06	0.03
308.15	0.04	1225.25	0.40	0.26	0.90	0.05	0.03
318.15	0.03	1185.25	2.13	0.10	0.82	0.03	0.12

Table-6: Average absolute % deviation of isentropic compressibility along with association constant (K_{as}) and adjustable parameter (βs_{AB}) from 288.15-318.15K.

T/K	k_{as}	βs_{AB}	AAPD				
			βs^{PFP}	βs^{RS}	βs^{GLI}	βs^{Mc-3}	βs^{Mc-4}
288.15	0.02	778.65	2.61	1.67	1.09	0.14	0.04
298.15	0.03	835.65	3.70	2.06	1.19	0.17	0.04
308.15	0.04	889.23	0.80	2.44	1.29	0.21	0.04
318.15	0.03	972.67	4.19	2.46	1.60	0.24	0.03

Table-7: Average absolute % deviation of acoustic impedance along with association constant (K_{as}) and adjustable parameter (βs_{AB}) from 288.15-318.15K.

T/K	K_{as}	$Z_{AB}X10^{-6}$	AAPD				
			Z^{PFP}	Z^{RS}	Z^{GLI}	Z^{Mc-3}	Z^{MC-4}
288.15	0.02	1.00	1.30	1.00	1.61	0.04	0.02
298.15	0.03	0.96	1.80	1.00	1.92	0.03	0.03
308.15	0.04	0.92	0.40	0.99	2.20	0.04	0.03
318.15	0.03	0.88	2.13	1.24	2.16	0.05	0.03

Conclusion

On the basis of above analysis, it can be concluded that ultrasonic speed, isentropic compressibility and acoustic impedance computed for different models at different temperatures provide a way to understand the molecular interaction between the binary components. Ramaswamy and Glinski model based on association process gave more reliable results in comparison to PFP model based on non- associated model and are helpful in predicting the internal structure of molecular complexes during mixing through the fitted values of ultrasonic speed and other acoustical parameters.

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References

1. Awasthi N. (2021). Prediction of molecular interactions in binary system from 288.15 to 318.15K by ultrasonic speed and isentropic compressibility. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*., 12(6), 27-19.

2. Baluja, S., & Oza, S. (2001). Studies of some acoustical properties in binary solutions. *Fluid phase equilibria*, 178(1-2), 233-238.

3. Pandey J.D., Vyas V., Jain P., Dubey G. P., Tripathi N., & Dey R. (1999). Speed of sound, viscosity and refractive index of multicomponent systems: theoretical predictions from the properties of pure components. *Journal of molecular liquids*., 81(2), 123-133.

4. Nath, G., Sahu, S. & Paikaray, R. (2009). Study of acoustic parameters of binary mixtures of a nonpolar liquid with polar liquid at different frequencies. *Indian journal of physics*, 83, 429-436.

5. Deosarkar S.D., Tawde P.D., & Arsule A.D. (2021). An Insight into the Molecular Interactions of Ranitidine Hydrochloride in Aqueous-Alcoholic Mixtures at Different Temperatures through Ultrasonic Velocity Study. *Russian Journal of Physical Chemistry A*.,95(13),2578-85.

6. Duraivathi C., Priya J.J., Poongodi J. & Jeyakumar H. J. (2022). Ultrasonic study of molecular interactions in organic liquid with CCl_4 at different temperature. *Materials Today: Proceedings*, 49, 1968-72.

7. Abe, A., & Flory, P. J. (1965). The thermodynamic properties of mixtures of small, nonpolar molecules. *Journal of the American Chemical Society*, 87(9), 1838-1846.

8. Flory, P. J., Orwoll, R. A., & Vrij, A. (1964). Statistical thermodynamics of chain molecule liquids. II. Liquid mixtures of normal paraffin hydrocarbons. *Journal of the American Chemical Society*, 86(17), 3515-3520.

9. Prigogine I and Ballemans. A (1957). Method V. A. Molecular theory of solutions. Amsterdam: North –Holland Publ. Company.

10. Prigogine, I., & Saraga, L. (1952). Test of monolayer model for surface tension of simple liquid. *J. chem. Phys*, 49, 399-407.

11. Flory P.D., (1965). Statistical thermodynamics of liquid mixtures. *Journal of the American Chemical Society*, 87(9), 1833-1838.

12. Patterson D. & Rastogi A.K. (1970). The surface tension of polymeric liquids and the principle of corresponding states. *J Phy Chem*., 74, 1067-1071.

13. Ramaswamy, K., & Anbananthan, D. (1981). Original article unavailable, Information taken from Ref.[3]. *Acustica*, 48, 281-282.

14. Gliński, J. (2003). Determination of the conditional association constants from the sound velocity data in binary liquid mixtures. *The Journal of chemical physics*, 118(5), 2301-2307.

15. McAllister, R. A. (1960). The viscosity of liquid mixtures. *AIChE Journal*, 6(3), 427-431.

16. Redlich, O., & Kister, A. T. (1948). Algebraic representation of thermodynamic properties and the classification of solutions. *Industrial & Engineering Chemistry*, 40(2), 345-348.

17. Troncoso, J., Valencia, J. L., Souto-Caride, M., González-Salgado, D., & Peleteiro, J. (2004). Thermodynamic properties of dodecane+ 1-butanol and+ 2-butanol systems. *Journal of Chemical & Engineering Data*, 49(6), 1789-1793.

18. Shukla, R. K., Kumar, A., Awasthi, N., Srivastava, U., & Srivastava, K. (2017). Speed of sound and isentropic compressibility of benzonitrile, chlorobenzene, benzyl chloride and benzyl alcohol with benzene from various models at temperature range 298.15–313.15 K. *Arabian Journal of Chemistry*, 10(7), 895-905.

19. Shukla, R. K., Awasthi, N., Kumar, A., Shukla, A., & Pandey, V. K. (2011). Prediction of associational behaviour of binary liquid mixtures from viscosity data at 298.15, 303.15, 308.15 and 313.15 K. *Journal of Molecular Liquids*, 158(2), 131-138.

20. Shukla, R. K., Kumar, A., Srivastava, U., Awasthi, N., & Pandey, J. D. (2012). Estimation of the surface tensions of benzonitrile, chlorobenzene, benzyl chloride and benzyl alcohol in mixtures with benzene by associated and non-associated processes at 298.15, 303.15 and 313.15 K. *Journal of solution chemistry*, 41, 1112-1132.

21. Natarajan, R., & Ramesh, P. (2011). Ultrasonic velocity determination in binary liquid mixtures. *Journal of Pure Applied and Industrial Physics*, 1(4), 212-277.

22. Kiyohara, O., & Benson, G. C. (1979). Ultrasonic speeds and isentropic compressibilities of n-alkanol+ n-heptane mixtures at 298.15 K. *The Journal of Chemical Thermodynamics*, 11(9), 861-873.

23. Kumar, H., Kundi, V., Singla, M., & Sharma, S. (2013). Mixing Properties of Binary Liquid Mixtures of Alkoxypropanols with Branched Alkanols at Different Temperatures. *Bulletin of the Chemical Society of Japan*, 86(12), 1435-1446.