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Excess Thermodynamic Parameters of Binary Liquid Mixtures of Dimethyl Malonate with Isomeric Xylenes at Different Temperatures

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Over the complete composition range of mole fractions, densities and ultrasonic velocities of binary liquid mixtures of dimethyl malonate with *o*-xylene, *p*-xylene and *m*-xylene were investigated at 303.15-318.15 K. These parameters were chosen to investigate the impact of substituents and specific locations on several thermodynamic characteristics of binary mixtures. The deviation in adiabatic compressibility ($\Delta\beta_{ad}$), excess molar volume (V^E) and excess intermolecular free length (L_f^E) were estimated using the experimental measurements. These extraneous parameters are fitted to a polynomial equation of the Redlich-Kister type. Along with the obtained parameter values, the standard deviation (σ) was also determined.

Keywords: Dimethyl malonate, Isomeric xylenes, Adiabatic compressibility, Excess molar volume, Excess inter molecular free length.

INTRODUCTION

The most significant purpose for studying the thermophysical characteristics of liquids and liquid mixtures is to learn more about the molecular interactions that take place in these systems [1], which are crucial for both theoretical and practical considerations. The literature studies shows of preferred relations of polymers, polymer phase diagrams and mixed solvents are just a few of the fields in which the binary mixtures of aromatic hydrocarbons are particularly valuable [2,3]. One of the unique classes of compounds, esters has a sweet scent and a less harmful.

The octane of automobile fuels is routinely increased by adding aromatic compounds like xylenes. Therefore, it is highly intriguing to investigate the different xylene mixtures at various temperatures affect the physical and chemical characteristics of dimethyl malonate. The occurrence of significant effects caused by intermolecular interactions can be highly predicted by observing the excessive properties of binary liquid mixtures [4,5]. Theoretical models for determining and predicting fluid phase equilibria can be improved by providing experimental background; secondly, a wide range of options for continuously modifying the physical properties of the solvent can be uncovered through an exhaustive investigation of this interaction [6]. A thorough review of the literature revealed that several combinations of xylenes have been studied at various temperatures in order to determine their excess characteristics.

However, experiments with dimethyl malonate combination have only been undertaken at 303.15 K and 313.15 K, and the ultrasonic investigations have not yielded any results. Therefore, considering the ultrasonic velocities and their related parameters, this system was chosen to under a better knowledge of the nature of interactions between dimethyl malonate and isomeric xylenes. An extensive study on the excess qualities has been reported on the properties of *o*-xylene with propan-2-ol, butan-2-ol and pentan-2-ol [7], 2-butanol + *m*-xylene [8], poly(propylene glycol) + toluene/*o*-xylene/*m*-xylene/*p*-xylene [9], isomeric xylenes and diethyl malonate [10], methanol with *o*, *m* and *p*-xylenes [11], cyclohexane with toluene, *o*-xylene and mesitylene [12], xylene and certain alkanols (C4-C8) [13], dimethyl formamide (DMF) with benzene, *o*-xylene, 1,4-dioxane and tetra hydrofuran [14], 1,4-dioxane with *o*-, *m*-, *p*-xylene, toluene,

benzene and mesitylene [15], benzene, toluene, *o*-, *m*-, *p*-xylene and mesitylene with 1,4-dioxane [16], ethylbenzene + *p*-xylene [17], quinolone + *m*-xylene [18] and *o*-xylene with ethyl oleate [19].

As already known, dimethyl malonate has several applications in industries, similarly isomeric xylenes are also one of the key chemicals for industrial applications. These reasons led us to compare the molecular interactions between three distinct xylenes and dimethyl malonate. In this work, the excess molar volume (V^E), deviation in the adiabatic compressibility ($\Delta\beta_{ad}$) and excess intermolecular free length (L_f^E) of the binary systems of dimethyl malonate with *ortho*, *meta* and *para*-xylene is presented. These results have been utilized to investigate the inductive effect in terms of induced dipole-dipole interaction in the xylene interaction with dimethyl malonate. The current study also aimed to investigate the effect of the position of CH_3 group in different thermodynamic functions which can affects the sign and magnitude in the presence of dimethyl malonate.

EXPERIMENTAL

The chemicals used in the current investigation dimethyl malonate, *o*-xylene, *p*-xylene and *m*-xylene were purchased from Loba Chemicals of analytical grade with > 99% purity. Ultrasonic velocities were determined in pure liquids and their binary mixtures using a single crystal variable-path multi-frequency ultrasonic interferometer operated at 3 MHz. The double-arm pycnometer was calibrated using conductive water at a density of 995.61 kg m^3 at 303.15 K using a thermostat to maintain a consistent temperature. All the chemicals were weighed using a Mettler Toledo digital balance with an accuracy of ±0.01 mg.

Density measurement: In this investigation, the density (ρ) of all liquid mixtures and pure liquids was measured at 303.15 using a 105 mL double-arm pycnometer as reported by Nikkam *et al.* [20,21]. In order to calibrate the pycnometer, water with a conductivity and a density of 995.61 kg/m^3 was employed. By using a moving microscope with a resolution of 0.01 mm the locations of the liquid levels in the two arms of air bubble free pycnometer were noted. With a measurement uncertainty of two parts in 10^4, the density values derived from triplicate replication at each temperature were repeatable to within 2×10^{-1} kg/m^3.

RESULTS AND DISCUSSION

Table-1 clearly shows a high agreement between experimental results and values found in the literature. To prove the existence of molecular interactions, it is important to examine the excess parameters. Excess liquid mixture properties were used to calculate deviations from ideal behavior in liquid mixtures. To understand the molecular interactions, both the positive and negative contributions of the excess parameters were taken into account. The following standard relations were used to compute the excess values of molar volume (V^E), intermolecular free length (L_f^E) and variation in adiabatic compressibility ($\Delta\beta_{ad}$)

Excess molar volume (V^E):

$$V^E = (V-(V_1X_1 + V_2X_2)) \quad (1)$$

Deviation in adiabatic compressibility ($\Delta\beta_{ad}$):

$$\Delta\beta_{ad} = \beta_{ad1}X_1 + \beta_{ad2}X_2 \quad (2)$$

Excess intermolecular free length (L_f^E):

$$L_f^E = L_f - (L_{f1}X_1 + L_{f2}X_2) \quad (3)$$

The investigational values of sound speed and densities, deviation in adiabatic compressibility, excess molar volume and excess inter molecular free length expressed in mole fraction X_1 of dimethyl malonate ($0 \le X_1 \le 1$), at various temperatures, are listed in Tables 2-4 for liquid mixtures of dimethyl malonate with *o*-, *m*- and *p*-xylene.

The relative degree of the contractive and expansive effects that result from the mixing of liquid components will determine the sign and magnitude of the extra molar volume. Negative variations in excess molar volume (V^E) are observed in these three systems (Fig. 1), which is attributed due to the strong interactions between dissimilar molecules. Two polar bonds, C-O-C and >C=O, are present in dimethyl malonate molecules, whereas xylenes have two +I (methyl) groups. Despite *p*-xylene having a zero dipole moment, the +I (methyl) groups cause partial charges in xylene molecules, allowing dipole-induced dipole interactions between dimethyl malonate and xylene molecules. However, the presence of two adjacent methyl groups on the *o*-xylene molecules prevents other molecules from approaching them (steric hindrance; dimethyl malonate) [24,25]. The patterns for excess acoustic impedance (Z^E) and excess ultrasonic velocity (U^E) provide additional support for the observations.

The substituent attached to the benzene ring influences the electron density in its derivatives. Electron pairs on the carbonyl group of ester and the π-electrons of benzene ring in *p*-xylene molecules can interact in several manners (Fig. 2), which can be utilized to elucidate the divergence in adiabatic compressibility [26,27]. For example, (i) molecules become slower and more compressible as a result of changes in their sizes and shapes as well as the loss of dipole-dipole interaction, and (ii) the formation of hydrogen-bonded complexes or dipole-dipole interactions between molecules with opposite charges, results in an increase in the sound velocity and a decrease in the compressibility.

TABLE-1
COMPARISON OF EXPERIMENTAL VALUES WITH LITERATURE VALUES DATA AT 303.15 K

Liquid	Ultrasonic velocity (m/s)		Density (Kg/m^3)	
	Experimental	Literature	Experimental	Literature
Dimethyl malonate	1365.2	1365.20 [22]	1.1423	1.1423 [22]
o-Xylene	1328.2	1329.40 [23]	0.8627	0.8671 [23]
m-Xylene	1301.5	1302.46 [23]	0.8524	0.8526 [23]
p-Xylene	1286.3	1287.30 [23]	0.8466	0.8488 [23]

TABLE-2
ULTRASONIC VELOCITY (U), DENSITY (ρ), DEVIATION IN ADIABATIC COMPRESSIBILITY ($\Delta\beta_{ad}$), EXCESS MOLAR VOLUME (V^E) AND EXCESS INTERMOLECULAR FREE LENGTH (L_f^E) OF DIMETHYL MALONATE + *o*-XYLENE

X_1	U ($m\ s^{-1}$)	ρ ($kg\ m^{-3}$)	$\Delta\beta_{ad}$ (10^{-10} $m^2\ N^{-1}$)	V^E (10^6 $m^3\ mol^{-1}$)	L_f^E (10^{-11} m)	U ($m\ s^{-1}$)	ρ ($kg\ m^{-3}$)	$\Delta\beta_{ad}$ (10^{-10} $m^2\ N^{-1}$)	V^E (10^6 $m^3\ mol^{-1}$)	L_f^E (10^{-11} m)
			303.15 K					308.15 K		
0.0000	1328.2	0.8627	0.0000	0.0000	0.0000	1313.5	0.8645	0.0000	0.0000	0.0000
0.1052	1332.1	0.8918	-1.1777	-1.9577	-0.0683	1316.8	0.8935	-1.4388	-2.0330	-0.0884
0.2092	1335.9	0.9206	-2.0056	-3.3340	-0.1168	1321.1	0.9222	-2.2344	-3.4615	-0.1360
0.3120	1339.7	0.9491	-2.5251	-4.1977	-0.1478	1325.3	0.9506	-2.7308	-4.3573	-0.1662
0.4136	1343.5	0.9772	-2.7718	-4.6078	-0.1630	1329.5	0.9787	-2.9627	-4.7822	-0.1808
0.5141	1347.2	1.0051	-2.7765	-4.6156	-0.1639	1333.6	1.0064	-2.9601	-4.7895	-0.1815
0.6135	1350.9	1.0326	-2.5660	-4.2657	-0.1521	1337.7	1.0338	-2.7492	-4.4257	-0.1695
0.7117	1354.5	1.0598	-2.1638	-3.5970	-0.1288	1341.7	1.0609	-2.3527	-3.7314	-0.1462
0.8089	1358.1	1.0867	-1.5903	-2.6437	-0.0950	1345.7	1.0878	-1.7905	-2.7421	-0.1127
0.9050	1361.7	1.1133	-0.8637	-1.4359	-0.0518	1349.6	1.1143	-1.0803	-1.4891	-0.0698
1.0000	1365.2	1.1396	0.0000	0.0000	0.0000	1354.5	1.1405	0.0000	0.0000	0.0000
			313.15 K					318.15 K		
0.0000	1297.0	0.8918	0.0000	0.0000	0.0000	1284.2	0.8603	0.0000	0.0000	0.0000
0.1052	1298.9	0.9206	-1.5959	-2.0917	-0.0992	1285.0	0.8894	-1.7469	0.0000	-0.1102
0.2092	1302.5	0.9491	-2.3014	-3.5609	-0.1399	1288.1	0.9182	-2.4494	-2.1188	-0.1505
0.3120	1305.8	0.9772	-2.8155	-4.4817	-0.1711	1290.7	0.9466	-2.9725	-3.6068	-0.1825
0.4136	1308.9	1.0051	-3.0555	-4.9180	-0.1862	1293.5	0.9748	-3.1512	-4.5393	-0.1931
0.5141	1312.1	1.0326	-3.0526	-4.9249	-0.1869	1296.0	1.0026	-3.1592	-4.9809	-0.1947
0.6135	1315.2	1.0598	-2.8339	-4.5503	-0.1746	1298.4	1.0301	-2.9697	-4.9876	-0.1847
0.7117	1318.2	1.0867	-2.4231	-3.8360	-0.1505	1301.0	1.0572	-2.5309	-4.6080	-0.1587
0.8089	1321.3	1.1133	-1.8409	-2.8187	-0.1158	1303.4	1.0841	-1.9555	-3.8845	-0.1247
0.9050	1324.3	1.1396	-1.1055	-1.5306	-0.0716	1306.2	1.1107	-1.1159	-2.8542	-0.0724
1.0000	1328.3	0.8627	0.0000	0.0000	0.0000	1309.7	1.1370	0.0000	-1.5498	0.0000

TABLE-3
ULTRASONIC VELOCITY (U), DENSITY (ρ), DEVIATION IN ADIABATIC COMPRESSIBILITY ($\Delta\beta_{ad}$), EXCESS MOLAR VOLUME (V^E) AND EXCESS INTERMOLECULAR FREE LENGTH (L_f^E) OF DIMETHYL MALONATE + *m*-XYLENE

X_1	U ($m\ s^{-1}$)	ρ ($kg\ m^{-3}$)	$\Delta\beta_{ad}$ (10^{-10} $m^2\ N^{-1}$)	V^E (10^6 $m^3\ mol^{-1}$)	L_f^E (10^{-11} m)	U ($m\ s^{-1}$)	ρ ($kg\ m^{-3}$)	$\Delta\beta_{ad}$ (10^{-10} $m^2\ N^{-1}$)	V^E (10^6 $m^3\ mol^{-1}$)	L_f^E (10^{-11} m)
			303.15 K					308.15 K		
0.0000	1301.5	0.8524	0.0000	0.0000	0.0000	1297.0	0.8454	0.0000	0.0000	0.0000
0.1068	1308.2	0.8834	-1.1915	-2.7930	-0.0023	1299.2	0.8768	-1.4766	-2.9010	-0.0030
0.2121	1314.8	0.9139	-2.0098	-4.7270	-0.0039	1302.2	0.9078	-2.4507	-4.9080	-0.0051
0.3157	1321.2	0.9439	-2.5572	-5.9170	-0.0050	1305.5	0.9383	-2.9835	-6.1420	-0.0062
0.4178	1327.8	0.9735	-2.7716	-6.4590	-0.0055	1309.2	0.9683	-3.1216	-6.7040	-0.0065
0.5184	1334.1	1.0027	-2.7883	-6.4370	-0.0055	1312.8	0.9979	-2.9906	-6.6790	-0.0062
0.6176	1340.3	1.0314	-2.6023	-5.9190	-0.0052	1316.0	1.0271	-2.7360	-6.1410	-0.0057
0.7153	1346.5	1.0598	-2.2040	-4.9680	-0.0044	1318.8	1.0558	-2.3413	-5.1530	-0.0049
0.8116	1352.8	1.0877	-1.6064	-3.6350	-0.0032	1321.5	1.0842	-1.7261	-3.7690	-0.0037
0.9065	1358.9	1.1152	-0.8917	-1.9660	-0.0018	1324.5	1.1121	-0.9830	-2.0380	-0.0021
1.0000	1365.2	1.1423	0.0000	0.0000	0.0000	1328.3	1.1396	0.0000	0.0000	0.0000
			313.15 K					318.15 K		
0.0000	1281.0	0.8493	0.0000	0.0000	0.0000	1241.0	0.8420	0.0000	0.0000	0.0000
0.1068	1287.5	0.8804	-1.7637	-3.0980	-0.0034	1245.5	0.8735	-1.8950	-3.1960	-0.0041
0.2121	1294.4	0.9111	-2.8216	-5.2390	-0.0054	1251.6	0.9046	-2.9330	-5.4040	-0.0064
0.3157	1301.7	0.9413	-3.3974	-6.5540	-0.0065	1258.4	0.9352	-3.4482	-6.7590	-0.0075
0.4178	1309.4	0.9710	-3.5234	-7.1500	-0.0067	1265.7	0.9653	-3.5508	-7.3720	-0.0077
0.5184	1317.2	1.0003	-3.3836	-7.1210	-0.0064	1272.8	0.9950	-3.4649	-7.3410	-0.0075
0.6176	1324.7	1.0292	-3.0895	-6.5450	-0.0059	1279.5	1.0242	-3.2665	-6.7460	-0.0072
0.7153	1331.9	1.0576	-2.6652	-5.4900	-0.0051	1286.5	1.0530	-2.8076	-5.6580	-0.0062
0.8116	1339.3	1.0856	-2.0581	-4.0150	-0.0040	1293.8	1.0814	-2.1104	-4.1370	-0.0047
0.9065	1346.7	1.1133	-1.1960	-2.1700	-0.0024	1300.2	1.1094	-1.4700	-2.2360	-0.0034
1.0000	1354.5	1.1405	0.0000	0.0000	0.0000	1309.7	1.1370	0.0000	0.0000	0.0000

TABLE-4
ULTRASONIC VELOCITY (U), DENSITY (ρ), DEVIATION IN ADIABATIC COMPRESSIBILITY ($\Delta\beta_{ad}$), EXCESS MOLAR VOLUME (V^E) AND EXCESS INTERMOLECULAR FREE LENGTH (L_f^E) OF DIMETHYL MALONATE + *p*-XYLENE

X_1	U (m s^{-1})	ρ (kg m^{-3})	$\Delta\beta_{ad}$ (10^{-10} m^2 N^{-1})	V^E (10^6 m^3 mol^{-1})	L_f^E (10^{-11} m)	U (m s^{-1})	ρ (kg m^{-3})	$\Delta\beta_{ad}$ (10^{-10} m^2 N^{-1})	V^E (10^6 m^3 mol^{-1})	L_f^E (10^{-11} m)
	303.15 K					308.15 K				
0.0000	1286.3	0.8466	0.0000	0.0000	0.0000	1265.6	0.8455	0.0000	0.0000	0.0000
0.1073	1294.3	0.8783	-1.2438	-3.1190	-0.0025	1273.7	0.8777	-1.5522	-3.8880	-0.0033
0.2129	1302.5	0.9095	-2.0425	-5.2690	-0.0041	1282.0	0.9092	-2.5887	-6.4630	-0.0056
0.3167	1310.4	0.9403	-2.5978	-6.5830	-0.0053	1291.3	0.9400	-2.9878	-7.9410	-0.0064
0.4190	1318.5	0.9705	-2.7782	-7.1740	-0.0057	1300.5	0.9703	-3.1559	-8.6310	-0.0068
0.5196	1326.0	1.0002	-2.8762	-7.1370	-0.0059	1309.2	1.0003	-3.2403	-8.9300	-0.0070
0.6187	1334.0	1.0295	-2.6136	-6.5530	-0.0054	1318.3	1.0293	-2.9098	-8.0240	-0.0063
0.7162	1341.7	1.0584	-2.2338	-5.4910	-0.0046	1326.8	1.0578	-2.5590	-6.6600	-0.0056
0.8123	1349.5	1.0868	-1.6439	-4.0120	-0.0034	1336.5	1.0862	-1.7845	-5.1420	-0.0039
0.9068	1357.3	1.1148	-0.9149	-2.1670	-0.0019	1345.6	1.1140	-0.9963	-3.2070	-0.0022
1.0000	1365.2	1.1423	0.0000	0.0000	0.0000	1354.5	1.1405	0.0000	0.0000	0.0000
	313.15 K					318.15 K				
0.0000	1249.8	0.8426	0.0000	0.0000	0.0000	1229.7	0.8398	0.0000	0.0000	0.0000
0.1073	1256.4	0.8754	-1.7767	-4.5930	-0.0038	1236.0	0.8730	-1.9326	-5.1950	-0.0043
0.2129	1263.6	0.9069	-2.8314	-7.0160	-0.0061	1243.1	0.9046	-3.0286	-7.7020	-0.0067
0.3167	1271.2	0.9380	-3.4153	-8.5760	-0.0074	1250.8	0.9355	-3.5693	-9.0390	-0.0079
0.4190	1279.4	0.9685	-3.5486	-9.2380	-0.0077	1259.0	0.9662	-3.7575	-9.9130	-0.0084
0.5196	1287.7	0.9987	-3.4585	-9.5640	-0.0076	1267.6	0.9963	-3.6042	-10.0740	-0.0081
0.6187	1295.6	1.0281	-3.1856	-8.8180	-0.0070	1275.5	1.0256	-3.3666	-9.1940	-0.0076
0.7162	1303.7	1.0573	-2.7278	-7.9110	-0.0060	1283.9	1.0549	-2.8785	-8.3380	-0.0065
0.8123	1311.3	1.0856	-2.1559	-6.0760	-0.0048	1291.2	1.0835	-2.4436	-6.6920	-0.0057
0.9068	1320.2	1.1140	-1.2019	-4.4180	-0.0027	1300.4	1.1119	-1.4884	-5.0260	-0.0035
1.0000	1328.3	1.1396	0.0000	0.0000	0.0000	1309.7	1.1370	0.0000	0.0000	0.0000

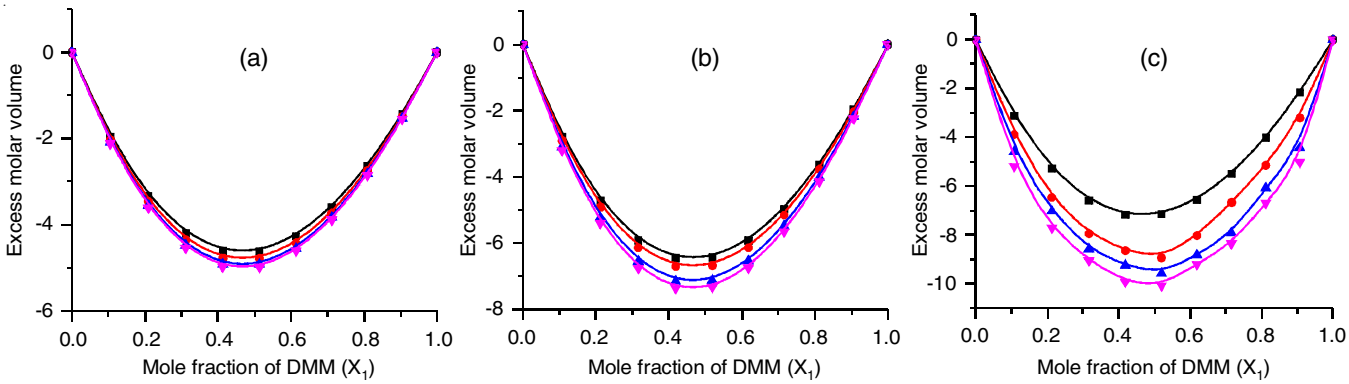

Fig. 1. Variation of excess molar volume with X_1 of DMM for the systems (a) dimethyl malonate + *o*-xylene, (b) dimethyl malonate + *m*-xylene and (c) dimethyl malonate + *p*-xylene

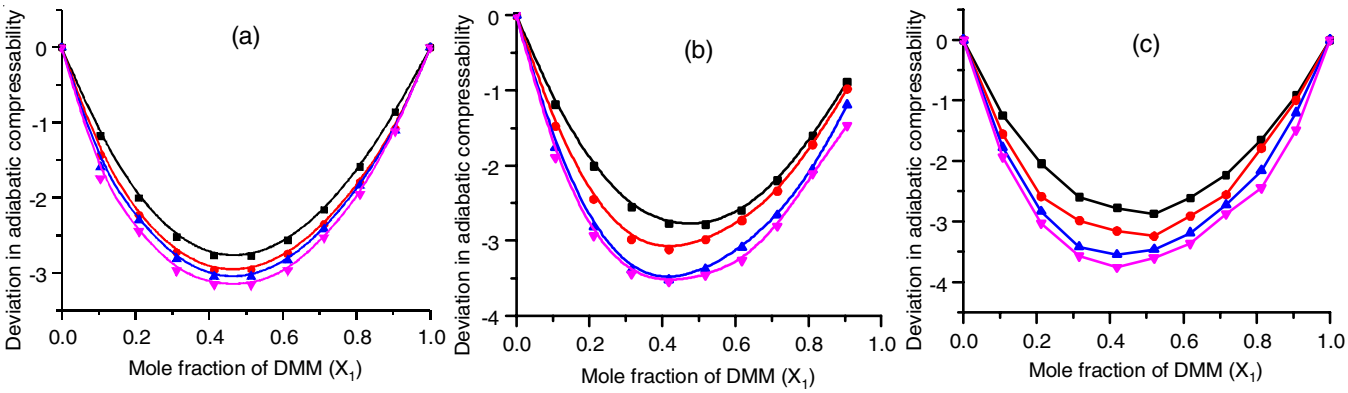

Fig. 2. Variation of deviation in adiabatic compressability with X_1 of DMM for the systems (a) dimethyl malonate + *o*-xylene, (b) dimethyl malonate + *m*-xylene and (c) dimethyl malonate + *p*-xylene

When excess values tend to shift from being increasingly positive to being increasingly negative, the strength of the interaction between the components expand or decreases. This can be qualitatively explained by the closer proximity of dissimilar molecules, which results in a decrease in compressibility and volume. The negative intermolecular free length (L_f^E) values show that the distance over which the sound wave must travel is smaller (Fig. 3). It occurs because the interactions between molecules with different molecular properties are more common. The similar concentrations of the $\Delta\beta_{ad}$ and L_f^E minima provide more evidence for the presence of molecular interactions.

The excess parameters determined were fitted into the Redlich-Kister equation and the standard deviation (σ) values are also included with the obtained parameter values in Table-5. The sign of the volumetric expansion (V^E) for a system is determined by the relative size of the expansion and contraction of the two liquids when mixed [28]. The following reasons are deduced for the volume increase after mixing: (i) steric hindrance caused by chain branching, (ii) division of either one component or all components, and (iii) weak solute-solvent bonds are formed rather than solute-solute and solvent-solvent bonds. Whereas the other reasons lead to a decrease in volume when mixed are (i) intense and specialized interaction, usually invol-ving chemical processes; (ii) strong physical interactions such as those involving dipoles or inducing the formation of dipoles; and (iii) when there is a significant disparity in the molecular sizes of components, one component may occupy the empty spaces of another component.

A sound propagation model put forth by Eyring & Kincaid led to the development of the relationship between intermolecular free length and ultrasonic velocity. Once the components have been mixed, the ultrasonic velocity in the solution will be affected by the change in intermolecular free length. The current study for the systems dimethyl malonate + *p*-xylene >

TABLE-5
THE VALUES OF COEFFICIENT AND STANDARD DEVIATIONS (σ) OF DIMETHYL MALONATE (X_1) + *o*-XYLENE (X_2), DIMETHYL MALONATE (X_1) + *m*-XYLENE (X_2) DIMETHYL MALONATE (X_1) + *p*-XYLENE (X_2) SYSTEM

	Temp. (K)	A_0	A_1	A_2	A_3	A_4	α
				ortho-Xylene			
Excess molar volume (V^E)	303.15 K	-25.9214	-3.7678	-0.5399	-0.0805	-0.0289	0.0003
	308.15 K	-26.8968	-3.9331	-0.5718	-0.0994	-0.0224	0.0002
	313.15 K	-28.6789	-4.2522	-0.6266	-0.0988	-0.0164	0.0003
	318.15 K	-29.5658	-4.4094	-0.6572	-0.0971	-0.0120	0.0003
Deviation in adiabatic compressibility ($\Delta\beta_{ad}$)	303.15 K	-11.1578	-1.5292	-0.2058	-0.0257	-0.0125	0.0001
	308.15 K	-11.8948	-1.6200	-0.9235	-0.3002	-3.5689	0.0104
	313.15 K	-12.2598	-1.4269	-0.7358	-2.0162	-5.4432	0.0310
	318.15 K	-12.6883	-1.5322	-2.3048	-3.2964	-4.1159	0.0484
Excess inter molecular free length (L_f^E)	303.15 K	-0.6583	-0.0764	-0.0107	-0.0012	0.0006	0.0000
	308.15 K	-0.7289	-0.0829	-0.0601	-0.0075	-0.2665	0.0007
	313.15 K	-0.7501	-0.0672	-0.0484	-0.1290	-0.4040	0.0022
	318.15 K	-0.7813	-0.0720	-0.1683	-0.2260	-0.2992	0.0035
				meta-Xylene			
Excess molar volume (V^E)	303.15 K	-25.9208	-3.7681	-0.5501	-0.0801	-0.0402	0.0005
	308.15 K	-26.8962	-3.9334	-0.5824	-0.0990	-0.0341	0.0006
	313.15 K	-28.6783	-4.2525	-0.6380	-0.0984	-0.0288	0.0007
	318.15 K	-29.5652	-4.4097	-0.6689	-0.0968	-0.0248	0.0007
Deviation in adiabatic compressibility ($\Delta\beta_{ad}$)	303.15 K	-11.2165	-1.3493	-1.1134	0.1910	1.0012	0.0201
	308.15 K	-12.0952	-3.3388	-4.5826	1.4267	3.6135	0.0247
	313.15 K	-13.6875	-3.8636	-5.4072	1.6439	2.0440	0.0194
	318.15 K	-14.0017	-3.5531	-5.4166	2.7183	-2.7230	0.0798
Excess inter molecular free length (L_f^E)	303.15 K	-0.0221	-0.0021	-0.0024	0.0005	0.0024	0.0001
	308.15 K	-0.0251	-0.0070	-0.0106	0.0045	0.0091	0.0000
	313.15 K	-0.0259	-0.0077	-0.0121	0.0046	0.0041	0.0001
	318.15 K	-0.0303	-0.0077	-0.0140	0.0083	-0.0053	0.0002
				para-Xylene			
Excess molar volume (V^E)	303.15 K	-28.7591	-4.2889	-0.6276	-0.0900	-0.0095	0.0007
	308.15 K	-36.0095	-5.5364	11.6057	5.1185	-25.9422	0.1510
	313.15 K	-38.4155	-2.6080	-0.7653	6.7471	-27.0251	0.2155
	318.15 K	-40.4747	-2.9420	1.2557	7.4266	-41.5821	0.1920
Deviation in adiabatic compressibility ($\Delta\beta_{ad}$)	303.15 K	-11.5715	-1.2325	0.4433	-0.2534	-1.5670	0.0403
	308.15 K	-13.0269	-1.2233	-1.5312	-2.4825	-0.1836	0.0815
	313.15 K	-13.9808	-3.3880	-4.6952	0.9380	1.4062	0.0328
	318.15 K	-14.5800	-3.7814	-4.5874	3.0150	-3.3037	0.0571
Excess inter molecular free length (L_f^E)	303.15 K	-0.0237	-0.0023	0.0011	0.0000	-0.0031	0.0001
	308.15 K	-0.0281	-0.0019	-0.0038	-0.0054	0.0003	0.0002
	313.15 K	-0.0307	-0.0069	-0.0084	0.0028	0.0006	0.0001
	318.15 K	-0.0327	-0.0077	-0.0081	0.0076	-0.0125	0.0002

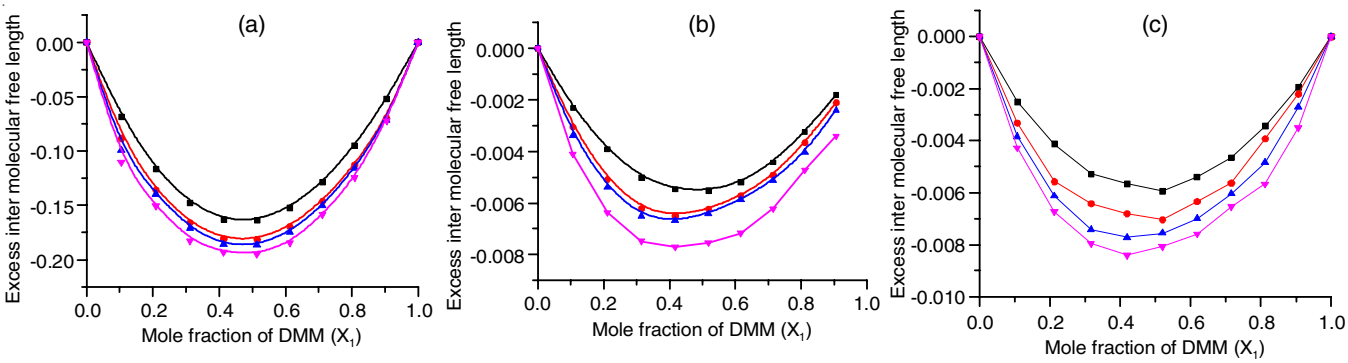

Fig. 3. Variation of excess intermolecular free length with the X_1 of DMM for the systems (a) dimethyl malonate + *o*-xylene, (b) dimethyl malonate + *m*-xylene and (c) dimethyl malonate + *p*-xylene

dimethyl malonate + *o*-xylene > dimethylmalonate + *m*-xylene has confirmed this finding. Additionally, it has been found that velocity at any concentration decreases as the temperature increases which is due to the breakup of hetero and homo molecule clusters at high temperatures [29].

Conclusion

For binary mixtures of dimethyl malonate with *o*-, *m*- and *p*-xylene, the ultrasonic velocities and densities in the temperature range of 303.15-318.15 K have been established. Excess molar volume (V^E), excess intermolecular free length (L_f^E) and deviation in adiabatic compressibility ($\Delta\beta_{ad}$) were computed from the experimental data. For the studied binary mixtures at the different temperatures range, the excess values and deviations were found to be negative, which indicated that binary mixtures exhibit strong interactions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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