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Densities and Volumetric Properties of Binary Mixtures of Butyl Acrylate with Benzene, Toluene, *o*-Xylene, *m*-Xylene, *p*-Xylene, and Mesitylene at Temperatures from 288.15 K to 318.15 K

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Abstract The densities, ρ, of binary mixtures of butyl acrylate (BA) with benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene, including those of pure liquids, over the entire composition range were measured at the temperatures (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K and atmospheric pressure. From the experimental data, the excess molar volumes, V_m^E were calculated. The V_m^E values were negative over the whole composition range for all the mixtures and at each temperature studied, except for BA + mesitylene which exhibit positive V_m^E values, indicating the presence of specific interactions between BA and aromatic hydrocarbon molecules. The deviations in V_m^E values follow the order: benzene < toluene < *p*-xylene < *m*-xylene < *o*-xylene < mesitylene. It is observed that V_m^E values depend upon the number and position of the methyl groups in these aromatic hydrocarbons.

Keywords Aromatic hydrocarbons · Butyl acrylate · Density · Excess molar volume · Molecular interactions

1 Introduction

The volumetric properties of multicomponent liquid mixtures have proved to be a useful indicator of the existence of significant effects resulting from intermolecular interactions [1,2]. A knowledge of the physicochemical properties of non-aqueous binary liquid mixtures has relevance in theoretical and applied areas of research, and

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Table 1 Experimental values of density, ρ, of pure liquids along with the corresponding values available in the literature at 298.15 K

Liquid	T (K)	ρ ($\mathrm{g \cdot cm^{-3}}$)		
		Experimental	Literature	Reference
BA	298.15	0.89410	0.89410	[19]
			0.89398	[20]
Benzene	298.15	0.87361	0.87362	[2]
			0.87357	[21]
Toluene	298.15	0.86236	0.86231	[22]
o-Xylene	298.15	0.87557	0.87558	[23]
m-Xylene	298.15	0.86002	0.86000	[24]
			0.86006	[23]
p-Xylene	298.15	0.85682	0.85685	[25]
			0.85672	[23]
Mesitylene	298.15	0.86145	0.86114	[2]
			0.86150	[4]

such results are frequently used in process design (flow, mass transfer, or heat transfer calculations) in many chemical and industrial processes. Binary mixtures containing aromatic hydrocarbons are interesting because they find applications in the studies of polymer phase diagrams and preferential interaction of polymers in mixed solvents [3,4]. As a part of our ongoing research focusing on experimental and theoretical studies of volumetric properties of non-aqueous binary liquid mixtures [5–15], here we report the results of our study on binary mixtures of butyl acrylate (BA) with six aromatic hydrocarbons (benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene) over the entire composition range at six different temperatures. BA is a very important industrial chemical and is widely used commercially for the production of technically important high polymeric and latex compounds. BA is a polar, aprotic, and unassociated liquid, and the aromatic hydrocarbon molecules possess large quadrupole moments [16], causing an orientational order in these liquids. The orientational order is thought of as a partial alignment of neighboring segments or possibly of whole molecules [16]. The objective underlying this study is to obtain information regarding molecular interactions in mixtures of a polar liquid with non-polar liquids, which is essential for an understanding of many chemical and industrial processes in these media. A survey of the literature indicates that there has been no study on these systems from the point of view of their volumetric behavior.

In this article, we report densities, ρ, of (BA + benzene, or toluene, or *o*-xylene, or *m*-xylene, or *p*-xylene, or mesitylene), including those of pure liquids at atmospheric pressure and temperatures (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K, covering the entire composition range, expressed by the mole fraction x of BA ($0 \leq x \leq 1$). The experimental values of ρ have been used to calculate excess molar volumes, V_m^E. The variation of the excess molar volume with composition and temperature of the mixtures has been discussed in terms of molecular interactions in

Table 2 Densities, ρ, and excess molar volumes, V_m^E of BA + benzene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ ($g \cdot cm^{-3}$)	V_m^E ($cm^3 \cdot mol^{-1}$)	x	ρ ($g \cdot cm^{-3}$)	V_m^E ($cm^3 \cdot mol^{-1}$)
T = 288.15 K					
0.0000	0.88430	0.000	0.5818	0.90063	−0.398
0.0722	0.88723	−0.082	0.6423	0.90147	−0.387
0.1420	0.88979	−0.155	0.7226	0.90236	−0.350
0.2062	0.89194	−0.218	0.7902	0.90291	−0.296
0.2794	0.89412	−0.279	0.8563	0.90329	−0.225
0.3586	0.89624	−0.337	0.9305	0.90353	−0.120
0.4363	0.89802	−0.376	1.0000	0.90360	0.000
0.5074	0.89940	−0.395			
T = 293.15 K					
0.0000	0.87895	0.000	0.5818	0.89553	−0.381
0.0722	0.88189	−0.077	0.6423	0.89640	−0.369
0.1420	0.88448	−0.148	0.7226	0.89734	−0.332
0.2062	0.88665	−0.208	0.7902	0.89794	−0.280
0.2794	0.88887	−0.268	0.8563	0.89838	−0.212
0.3586	0.89102	−0.323	0.9305	0.89869	−0.112
0.4363	0.89283	−0.359	1.0000	0.89885	0.000
0.5074	0.89425	−0.377			
T = 298.15 K					
0.0000	0.87361	0.000	0.5818	0.89043	−0.363
0.0722	0.87656	−0.072	0.6423	0.89133	−0.350
0.1420	0.87917	−0.140	0.7226	0.89232	−0.314
0.2062	0.88136	−0.197	0.7902	0.89297	−0.263
0.2794	0.88362	−0.255	0.8563	0.89347	−0.199
0.3586	0.88580	−0.308	0.9305	0.89385	−0.103
0.4363	0.88764	−0.342	1.0000	0.89410	0.000
0.5074	0.88911	−0.360			
T = 303.15 K					
0.0000	0.86826	0.000	0.5818	0.88533	−0.345
0.0722	0.87123	−0.068	0.6423	0.88626	−0.331
0.1420	0.87386	−0.132	0.7226	0.88730	−0.295
0.2062	0.87608	−0.187	0.7902	0.88800	−0.247
0.2794	0.87837	−0.243	0.8563	0.88856	−0.186
0.3586	0.88058	−0.293	0.9305	0.88901	−0.095
0.4363	0.88246	−0.325	1.0000	0.88935	0.000
0.5074	0.88397	−0.343			
T = 308.15 K					
0.0000	0.86290	0.000	0.5818	0.88023	−0.327
0.0722	0.86590	−0.065	0.6423	0.88120	−0.313
0.1420	0.86856	−0.126	0.7226	0.88229	−0.278

Table 2 continued

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
0.2062	0.87080	−0.179	0.7902	0.88303	−0.229
0.2794	0.87312	−0.231	0.8563	0.88365	−0.172
0.3586	0.87536	−0.278	0.9305	0.88418	−0.087
0.4363	0.87728	−0.309	1.0000	0.88460	0.000
0.5074	0.87883	−0.326			
T = 313.15 K					
0.0000	0.85756	0.000	0.5818	0.87513	−0.308
0.0722	0.86057	−0.060	0.6423	0.87614	−0.295
0.1420	0.86326	−0.119	0.7226	0.87728	−0.260
0.2062	0.86552	−0.168	0.7902	0.87807	−0.213
0.2794	0.86787	−0.218	0.8563	0.87875	−0.160
0.3586	0.87014	−0.262	0.9305	0.87935	−0.080
0.4363	0.87210	−0.291	1.0000	0.87985	0.000
0.5074	0.87369	−0.307			
T = 318.15 K					
0.0000	0.85223	0.000	0.5818	0.87003	−0.288
0.0722	0.85524	−0.054	0.6423	0.87108	−0.275
0.1420	0.85796	−0.110	0.7226	0.87227	−0.241
0.2062	0.86024	−0.156	0.7902	0.87311	−0.196
0.2794	0.86262	−0.204	0.8563	0.87385	−0.147
0.3586	0.86492	−0.245	0.9305	0.87452	−0.072
0.4363	0.86692	−0.273	1.0000	0.87510	0.000
0.5074	0.86855	−0.288			

Table 3 Densities, ρ, and excess molar volumes, V_m^E of BA + toluene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
T = 288.15 K					
0.0000	0.87179	0.000	0.5836	0.89508	−0.357
0.0704	0.87540	−0.084	0.6584	0.89710	−0.342
0.1402	0.87872	−0.154	0.7198	0.89860	−0.316
0.2054	0.88163	−0.212	0.7912	0.90018	−0.270
0.2799	0.88472	−0.265	0.8578	0.90148	−0.209
0.3604	0.88781	−0.311	0.9324	0.90274	−0.119
0.4338	0.89040	−0.339	1.0000	0.90360	0.000
0.5098	0.89288	−0.356			
T = 293.15 K					
0.0000	0.86708	0.000	0.5836	0.89019	−0.340
0.0704	0.87063	−0.078	0.6584	0.89222	−0.325
0.1402	0.87392	−0.145	0.7198	0.89373	−0.300

Table 3 continued

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
0.2054	0.87680	−0.200	0.7912	0.89532	−0.255
0.2799	0.87986	−0.250	0.8578	0.89664	−0.197
0.3604	0.88294	−0.295	0.9324	0.89793	−0.111
0.4338	0.88552	−0.322	1.0000	0.89885	0.000
0.5098	0.88800	−0.339			
T = 298.15 K					
0.0000	0.86236	0.000	0.5836	0.88531	−0.323
0.0704	0.86586	−0.072	0.6584	0.88734	−0.309
0.1402	0.86912	−0.137	0.7198	0.88886	−0.285
0.2054	0.87197	−0.189	0.7912	0.89046	−0.241
0.2799	0.87500	−0.236	0.8578	0.89180	−0.185
0.3604	0.87807	−0.280	0.9324	0.89312	−0.102
0.4338	0.88064	−0.306	1.0000	0.89410	0.000
0.5098	0.88312	−0.323			
T = 303.15 K					
0.0000	0.85764	0.000	0.5836	0.88043	−0.306
0.0704	0.86109	−0.067	0.6584	0.88246	−0.292
0.1402	0.86432	−0.129	0.7198	0.88399	−0.269
0.2054	0.86714	−0.177	0.7912	0.88560	−0.226
0.2799	0.87015	−0.223	0.8578	0.88696	−0.172
0.3604	0.87320	−0.264	0.9324	0.88831	−0.093
0.4338	0.87577	−0.290	1.0000	0.88935	0.000
0.5098	0.87824	−0.306			
T = 308.15 K					
0.0000	0.85293	0.000	0.5836	0.87555	−0.288
0.0704	0.85632	−0.061	0.6584	0.87758	−0.274
0.1402	0.85952	−0.120	0.7198	0.87912	−0.252
0.2054	0.86231	−0.165	0.7912	0.88075	−0.212
0.2799	0.86531	−0.209	0.8578	0.88212	−0.159
0.3604	0.86834	−0.249	0.9324	0.88350	−0.085
0.4338	0.87090	−0.274	1.0000	0.88460	0.000
0.5098	0.87336	−0.289			
T = 313.15 K					
0.0000	0.84821	0.000	0.5836	0.87067	−0.271
0.0704	0.85155	−0.055	0.6584	0.87270	−0.256
0.1402	0.85472	−0.111	0.7198	0.87425	−0.235
0.2054	0.85748	−0.153	0.7912	0.87590	−0.197
0.2799	0.86047	−0.197	0.8578	0.87728	−0.146
0.3604	0.86348	−0.234	0.9324	0.87869	−0.075
0.4338	0.86603	−0.258	1.0000	0.87985	0.000
0.5098	0.86848	−0.271			

Table 3 continued

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
T = 318.15 K					
0.0000	0.84349	0.000	0.5836	0.86579	−0.253
0.0704	0.84679	−0.051	0.6584	0.86782	−0.238
0.1402	0.84992	−0.102	0.7198	0.86938	−0.218
0.2054	0.85265	−0.141	0.7912	0.87105	−0.183
0.2799	0.85563	−0.184	0.8578	0.87244	−0.133
0.3604	0.85862	−0.218	0.9324	0.87388	−0.066
0.4338	0.86116	−0.241	1.0000	0.87510	0.000
0.5098	0.86360	−0.253			

Table 4 Densities, ρ, and excess molar volumes, V_m^E of BA + *o*-xylene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
T = 288.15 K					
0.0000	0.88409	0.000	0.5890	0.89705	−0.103
0.0685	0.88581	−0.022	0.6522	0.89820	−0.100
0.1306	0.88732	−0.040	0.7283	0.89951	−0.090
0.2018	0.88900	−0.060	0.7924	0.90056	−0.077
0.2738	0.89063	−0.075	0.8587	0.90160	−0.059
0.3654	0.89261	−0.090	0.9298	0.90264	−0.033
0.4331	0.89401	−0.097	1.0000	0.90360	0.000
0.5072	0.89549	−0.102			
T = 293.15 K					
0.0000	0.87983	0.000	0.5890	0.89245	−0.099
0.0685	0.88150	−0.021	0.6522	0.89357	−0.096
0.1306	0.88297	−0.038	0.7283	0.89485	−0.086
0.2018	0.88460	−0.056	0.7924	0.89587	−0.073
0.2738	0.88619	−0.071	0.8587	0.89688	−0.055
0.3654	0.88812	−0.086	0.9298	0.89790	−0.030
0.4331	0.88949	−0.093	1.0000	0.89885	0.000
0.5072	0.89093	−0.098			
T = 298.15 K					
0.0000	0.87557	0.000	0.5890	0.88785	−0.095
0.0685	0.87719	−0.019	0.6522	0.88894	−0.092
0.1306	0.87862	−0.036	0.7283	0.89019	−0.083
0.2018	0.88020	−0.052	0.7924	0.89118	−0.069
0.2738	0.88175	−0.068	0.8587	0.89216	−0.051
0.3654	0.88363	−0.082	0.9298	0.89316	−0.027
0.4331	0.88497	−0.090	1.0000	0.89410	0.000
0.5072	0.88637	−0.094			

Table 4 continued

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
T = 303.15 K					
0.0000	0.87131	0.000	0.5890	0.88325	−0.091
0.0685	0.87288	−0.018	0.6522	0.88431	−0.088
0.1306	0.87427	−0.034	0.7283	0.88553	−0.079
0.2018	0.87580	−0.049	0.7924	0.88649	−0.065
0.2738	0.87731	−0.064	0.8587	0.88745	−0.048
0.3654	0.87914	−0.077	0.9298	0.88842	−0.025
0.4331	0.88045	−0.086	1.0000	0.88935	0.000
0.5072	0.88181	−0.090			
T = 308.15 K					
0.0000	0.86705	0.000	0.5890	0.87865	−0.087
0.0685	0.86857	−0.017	0.6522	0.87968	−0.083
0.1306	0.86992	−0.032	0.7283	0.88087	−0.075
0.2018	0.87141	−0.047	0.7924	0.88180	−0.061
0.2738	0.87287	−0.060	0.8587	0.88274	−0.045
0.3654	0.87465	−0.073	0.9298	0.88369	−0.023
0.4331	0.87593	−0.083	1.0000	0.88460	0.000
0.5072	0.87725	−0.086			
T = 313.15 K					
0.0000	0.86279	0.000	0.5890	0.87406	−0.084
0.0685	0.86426	−0.015	0.6522	0.87506	−0.080
0.1306	0.86557	−0.030	0.7283	0.87621	−0.072
0.2018	0.86702	−0.044	0.7924	0.87712	−0.058
0.2738	0.86844	−0.058	0.8587	0.87803	−0.043
0.3654	0.87017	−0.070	0.9298	0.87896	−0.022
0.4331	0.87141	−0.079	1.0000	0.87985	0.000
0.5072	0.87270	−0.084			
T = 318.15 K					
0.0000	0.85853	0.000	0.5890	0.86947	−0.081
0.0685	0.85995	−0.014	0.6522	0.87044	−0.077
0.1306	0.86122	−0.028	0.7283	0.87155	−0.068
0.2018	0.86263	−0.042	0.7924	0.87244	−0.056
0.2738	0.86401	−0.055	0.8587	0.87332	−0.040
0.3654	0.86569	−0.068	0.9298	0.87423	−0.020
0.4331	0.86689	−0.076	1.0000	0.87510	0.000
0.5072	0.86814	−0.079			

these mixtures. The effect of the number and position of the methyl groups in these aromatic hydrocarbons on molecular interactions in these mixtures has also been discussed.

Table 5 Densities, ρ, and excess molar volumes, V_m^E of BA + *m*-xylene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
T = 288.15 K					
0.0000	0.86859	0.000	0.5778	0.89095	−0.132
0.0732	0.87173	−0.029	0.6534	0.89346	−0.128
0.1432	0.87465	−0.054	0.7204	0.89560	−0.118
0.2103	0.87737	−0.075	0.7935	0.89784	−0.101
0.2841	0.88028	−0.095	0.8579	0.89973	−0.078
0.3605	0.88319	−0.111	0.9306	0.90178	−0.046
0.4318	0.88582	−0.122	1.0000	0.90360	0.000
0.5006	0.88828	−0.129			
T = 293.15 K					
0.0000	0.86431	0.000	0.5778	0.88634	−0.127
0.0732	0.86739	−0.026	0.6534	0.88881	−0.122
0.1432	0.87026	−0.049	0.7204	0.89093	−0.113
0.2103	0.87294	−0.069	0.7935	0.89313	−0.094
0.2841	0.87581	−0.089	0.8579	0.89500	−0.073
0.3605	0.87868	−0.105	0.9306	0.89703	−0.042
0.4318	0.88128	−0.117	1.0000	0.89885	0.000
0.5006	0.88370	−0.123			
T = 298.15 K					
0.0000	0.86002	0.000	0.5778	0.88173	−0.122
0.0732	0.86305	−0.024	0.6534	0.88417	−0.117
0.1432	0.86587	−0.046	0.7204	0.88626	−0.109
0.2103	0.86851	−0.065	0.7935	0.88843	−0.090
0.2841	0.87134	−0.085	0.8579	0.89027	−0.067
0.3605	0.87417	−0.100	0.9306	0.89228	−0.038
0.4318	0.87674	−0.113	1.0000	0.89410	0.000
0.5006	0.87912	−0.117			
T = 303.15 K					
0.0000	0.85574	0.000	0.5778	0.87712	−0.116
0.0732	0.85871	−0.021	0.6534	0.87953	−0.112
0.1432	0.86148	−0.041	0.7204	0.88159	−0.104
0.2103	0.86408	−0.060	0.7935	0.88373	−0.085
0.2841	0.86687	−0.079	0.8579	0.88554	−0.062
0.3605	0.86966	−0.094	0.9306	0.88753	−0.034
0.4318	0.87220	−0.107	1.0000	0.88935	0.000
0.5006	0.87455	−0.112			
T = 308.15 K					
0.0000	0.85145	0.000	0.5778	0.87251	−0.111
0.0732	0.85437	−0.020	0.6534	0.87489	−0.108
0.1432	0.85710	−0.039	0.7204	0.87692	−0.099

Table 5 continued

x	ρ (g $\cdot$ cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 $\cdot$ mol^{-1})	x	ρ (g $\cdot$ cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 $\cdot$ mol^{-1})
0.2103	0.85966	−0.057	0.7935	0.87903	−0.080
0.2841	0.86241	−0.076	0.8579	0.88082	−0.058
0.3605	0.86516	−0.090	0.9306	0.88279	−0.031
0.4318	0.86766	−0.103	1.0000	0.88460	0.000
0.5006	0.86998	−0.108			
$T = 313.15$ K					
0.0000	0.84717	0.000	0.5778	0.86790	−0.105
0.0732	0.85004	−0.018	0.6534	0.87025	−0.102
0.1432	0.85272	−0.035	0.7204	0.87225	−0.094
0.2103	0.85524	−0.053	0.7935	0.87433	−0.074
0.2841	0.85795	−0.071	0.8579	0.87610	−0.053
0.3605	0.86066	−0.086	0.9306	0.87805	−0.028
0.4318	0.86312	−0.097	1.0000	0.87985	0.000
0.5006	0.86541	−0.103			
$T = 318.15$ K					
0.0000	0.84288	0.000	0.5778	0.86330	−0.102
0.0732	0.84571	−0.018	0.6534	0.86561	−0.098
0.1432	0.84834	−0.033	0.7204	0.86758	−0.088
0.2103	0.85082	−0.050	0.7935	0.86963	−0.069
0.2841	0.85349	−0.068	0.8579	0.87138	−0.049
0.3605	0.85616	−0.082	0.9306	0.87331	−0.025
0.4318	0.85858	−0.092	1.0000	0.87510	0.000
0.5006	0.86084	−0.098			

Table 6 Densities, ρ, and excess molar volumes, $V_{\mathrm{m}}^{\mathrm{E}}$ of BA + p-xylene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ (g $\cdot$ cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 $\cdot$ mol^{-1})	x	ρ (g $\cdot$ cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 $\cdot$ mol^{-1})
$T = 288.15$ K					
0.0000	0.86552	0.000	0.5829	0.89035	−0.197
0.0712	0.86891	−0.041	0.6542	0.89291	−0.191
0.1429	0.87225	−0.083	0.7216	0.89522	−0.175
0.2130	0.87539	−0.115	0.7922	0.89754	−0.151
0.2833	0.87845	−0.144	0.8586	0.89961	−0.117
0.3623	0.88176	−0.168	0.9294	0.90167	−0.065
0.4313	0.88456	−0.185	1.0000	0.90360	0.000
0.5088	0.88758	−0.195			
$T = 293.15$ K					
0.0000	0.86117	0.000	0.5829	0.88568	−0.188
0.0712	0.86450	−0.038	0.6542	0.88821	−0.181
0.1429	0.86779	−0.077	0.7216	0.89050	−0.166

Table 6 continued

x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	V_m^E (cm^3 · mol^{-1})
0.2130	0.87089	−0.108	0.7922	0.89280	−0.142
0.2833	0.87391	−0.136	0.8586	0.89485	−0.109
0.3623	0.87719	−0.161	0.9294	0.89691	−0.060
0.4313	0.87995	−0.176	1.0000	0.89885	0.000
0.5088	0.88294	−0.186			
T = 298.15 K					
0.0000	0.85682	0.000	0.5829	0.88101	−0.178
0.0712	0.86009	−0.034	0.6542	0.88351	−0.171
0.1429	0.86333	−0.071	0.7216	0.88578	−0.157
0.2130	0.86639	−0.101	0.7922	0.88806	−0.134
0.2833	0.86937	−0.127	0.8586	0.89009	−0.101
0.3623	0.87262	−0.153	0.9294	0.89215	−0.055
0.4313	0.87534	−0.166	1.0000	0.89410	0.000
0.5088	0.87830	−0.177			
T = 303.15 K					
0.0000	0.85247	0.000	0.5829	0.87634	−0.168
0.0712	0.85568	−0.030	0.6542	0.87882	−0.162
0.1429	0.85887	−0.065	0.7216	0.88106	−0.147
0.2130	0.86189	−0.094	0.7922	0.88332	−0.125
0.2833	0.86484	−0.120	0.8586	0.88533	−0.092
0.3623	0.86805	−0.145	0.9294	0.88739	−0.050
0.4313	0.87074	−0.158	1.0000	0.88935	0.000
0.5088	0.87366	−0.167			
T = 308.15 K					
0.0000	0.84812	0.000	0.5829	0.87168	−0.160
0.0712	0.85128	−0.028	0.6542	0.87413	−0.153
0.1429	0.85442	−0.060	0.7216	0.87635	−0.139
0.2130	0.85739	−0.086	0.7922	0.87858	−0.116
0.2833	0.86031	−0.113	0.8586	0.88058	−0.085
0.3623	0.86348	−0.137	0.9294	0.88263	−0.045
0.4313	0.86614	−0.150	1.0000	0.88460	0.000
0.5088	0.86903	−0.159			
T = 313.15 K					
0.0000	0.84377	0.000	0.5829	0.86702	−0.151
0.0712	0.84688	−0.026	0.6542	0.86944	−0.144
0.1429	0.84997	−0.055	0.7216	0.87164	−0.130
0.2130	0.85290	−0.080	0.7922	0.87385	−0.108
0.2833	0.85578	−0.105	0.8586	0.87583	−0.077
0.3623	0.85891	−0.128	0.9294	0.87788	−0.041
0.4313	0.86154	−0.141	1.0000	0.87985	0.000
0.5088	0.86440	−0.151			

Table 6 continued

x	ρ (g · cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 · mol^{-1})
T = 318.15 K					
0.0000	0.83942	0.000	0.5829	0.86236	−0.143
0.0712	0.84248	−0.023	0.6542	0.86475	−0.135
0.1429	0.84552	−0.050	0.7216	0.86693	−0.122
0.2130	0.84841	−0.074	0.7922	0.86912	−0.100
0.2833	0.85125	−0.098	0.8586	0.87108	−0.070
0.3623	0.85434	−0.120	0.9294	0.87313	−0.038
0.4313	0.85694	−0.132	1.0000	0.87510	0.000
0.5088	0.85977	−0.142			

Table 7 Densities, ρ, and excess molar volumes, $V_{\mathrm{m}}^{\mathrm{E}}$ of BA + mesitylene mixtures as a function of mole fraction, x, of BA at temperatures from 288.15 K to 318.15 K

x	ρ (g · cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 · mol^{-1})	x	ρ (g · cm^{-3})	$V_{\mathrm{m}}^{\mathrm{E}}$ (cm^3 · mol^{-1})
T = 288.15 K					
0.0000	0.86928	0.000	0.5724	0.88847	0.105
0.0724	0.87163	0.031	0.6578	0.89146	0.093
0.1414	0.87388	0.057	0.7131	0.89341	0.082
0.2135	0.87624	0.081	0.7823	0.89586	0.065
0.2846	0.87860	0.099	0.8563	0.89849	0.045
0.3512	0.88084	0.109	0.9295	0.90109	0.023
0.4223	0.88326	0.114	1.0000	0.90360	0.000
0.4998	0.88594	0.112			
T = 293.15 K					
0.0000	0.86537	0.000	0.5724	0.88405	0.111
0.0724	0.86764	0.034	0.6578	0.88697	0.098
0.1414	0.86982	0.063	0.7131	0.88887	0.088
0.2135	0.87211	0.089	0.7823	0.89126	0.071
0.2846	0.87442	0.105	0.8563	0.89383	0.050
0.3512	0.87660	0.116	0.9295	0.89638	0.026
0.4223	0.87897	0.120	1.0000	0.89885	0.000
0.4998	0.88158	0.118			
T = 298.15 K					
0.0000	0.86145	0.000	0.5724	0.87963	0.116
0.0724	0.86365	0.036	0.6578	0.88248	0.103
0.1414	0.86576	0.067	0.7131	0.88433	0.093
0.2135	0.86799	0.093	0.7823	0.88666	0.077
0.2846	0.87024	0.110	0.8563	0.88917	0.055
0.3512	0.87237	0.120	0.9295	0.89167	0.030
0.4223	0.87468	0.124	1.0000	0.89410	0.000
0.4998	0.87722	0.123			

Table 7 continued

x	ρ ($g \cdot cm^{-3}$)	V_m^E ($cm^3 \cdot mol^{-1}$)	x	ρ ($g \cdot cm^{-3}$)	V_m^E ($cm^3 \cdot mol^{-1}$)
$T = 303.15$ K					
0.0000	0.85754	0.000	0.5724	0.87521	0.122
0.0724	0.85966	0.040	0.6578	0.87799	0.109
0.1414	0.86170	0.073	0.7131	0.87980	0.098
0.2135	0.86387	0.099	0.7823	0.88207	0.082
0.2846	0.86606	0.116	0.8563	0.88452	0.059
0.3512	0.86814	0.126	0.9295	0.88696	0.033
0.4223	0.87039	0.130	1.0000	0.88935	0.000
0.4998	0.87287	0.128			
$T = 308.15$ K					
0.0000	0.85363	0.000	0.5724	0.87080	0.127
0.0724	0.85567	0.043	0.6578	0.87350	0.115
0.1414	0.85764	0.078	0.7131	0.87527	0.102
0.2135	0.85975	0.105	0.7823	0.87748	0.086
0.2846	0.86188	0.122	0.8563	0.87987	0.063
0.3512	0.86391	0.131	0.9295	0.88226	0.035
0.4223	0.86610	0.135	1.0000	0.88460	0.000
0.4998	0.86852	0.133			
$T = 313.15$ K					
0.0000	0.84971	0.000	0.5724	0.86639	0.130
0.0724	0.85168	0.045	0.6578	0.86902	0.118
0.1414	0.85358	0.083	0.7131	0.87074	0.106
0.2135	0.85563	0.110	0.7823	0.87289	0.090
0.2846	0.85771	0.126	0.8563	0.87522	0.067
0.3512	0.85968	0.135	0.9295	0.87756	0.037
0.4223	0.86181	0.140	1.0000	0.87985	0.000
0.4998	0.86417	0.137			
$T = 318.15$ K					
0.0000	0.84580	0.000	0.5724	0.86198	0.135
0.0724	0.84769	0.049	0.6578	0.86454	0.122
0.1414	0.84952	0.089	0.7131	0.86621	0.111
0.2135	0.85151	0.116	0.7823	0.86830	0.095
0.2846	0.85354	0.131	0.8563	0.87057	0.071
0.3512	0.85545	0.141	0.9295	0.87286	0.039
0.4223	0.85753	0.144	1.0000	0.87510	0.000
0.4998	0.85982	0.141			

2 Experimental

Butyl acrylate and the aromatic hydrocarbons (benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene) used in the study were products from Spectrochem Pvt.

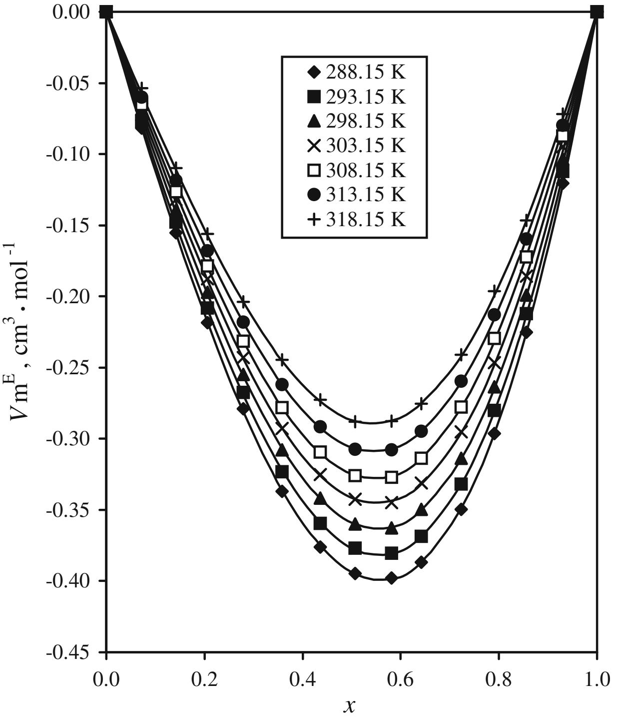


Fig. 1 Variation of excess molar volume, V_m^E against mole fraction, x, of BA for BA + benzene mixtures at different temperature. *Points* represent experimental values and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

Ltd., India and were purified using methods described in the literature [17,18]; the mass fraction purities as determined by gas chromatography are: BA > 0.994, benzene > 0.998, toluene > 0.998, *o*-xylene > 0.997, *m*-xylene > 0.997, *p*-xylene > 0.997, and mesitylene > 0.995. Before use, the pure chemicals were stored over 0.4 nm molecular sieves for 72 h to remove water content, if any, and were degassed at low pressure. The mixtures were prepared by mass and were kept in special airtight stopper glass bottles to avoid evaporation. The weighings were done on an electronic balance (A & D Co., Model GR-202R, Japan) with a precision of ±0.01 mg. The probable error in the mole fraction was estimated to be less than $\pm 1 \times 10^{-4}$.

The densities of the pure liquids and their binary mixtures were measured using a single-capillary pycnometer (made of Borosil glass) having a bulb capacity of ≈10 ml. The capillary, with graduated marks, had a uniform bore and could be closed by a well-fitting glass cap. The marks on the capillary were calibrated using triply distilled water. The reproducibility of density measurements was within $\pm 2 \times 10^{-5}$ g · cm^{-3}. The temperature of the test liquids during the measurements was maintained to an uncertainty of ±0.01 K in an electronically controlled thermostatic water bath (JULABO, Model ME-31A, Germany). The reliability of the experimental measurements of ρ was demonstrated by comparing the experimental data of the pure liquids with corresponding

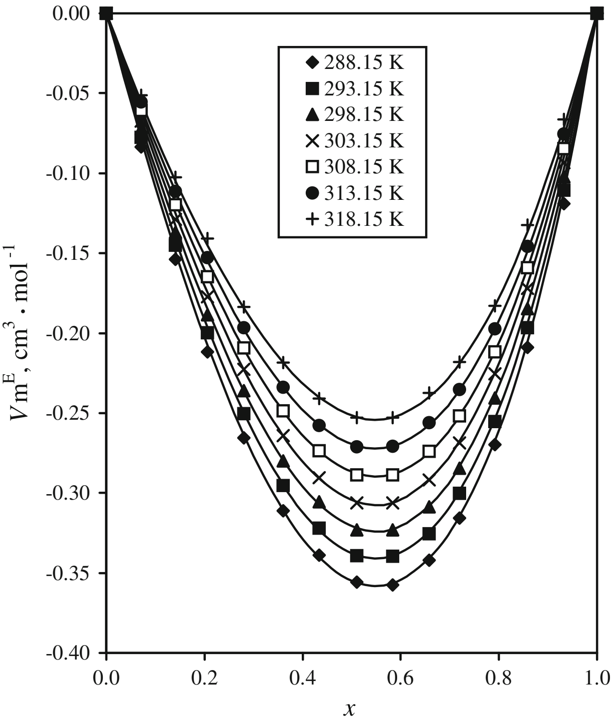


Fig. 2 Variation of excess molar volume, V_m^E against mole fraction, x, of BA for BA + toluene mixtures at different temperatures. *Points* represent experimental values, and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

literature [2,4,19–25] values at 298.15 K. This comparison is given in Table 1, and the agreement between the experimental and the literature values is found to be good.

3 Results and Discussion

The experimental values of densities, ρ, of binary mixtures of BA with benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene, with BA as a common component, over the whole composition range, expressed in mole fraction x of BA, at different temperatures are listed in Tables 2–7. The excess molar volumes V_m^E were calculated using the following relation:

$$V_\mathrm{m}^\mathrm{E} = xM_1\,(1/\rho - 1/\rho_1) + (1-x)M_2\,(1/\rho - 1/\rho_2) \tag{1}$$

where M is the molar mass; subscripts 1 and 2 stand for the pure components, BA and aromatic hydrocarbon, respectively. The values of V_m^E calculated using Eq. 1 are included in Tables 2–7. The variations of V_m^E with mole fraction, x, of BA for all the six binaries, along with smoothed V_m^E values using the Redlich–Kister equation [26] are presented graphically in Figs. 1–7.

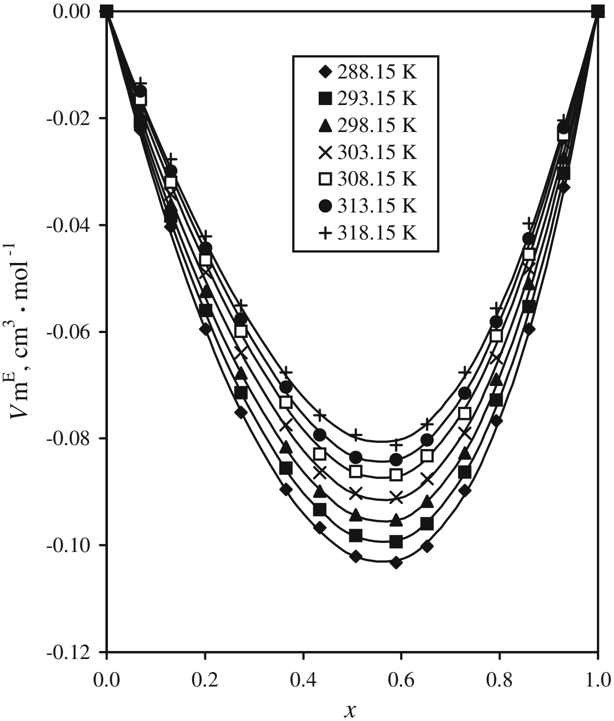


Fig. 3 Variation of excess molar volume, $V_{\mathrm{m}}^{\mathrm{E}}$ against mole fraction, x, of BA for BA + *o*-xylene mixtures at different temperatures. *Points* represent experimental values and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

The results presented in Tables 2–7 and Figs. 1–6 indicate that $V_{\mathrm{m}}^{\mathrm{E}}$ values are negative for BA + benzene/toluene/*o*-xylene/*m*-xylene/*p*-xylene and positive for BA + mesitylene mixtures over the entire mole fraction range and at all temperatures investigated. The deviations in $V_{\mathrm{m}}^{\mathrm{E}}$ from a linear dependence on mole fraction (Tables 2–7; Fig. 7) follow the sequence: benzene < toluene < *p*-xylene < *m*-xylene < *o*-xylene < mesitylene.

The behavior of $V_{\mathrm{m}}^{\mathrm{E}}$ with composition of a mixture can be qualitatively examined by considering the nature of the component molecules in the pure state and in the mixture. The molecules of BA are polar, and those of the aromatic hydrocarbons (benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene) have large quadrupole moments [16], which cause molecular order in the pure state. BA on mixing with the aromatic hydrocarbons, would induce a decrease in the molecular order in the latter, resulting in an expansion in volume, and hence, positive $V_{\mathrm{m}}^{\mathrm{E}}$ values. On the other hand, there is a possibility of electron donor–acceptor-type interactions [21] between the highly electronegative oxygen atoms of BA (acting as a donor) and the π-electrons aromatic hydrocarbon molecules (acting as an acceptor), resulting in negative $V_{\mathrm{m}}^{\mathrm{E}}$ values. The observed negative $V_{\mathrm{m}}^{\mathrm{E}}$ values (Figs. 1–5) suggest the presence of significant donor–acceptor (charge transfer) interactions between BA and aromatic hydrocarbon

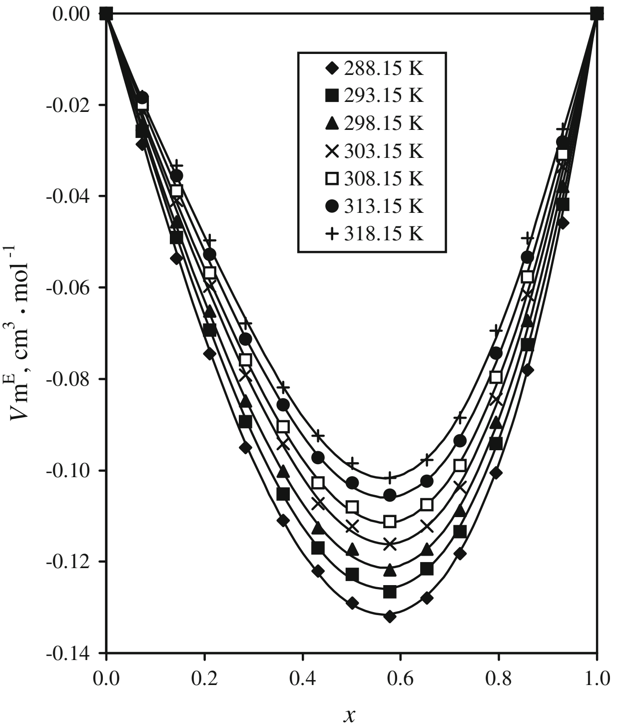


Fig. 4 Variation of excess molar volume, $V_{\mathrm{m}}^{\mathrm{E}}$ against mole fraction, x, of BA for BA + *m*-xylene mixtures at different temperatures. *Points* represent experimental values, and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

molecules in these mixtures. Recently, Ma et al. [21] have also reported a similar type of donor–acceptor interactions between the oxygen atoms of sulpholane and the π-electrons of the aromatic hydrocarbon (benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene) binary mixtures.

It is observed that $V_{\mathrm{m}}^{\mathrm{E}}$ becomes less negative and finally turns positive as the number of $–CH_3$ group in the ring increase from benzene (without $–CH_3$ group) to mesitylene (with three $–CH_3$ groups). This is due to the fact that the methyl group ($–CH_3$), being an electron-releasing group, would enhance the electron density of the benzene ring of the aromatic molecules. However, the electron-accepting tendency of the aromatic ring would however decrease, as we move from benzene to mesitylene, resulting in decreased donor–acceptor interactions between unlike molecules with an increase in the number of the methyl group ($–CH_3$) in the aromatic hydrocarbon molecule, causing an increase in $V_{\mathrm{m}}^{\mathrm{E}}$ values in the sequence: benzene < toluene < xylenes < mesitylene.

Another factor that would cause an increase in the $V_{\mathrm{m}}^{\mathrm{E}}$ values is the steric hindrance due to $–CH_3$ groups of the rings. As the number of the methyl group in the ring increases from benzene to mesitylene, the closer approach of the BA molecule to the aromatic ring becomes increasingly difficult, resulting in decreased interactions between BA and aromatic hydrocarbon molecules. The values of $V_{\mathrm{m}}^{\mathrm{E}}$ increase with an

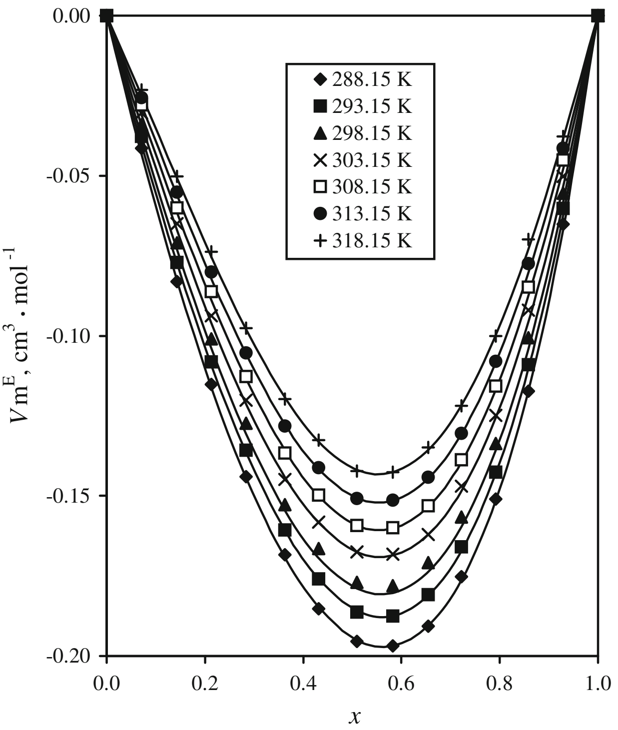


Fig. 5 Variation of excess molar volume, $V_{\mathrm{m}}^{\mathrm{E}}$ against mole fraction, x, of BA for BA + *p*-xylene mixtures at different temperatures. *Points* represent experimental values, and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

increase in the temperature of the mixture for all the six binary systems under study (Figs. 1–7). The increase in $V_{\mathrm{m}}^{\mathrm{E}}$ is attributed to the breaking of donor–acceptor interactions between unlike molecules with a rise in temperature, leading to an expansion in volume, hence, resulting in an increase in $V_{\mathrm{m}}^{\mathrm{E}}$ values.

4 Conclusion

The densities of binary mixtures of BA + benzene, or toluene, or *o*-xylene, or *m*-xylene, or *p*-xylene, or mesitylene, including those of pure liquids have been measured at different temperatures. The values of $V_{\mathrm{m}}^{\mathrm{E}}$ for the mixtures were calculated. The $V_{\mathrm{m}}^{\mathrm{E}}$ values were negative for all the mixtures, except for BA + mesitylene for which the values are positive, indicating the presence of specific interactions between BA and aromatic hydrocarbon molecules. The extent of negative deviations in $V_{\mathrm{m}}^{\mathrm{E}}$ values shows that the interactions in these mixtures follow the order: benzene > toluene > *p*-xylene > *m*-xylene > *o*-xylene > mesitylene. It is observed that the magnitude of $V_{\mathrm{m}}^{\mathrm{E}}$ depends upon the number and position of methyl groups in these aromatic hydrocarbon molecules.

Fig. 6 Variation of excess molar volume, V_m^E against mole fraction, x, of BA for BA + mesitylene mixtures at different temperatures. *Points* represent experimental values, and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]

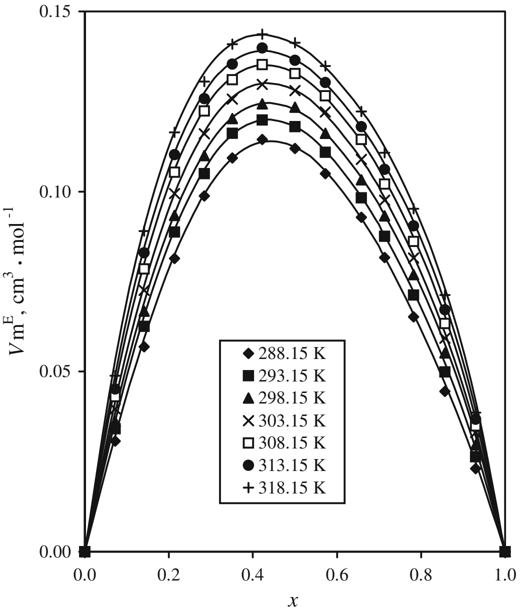
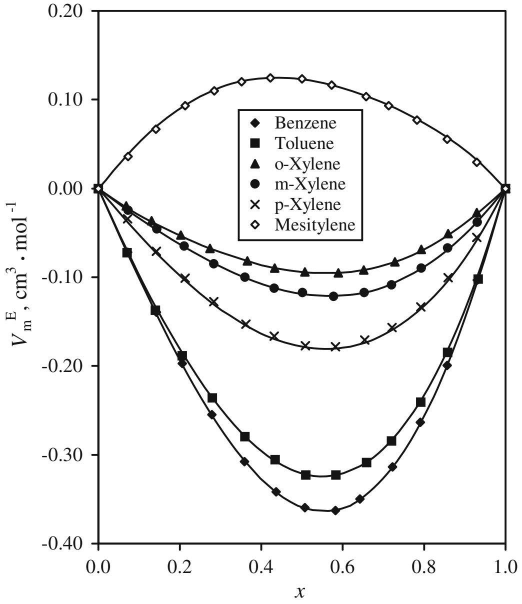


Fig. 7 Variation of excess molar volume, V_m^E against mole fraction, x, of BA for BA + aromatic hydrocarbon mixtures at $T = 298.15\,\text{K}$. *Points* represent experimental values, and *lines* represent smoothed values calculated from the Redlich–Kister equation [26]



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