



Molecular Interactions in Binary Liquid Mixtures of Cyclohexanone with Morpholine, Bromobenzene and Anisole at 308.15 K and 318.15 K

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Densities, viscosities and ultrasonic velocities have been measured for the binary mixtures of cyclohexanone with morpholine, bromobenzene and anisole at 308.15 K and 318.15 K over the entire range of mole fraction. Thermodynamic parameters like excess volume, adiabatic compressibility, free volume, linear free energy, acoustic impedance and viscosity are calculated. From these values the excess properties are also calculated. The deviations of the liquid mixture from ideality have been explained based on the nature molecular interactions between unlike molecules.

Keywords: Density, Viscosity, Ultrasonic velocity, Adiabatic compressibility, Acoustic impedance.

INTRODUCTION

Physical and transport properties of binary liquid mixtures¹⁻⁵ are of great importance in industrial process. Cyclohexanone⁶⁻⁹ is a cyclic ketone which finds many application in organic synthesis and industrial applications. Similarly morpholine¹⁰⁻¹², bromobenzene¹³⁻¹⁵ and anisole¹⁶⁻¹⁸ are of great importance in organic process. This lead to study the properties of binary liquid mixtures of these liquids based on the nature of interactions between the mixing liquids. In the present study the nature of interactions has been studied based on the measurement of densities, viscosities and ultrasonic velocities of all pure liquids and their constituent binaries at 308.15 K and 318.15 K. From these values excess volume, adiabatic compressibility, linear free energy, acoustic impedance, free volume and viscosities were calculated. Excess values for all these thermodynamic parameters were calculated and fitted to Redlich-Kister polynomial to derive the binary coefficients and standard deviations between the calculated and fit parameters.

EXPERIMENTAL

Cyclohexanone (Merck, Mumbai), morpholine (Merck, Mumbai), bromo benzene (Nice chemicals, Cochin) and anisole (Nice chemicals, Cochin), all AnalaR grades¹⁹ were dried using suitable drying agents and distilled based on standard methods. Binary liquid mixtures of various compositions were prepared by mixing measured amount of pure

liquids in air tight stopper bottles of 50 mL capacity. Densities of pure liquids and liquid mixtures were measured by relative density method using 10 mL relative density bottle with an accuracy of $\pm 0.001 \text{ kgm}^{-3}$. Viscosities of all pure and liquid mixtures were measured using Ostwald viscometer of 10 mL capacity with an accuracy of $\pm 0.001 \text{ cP}$. Ultrasonic velocities of pure and liquid mixtures were measured by a single crystal variable path interferometer (Mittal Enterprises, New Delhi, model F-80) at a frequency of 2 MHz with an accuracy of $\pm 0.02 \%$. All the measurements were made at both 308.15 K and 318.15 K with the help of a digital thermostat with a temperature accuracy of $\pm 0.01 \text{ K}$.

RESULTS AND DISCUSSION

The experimental densities (ρ), viscosity (η) and ultrasonic velocity (u) of the pure liquids and binary systems are presented in Table-1a and 1b, 2a and 2b and 3a and 3b.

Adiabatic compressibility (K_s) has been calculated from Laplace's equation²⁰

$$K_s = 1/\rho u^2 \quad (1)$$

in which ρ and u are density and ultrasonic velocity in liquid, respectively.

Acoustic impedance (Z) has been calculated by the relation²¹

$$Z = u \rho \quad (2)$$

Linear free energy has been calculated by Jacobson's relation²²

$$L_f = K/\rho u^{1/2} \quad (3)$$

TABLE-1A

THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE MORPHOLINE (1)–CYCLOHEXANONE (2) 308.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	φ_1	ΔKs T Pa ⁻¹	$\Delta\eta$ cP	$\Delta L_r \times 10^5$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9312	0.0000	1358	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0985	0.9360	-0.0197	1367	0.0940	-1.1086	0.2560	-0.4316	2.5217	-1.5366
0.1980	0.9412	-0.0599	1371	0.1717	-1.5704	0.2651	-0.3149	0.8421	-1.5530
0.2934	0.9464	-0.1037	1376	0.2584	-2.8118	0.2764	-0.3392	0.6821	-1.5525
0.3958	0.9522	-0.1524	1382	0.3547	-4.4096	0.2863	-0.4393	1.4583	-1.5195
0.4934	0.9580	-0.2062	1388	0.4498	-5.9357	0.2988	-0.5729	2.9115	-1.4807
0.5903	0.9639	-0.2633	1392	0.5473	-5.6463	0.3123	-0.4966	2.7391	-1.4403
0.6987	0.9705	-0.2811	1396	0.6606	-4.5568	0.3229	-0.3506	2.1333	-1.3647
0.7998	0.9762	-0.2418	1400	0.7702	-3.1173	0.2924	-0.1992	1.2506	-1.1609
0.8944	0.9812	-0.1567	1404	0.8766	-1.4323	0.2631	-0.0518	0.2471	-0.9652
1.0000	0.9863	0.0000	1410	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE-1B

THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE MORPHOLINE (1)–CYCLOHEXANONE (2) 318.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	φ_1	ΔKs T Pa ⁻¹	$\Delta\eta$ cP	$\Delta L_r \times 10^5$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9234	0.0000	1275	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0985	0.9285	-0.0703	1308	0.0940	-22.0669	0.2631	-2.8954	19.5768	-2.0050
0.1980	0.9339	-0.1488	1334	0.1717	-38.3674	0.2550	-4.7389	33.1706	-1.7756
0.2934	0.9391	-0.2079	1355	0.2584	-48.7308	0.2295	-5.9277	42.8304	-1.4768
0.3958	0.9450	-0.2836	1372	0.3547	-53.9102	0.2216	-6.5105	48.6241	-1.3244
0.4934	0.9508	-0.3528	1379	0.4498	-50.5353	0.1965	-6.0154	45.8304	-1.1411
0.5903	0.9566	-0.4087	1380	0.5473	-41.9114	0.1908	-4.8654	37.5615	-1.1117
0.6987	0.9631	-0.4399	1382	0.6606	-32.3185	0.1822	-3.6626	29.0697	-1.0460
0.7998	0.9681	-0.3488	1384	0.7702	-22.3091	0.1739	-2.4707	19.8949	-0.9698
0.8944	0.9723	-0.2037	1386	0.8766	-12.2355	0.1472	-1.3279	10.7856	-0.7971
1.0000	0.9767	0.0000	1388	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE-2A

THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE BROMOBENZENE (1)–CYCLOHEXANONE (2) 308.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	φ_1	ΔKs T Pa ⁻¹	$\Delta\eta$ cP	$\Delta L_r \times 10^6$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9312	0.0000	1358	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0954	0.9864	-0.3095	1340	0.0963	-10.5349	0.0768	-0.1845	20.6010	-1.4449
0.1935	1.0420	-0.4881	1320	0.1951	-20.7921	-0.0192	-0.3182	36.6241	-1.3364
0.2908	1.0947	-0.4236	1300	0.2930	-27.5345	-0.0509	-0.4060	46.9600	-1.4656
0.3939	1.1483	-0.1667	1260	0.3964	-15.8133	-0.0705	-0.2422	31.1486	-1.7634
0.4931	1.1996	-0.0733	1222	0.4957	-2.5395	-0.1134	-0.0584	12.1387	-1.2863
0.5956	1.2517	-0.3681	1188	0.5981	8.9657	-0.1110	0.1010	-6.0821	-1.2644
0.6908	1.2983	-0.7597	1160	0.6930	18.7215	-0.0663	0.2361	-23.6020	-2.0927
0.8239	1.3670	-0.9710	1138	0.8254	15.9346	-0.0516	0.2063	-25.0544	-1.2130
0.9190	1.4220	-0.6535	1126	0.9198	9.1144	-0.0165	0.1197	-16.0183	-0.9878
1.0000	1.4743	0.0000	1118	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE-2B

THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE BROMOBENZENE (1)–CYCLOHEXANONE (2) 318.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	φ_1	ΔKs T Pa ⁻¹	$\Delta\eta$ cP	$\Delta L_r \times 10^5$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9234	0.0000	1275	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0954	0.9773	-0.2257	1212	0.0963	-34.8553	-0.0371	0.4789	-31.6525	-0.9080
0.1935	1.0312	-0.2885	1192	0.1951	-58.6987	-0.0010	0.4122	-26.8480	-2.1252
0.2908	1.0826	-0.1537	1152	0.2930	-40.9845	-0.0672	0.6837	-48.4561	-2.0319
0.3939	1.1368	-0.0105	1100	0.3964	-5.5940	-0.1003	1.1698	-87.0631	-2.3998
0.4931	1.1877	0.2170	1072	0.4957	4.3230	-0.1034	1.3449	-104.6740	-2.7044
0.5956	1.2403	0.4219	1048	0.5981	10.1347	-0.1138	1.4729	-119.7420	-2.4694
0.6908	1.2895	0.5596	1029	0.6930	12.5024	-0.0843	1.5557	-131.4000	-3.1659
0.8239	1.3598	0.6016	1007	0.8254	10.9829	-0.0263	1.6140	-143.1100	-4.5454
0.9190	1.4125	0.4307	994	0.9198	6.3452	-0.0376	1.6127	-147.0810	-3.3494
1.0000	1.4613	0.0000	1084	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

K is Jacobson's constant which is temperature dependent constant but independent of the nature of the liquid.

Viscosity has been calculated using the relation

$$\eta = (At-B/t)\rho \quad (4)$$

A and B are constants characteristic of viscometer calculated using standard liquids water and nitrobenzene, t time of flow in seconds.

Surianarayana²³ proposed a relation to calculate free volume

$$V_f = (M_{\text{eff}} u/K \eta)^{3/2} \quad (5)$$

K is a temperature independent constant which is equal to 4.28×10^9 for all liquids; M_{eff} is effective molecular weight of the mixture calculated using the relation

$M_{\text{eff}} = x_1 M_1 + x_2 M_2$. Where x_1, x_2 , are mole fraction and M_1, M_2 molecular weights of the component 1 and 2, respectively.

Excess volume (V^E) has been calculated using the relation

$$V^E = (x_1 M_1 + x_2 M_2)/\rho - (x_1 M_1/\rho_1) - (x_2 M_2/\rho_2) \quad (6)$$

ρ_1 and ρ_2 are densities of pure liquids 1 and 2 respectively, ρ is the density of liquid mixture.

Excess adiabatic compressibility (ΔK_s) has been calculated from the relation

$$\Delta K_s = K_s - (\phi_1 K_{s1} + \phi_2 K_{s2}) \quad (7)$$

K_{s1} and K_{s2} are adiabatic compressibility values of pure liquids and f_1 and f_2 are volume fraction for pure liquids calculated by the relation

$$\phi_1 = (x_1 M_1/\rho_1)/(x_1 M_1/\rho_1 + x_2 M_2/\rho_2) \text{ and } \phi_2 = 1 - \phi_1 \quad (8)$$

Excess values of other parameters are calculated using the relation

$$A^E = A_{\text{exp}} - A_{\text{id}} \quad (9)$$

$A_{\text{id}} = \sum x_i A_i$, x_i and A_i are mole fraction and parameters of the i^{th} component liquid.

All the calculated excess values were fitted to Redlich-Kister²⁴ type polynomial equation

$$A^E = x_1 x_2 [a + b(x_1 - x_2) + c(x_1 - x_2)^2] \quad (10)$$

by the method of least squares to derive the adjustable parameters a, b and c . From these a, b and c values theoretical values for all excess parameters were calculated and the standard deviation values were calculated using the relation.

$$\sigma = [(A^E_{\text{exp}} - A^E_{\text{cal}})^2 / (n-m)]^{1/2} \quad (11)$$

here n is the number of measurements and m the number of adjustable parameters. The values of a, b, c and σ are given in the Tables 1c, 2c and 3c.

From Tables 1a and 1b it can be seen that all excess values except for viscosity and acoustic impedance are negative at 308.15 K predicting the presence of strong interaction between morpholine and cyclohexanone. This is due to dipole-dipole, hydrogen bonded network structure formation^{25,26} and electron donor-acceptor complex formation between the mixing liquids, since cyclohexanone is a dipolar molecule and morpholine has two donor centers. Due to these interactions volume contraction takes place and excess volume becomes negative. This nature of interaction is also supported by the negative values of $\Delta K_s, \Delta L_f$ and ΔV_f values, which indicate the presence of compact structure making ability between the liquids. Existence of these specific interaction is also supported by the positive value of ΔZ value, since positive values predicts the presence of strong interaction between the liquids. $\Delta \eta$ values are positive over entire mole fraction indicating that flow of

TABLE-3A
THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE ANISOLE (1)-CYCLOHEXANONE (2) 308.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	ϕ_1	ΔK_s T Pa ⁻¹	$\Delta \eta$ cP	$\Delta L_f \times 10^5$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9312	0.0000	1358	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0956	0.9350	0.1106	1363	0.0997	0.8387	0.1852	-0.3644	2.3055	-1.6609
0.1987	0.9394	0.1903	1362	0.2062	2.9658	0.0844	-0.0612	-0.7568	-1.4248
0.2962	0.9437	0.2447	1361	0.3061	4.9261	0.0197	0.2223	-3.5230	-1.1903
0.3947	0.9482	0.2769	1360	0.4060	6.7833	-0.0464	0.4972	-6.1046	-0.6753
0.4996	0.9534	0.2594	1360	0.5113	7.6115	-0.0449	0.6413	-7.2945	-0.7640
0.5948	0.9583	0.2183	1362	0.6060	6.5963	-0.0505	0.5391	-6.2119	-0.6134
0.6974	0.9636	0.1667	1365	0.7072	4.8302	-0.0748	0.3399	-4.1832	0.0589
0.8326	0.9706	0.0892	1369	0.8390	2.5142	-0.0127	0.0813	-1.3942	-0.6203
0.8936	0.9737	0.0579	1371	0.8980	1.3722	-0.0430	0.0483	-0.0072	0.3509
1.0000	0.9791	0.0000	1372	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE-3B
THERMODYNAMIC EXCESS PARAMETERS FOR THE BINARY MIXTURE ANISOLE (1)-CYCLOHEXANONE (2) 318.15 K

x_1	$\rho \times 10^3$ (Kg m ⁻³)	$V^E \times 10^3$ (m ³ mol ⁻¹)	U (m s ⁻¹)	ϕ_1	ΔK_s T Pa ⁻¹	$\Delta \eta$ cP	$\Delta L_f \times 10^5$ m	$\Delta Z \times 10^3$ (Kg m ⁻² s ⁻¹)	$\Delta V_f \times 10^{-8}$ (m ³ mol ⁻¹)
0.0000	0.9234	0.0000	1275	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0956	0.9270	0.1189	1262	0.0997	23.1437	0.1879	2.4606	-18.5910	-2.4287
0.1987	0.9312	0.2051	1248	0.2062	44.2806	0.0313	5.1173	-38.3251	-1.6144
0.2962	0.9354	0.2551	1236	0.3061	63.0012	-0.0172	7.4712	-55.6544	-1.5477
0.3947	0.9399	0.2708	1226	0.4060	79.4717	-0.0087	9.5558	-70.9538	-2.1291
0.4996	0.9449	0.2579	1222	0.5113	89.2275	-0.0362	10.8381	-80.8107	-2.0005
0.5948	0.9496	0.2227	1232	0.6060	82.2997	-0.0891	10.0900	-76.6497	-0.8553
0.6974	0.9547	0.1756	1252	0.7072	65.1799	-0.0607	8.0793	-63.2120	-1.0309
0.8326	0.9615	0.0964	1284	0.8390	38.9693	-0.0777	4.8640	-39.6637	0.4672
0.8936	0.9645	0.0657	1304	0.8980	22.7124	-0.0901	2.8148	-23.6202	1.6594
1.0000	0.9698	0.0000	1334	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE-1C
REDLICH-KISTER ADJUSTABLE PARAMETERS AND STANDARD DEVIATION FOR THE BINARY MIXTURE MORPHOLINE-CYCLOHEXANONE AT 308.15 K. VALUES IN PARENTHESIS ARE FOR 318.15 K

	a	b	c	σ
V^E (10^3 Kg m ³)	-0.8576 (-1.4654)	-0.9721 (-1.1116)	-0.2204 (-0.1888)	0.0005 (1.0824×10^{-5})
ΔK_s (T Pa ⁻¹)	-22.4896 (-188.3660)	-2.3187 (126.272)	20.2647 (-13.3548)	0.0113 (0.0127)
$\Delta\eta$ (cP)	1.1372 (0.7370)	0.1618 (-0.4588)	2.1313 (1.9584)	0.0008 (0.0007)
ΔL_r (m)	-193897 (-2.4791 $\times 10^6$)	77356 (873369)	19842 (1.5917 $\times 10^6$)	0.0023 (0.0112)
ΔZ (10^3 Kg m ⁻² s ⁻¹)	8.8372 (179.0630)	1.0099 (-78.9857)	-0.6622 (-29.0301)	0.0188 (0.0144)
ΔV_f (m ³ mol ⁻¹)	-5.5962×10^{-8} (-4.1814×10^{-8})	2.1300×10^{-8} (4.4462×10^{-8})	-1.0122×10^{-7} (-1.4400×10^{-7})	4.0825×10^{-5} (0.0054)

TABLE-2C
REDLICH-KISTER ADJUSTABLE PARAMETERS AND STANDARD DEVIATION FOR THE BINARY MIXTURE BROMOBENZENE-CYCLOHEXANONE AT 308.15 K. VALUES IN PARENTHESIS ARE FOR 318.15 K

	a	b	c	σ
V^E (10^3 Kg m ³)	0.3802 (0.8892)	7.0722 (4.6206)	2.8310 (0.6829)	0.0040 (0.0003)
ΔK_s (T Pa ⁻¹)	-13.3101 (14.4182)	216.2390 (318.1760)	1.6196 (-367.3560)	0.0209 (0.0525)
$\Delta\eta$ (cP)	-0.4402 (-0.4220)	-0.2229 (-0.1798)	0.9560 (0.2516)	0.0009 (0.0012)
ΔL_r (m)	-252222 (4.9115×10^6)	3.0745×10^6 (6.2596×10^6)	-247186 (7.5242×10^6)	0.0025 (0.0089)
ΔZ (10^3 Kg m ⁻² s ⁻¹)	49.8034 (-379.3750)	-350.6840 (-612.8740)	-34.0514 (-715.1980)	0.0228 (0.7638)
ΔV_f (m ³ mol ⁻¹)	-5.8140×10^{-8} (-9.3789×10^{-8})	4.1041×10^{-7} (-1.1359×10^{-7})	-1.0867×10^{-7} (-2.7988×10^{-7})	0.0027 (0.0008)

TABLE-3C
REDLICH-KISTER ADJUSTABLE PARAMETERS AND STANDARD DEVIATION FOR THE BINARY MIXTURE ANISOLE-CYCLOHEXANONE AT 308.15 K. VALUES IN PARENTHESIS ARE FOR 318.15 K

	a	b	c	σ
V^E (10^3 Kg m ³)	1.0275 (1.0265)	-0.4610 (-0.4703)	-0.2018 (-0.0234)	0.0001 (4.0824×10^{-5})
ΔK_s (T Pa ⁻¹)	29.0526 (343.6160)	2.0838 (21.9856)	-28.0633 (-164.6420)	0.0040 (0.0464)
$\Delta\eta$ (cP)	-0.2721 (-0.2441)	-0.7303 (-0.8094)	1.3724 (0.6510)	0.0007 (0.0011)
ΔL_r (m)	249637 (4.1928×10^6)	111137 (265507)	-681557 (-2.2134×10^6)	0.0010 (0.0045)
ΔZ (10^3 Kg m ⁻² s ⁻¹)	-28.5179 (-314.1320)	-7.0168 (-36.9455)	59.3328 (139.46)	0.0080 (0.0286)
ΔV_f (m ³ mol ⁻¹)	-2.2325×10^{-8} (-6.9025×10^{-8})	7.0257×10^{-8} (1.2480×10^{-7})	-8.7539×10^{-8} (6.1257×10^{-8})	0.0229 (0.0065)

the liquid mixtures is difficult when compared with pure liquids²⁷. The positive value implies the presence of more interaction due to hydrogen bond formation between cyclohexanone and morpholine. As the temperature is raised to 318.15 K, $\Delta\eta$ values decreases indicating that flow of liquid is made easy as molecules expand with temperature. But at 318.15 K the negative values of V^E , ΔK_s , ΔL_r and ΔV_f increases predicting the presence of more interaction between the mixing liquids. This may be due to opening up of agglomerates of morpholine so that more number of cyclohexanone molecules can interact. Similar explanation can be obtained from the ΔZ values.

From Tables 2a and 2b for bromobenzene-cyclohexanone mixture the excess values are negative at both the temperatures up to 0.4/0.5 mole fraction values after which the values become positive. But the values of $\Delta\eta$ and ΔV_f are negative over entire mole fraction values. V^E values are negative up to 0.4 mole fraction of bromobenzene predicting more interaction between the liquids through electron-donor acceptor complex formation since bromobenzene is an aromatic liquid with π electron cloud. As concentration of bromobenzene is increased it becomes more self aggregated²⁸ that cyclohexanone find it difficult to interact, so that the nature of interaction then slightly decreases. This nature of interaction is also supported²⁹ by the

ΔK_s , ΔL_f and ΔZ values. $\Delta\eta$ values are low negative predicting easy flow of the mixtures compared to pure liquids. Increase of temperature also has the same effect on the excess values and the values of parameters have increased showing more interaction between the mixing liquids.

From Tables 3a and 3b for anisole-cyclohexanone binary mixture V^E and ΔK_s values are positive predicting expansion of volume due to more liquid order breaking effect than association type of interaction. These values indicate non-specific physical interaction and unfavorable interaction between unlike molecules *ie*; dispersion type of force³⁰ prevails though both are polar liquids. At 318.15 K also same nature of interaction is predicted which can be seen from the positive values of excess parameters. The excess values of ΔL_f , ΔZ and ΔV_f predict the same nature of interaction at both temperatures. $\Delta\eta$ values are positive up to 0.3 mole fraction of anisole and then the value becomes negative, same effect is seen at higher temperature. This sign of $\Delta\eta$ predicts that flow of mixture is difficult at lower concentration of anisole and then the rate of flow increases as the concentration of anisole is increased.

Conclusion

From the density, viscosity and ultrasonic velocity of the binary systems studied at 308.15 K and 318.15 K it can be predicted that there is specific type of interaction between cyclohexanone and morpholine, bromobenzene and non-specific type of interaction between cyclohexanone and anisole. ΔK_s and V^E shows a trend morpholine > bromobenzene > anisole and $\Delta\eta$ shows a reverse trend on the nature of interactions with cyclohexanone.

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