Density, Speed of Sound, Isentropic Compressibility, and Excess Volume of Binary Mixtures of 1-Amino-2-propanol or 3-Amino-1-propanol with 2-Amino-2-methyl-1-propanol, Diethanolamine, or Triethanolamine from (293.15 to 323.15) K

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Density and speed of sound binary mixtures of 1-amino-2-propanol (MIPA) or 3-amino-1-propanol (AP) with 2-amino-1-methyl-1-propanol (AMP), diethanolamine (DEA), or triethanolamine (TEA) were measured over the entire composition range and at temperatures from (293.15 to 323.15) K. The experimental values were used to calculate the isentropic compressibilities, excess molar volumes, and isentropic compressibility deviations. Redlich−Kister type polynomial equations were used to fit the excess molar volumes and isentropic compressibility deviations.

Introduction

Gas absorption with chemical reactions is a method widely used in gas treating plants for the removal of carbon dioxide or hydrogen sulfide. The main objective of these processes is to minimize the environmental pollution and, specifically, the greenhouse effect. In particular, aqueous solutions of several amines are used to determine interfacial areas in gas−liquid contactors and to intensify the absorption rate of the process. Some of the most important alkanolamines used in industrial processes include monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), 2-amino-1-methyl-1-propanol (AMP), and *N*-methyldiethanolamine (MDEA). Other amines, such as di-isopropanolamine (DIPA), 1-amino-2-propanol (MIPA), or 3-amino-1-propanol (AP), have also been used, and some papers about these processes have been published.[1−4]

The use of mixtures of two alkanolamines (mainly aqueous solutions of a tertiary alkanolamine with a primary or secondary alkanolamine) has also been proposed with the aim of substituting at the industrial level the solutions of a single alkanolamine.[5,6] To fully characterize the physicochemical behavior of new formulations of solvents, it is important to create a database on those thermophysical properties that are relevant for the design, operation, and optimization of sour gas treatment plants. In this sense, our research group has been very active on the study of densities, viscosities, and surface tensions of binary or ternary aqueous solutions of alkanolamines,[7,8] and recently we have published several papers on the physical properties of binary nonaqueous solutions of alkanolamines.[9,10]

In this work, the density and the ultrasonic velocity of binary blends of two amines (MIPA and AP) with one of DEA, TEA, or AMP were measured over the range (293.15 to 323.15) K. These data represent the continuation of previous experimental works on binary mixtures of two alkanolamines.[11]

Experimental Section

All solutions were prepared by mass using an analytical balance with an accuracy of ± 0.1 mg. Alkanolamines were Merck reagents of nominal mass purity > 95 % for AMP (CAS Registry No. 124-68-5), > 98 % for MIPA (CAS Registry No. 2799-17-9), and > 99 % for AP (CAS Registry No. 156-87-6), DEA (CAS Registry No. 111-42-2), and TEA (CAS Registry No. 102-71-6). For all binary mixtures, the values of the mole fraction, x_1, correspond to 0 to 100 in mass fraction, at 10 % intervals of MIPA and AP.

The density, ρ, and speed of sound, u, of the pure alkanolamines and their mixtures were measured at 5 K intervals, between (293.15 and 323.15) K, using an Anton Paar DSA 5000 densimeter with an accuracy of $\pm\ 7 \cdot 10^{-5}$ $g \cdot cm^{-3}$ and $\pm\ 0.5\ m \cdot s^{-1}$, for the density and speed of sound, respectively. The apparatus allows varying the temperature in the range used, with a precision of ± 0.01 K. Before each series of measurements, the instrument was calibrated with double-distilled degassed water and dry air at atmospheric pressure. Densities of both water and dry air at the various working temperatures were supplied by the manufacturer in the instruction manual.

The measured densities and ultrasonic velocities of the pure components, to the temperature of the work, are included in Table 1 and are compared with values published by other authors.[12−19]

Finally, the isentropic compressibility, k_s, was calculated from the density and speed of sound values using the Newton−Laplace equation:

$$k_s/\text{Pa}^{-1} = \frac{1}{(u/(\text{m} \cdot \text{s}^{-1}))^2(\rho/(\text{kg} \cdot \text{m}^{-3}))} \qquad (1)$$

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Table 1. Review of the Literature Data for the Density and Speed of Sound of 1-Amino-2-propanol (MIPA), 3-Amino-1-propanol (AP), 2-Amino-2-methyl-1-propanol (AMP), Diethanolamine (DEA), and Triethanolamine (TEA)

	ρ/kg·m^{-3}		u/m·s^{-1}		ρ/kg·m^{-3}		u/m·s^{-1}	
T/K	this work	literature	this work	literature	this work	literature	this work	literature
		MIPA				AP		
293.15	961.223	960.38[a]	1560.07		991.349	986.50[b]	1727.44	
		959.46[b]						
298.15	957.114	956.40[a]	1544.07		987.421		1712.25	
303.15	952.980	952.39[a]	1527.85		983.399		1696.24	
308.15	948.828	948.36[a]	1511.56		979.316		1680.79	
313.15	944.656	944.30[a]	1495.14		975.191		1664.67	
318.15	940.462	940.20[a]	1478.68		971.043		1648.51	
323.15	936.244	936.08[a]	1462.09		966.881		1632.43	
		AMP				DEA		
293.15	936.751		1501.44		1097.250		1736.54	
298.15	932.596	929.9[c]	1483.44		1094.019	1093.70[e]	1723.96	1721.45[e]
303.15	928.395	927.0[c]	1461.22		1090.788	1089.4[f]	1711.55	
308.15	924.174	923.5[c]	1442.40		1087.508	1086.7[f]	1698.70	1697.2[e]
						1087.41[e]		
313.15	919.945	919.65[d]	1423.80		1084.199	1082.9[f]	1686.13	
		919.4[c]				1084.7[g]		
318.15	915.702		1405.28		1080.862	1080.3[f]	1673.76	
323.15	911.431	911.24[d]	1386.93		1077.491	1076.4[f]	1660.36	
						1077.4[g]		
		TEA						
293.15	1123.540		1617.81					
298.15	1120.820	1121.5[e]	1610.51					
303.15	1118.061		1600.52					
308.15	1115.255	1115.6[e]	1595.45					
313.15	1112.402	1112.3[h]	1586.99					
318.15	1109.604	1110.8[e]	1578.75					
323.15	1106.778		1570.58					

[a] Ref 12. [b] Ref 13. [c] Ref 14. [d] Ref 15. [e] Ref 16. [f] Ref 17. [g] Ref 18. [h] Ref 19.

Results and Discussion

Experimental densities and ultrasonic velocities of binary mixtures of MIPA (or AP) + (AMP, DEA, or TEA), from T = (293.15 to 323.15) K, are reported in Tables 2 to 7. In all systems studied, the density and speed of sound decreased linearly with increasing temperature for any given mole fraction of MIPA or AP. With regards to the influence of the composition, it is observed that, in the presence of DEA, the ultrasonic velocity decreases as the mixture is enriched in MIPA or AP, and that, for the binary mixtures with AMP or TEA, the ultrasonic velocity increases with the mole fraction of MIPA or AP. On the other hand, for the binary mixtures with DEA or TEA, the density decreases with the concentration of MIPA or AP. However, for the binary mixtures with AMP, the density increases as the mixture is enriched in MIPA or AP.

The excess molar volumes of mixtures (V^E) were calculated from density measurements by applying the following equation:[20]

$$V^E/(\text{cm}^3\cdot\text{mol}^{-1}) = \sum_{i=1}^{2} x_i M_i\left(\frac{1}{\rho_m} - \frac{1}{\rho_i}\right) \qquad (2)$$

where x_i represent the molar fraction of the component i in the mixture, ρ_i represent the density of the i^{th} pure component, and ρ_m is the measured mixture density.

On the other hand, the isentropic compressibility values (Tables 2 to 7) were used to calculate the isentropic compressibility deviations, Δk_s, defined by

$$\Delta k_s = k_{s,m} - \sum_{i=1}^{2} x_i k_{s,i} \qquad (3)$$

where x_i and $k_{s,i}$ represent the mole fraction and isentropic compressibility of the i^{th} pure component, respectively, and $k_{s,m}$ is the isentropic compressibility of the mixture.

Finally, a Redlich−Kister type equation is applied to correlate the excess molar volume and the isentropic compressibility deviation. For a binary system, this equation has the following expression:

$$Y = x_1 x_2 \sum_{i=0}^{4} a_i(1 - 2x_1)^i \qquad (4)$$

where Y represents the isentropic compressibility deviation or the excess molar volume, x_1 and x_2 are the mole fraction of the MIPA (or AP) and (AMP, DEA, or TEA), respectively. The coefficients a_i for the two functions, V^E and Δk_s, are presented in Tables 8 and 9, with the standard deviation (σ_{st}) between the experimental and the calculated values.

Equation 4 fits satisfactorily the excess molar volumes and the deviation values calculated from the experimental data of density and speed of sound (Figures 1 and 2). When we analyze the results obtained concerning the dependence of mixture composition upon the excess volumes, we can observe that the values of V^E are negative in all cases and temperatures, less for the MIPA (or AP) + AMP mixtures.

Also, the isentropic compressibility deviations for the mixtures of MIPA with (DEA or TEA), and for the mixtures of AP with (AMP, DEA, or TEA), are negative over the entire composition range. However, for the mixtures of MIPA with AMP, Δk_s show positive values for all temperatures and mole fractions.

Table 2. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for MIPA (1) + AMP (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
T/K = 293.15							
0.0000	936.751	1501.44	4.7354	0.6406	950.503	1533.86	4.4717
0.1176	938.737	1505.09	4.7025	0.7346	953.190	1540.17	4.4227
0.2292	940.760	1510.02	4.6618	0.8260	955.887	1546.64	4.3734
0.3381	942.978	1515.70	4.6161	0.9131	958.533	1553.18	4.3246
0.4424	945.342	1521.64	4.5686	1.0000	961.223	1560.07	4.2745
0.5422	947.842	1527.62	4.5210				
T/K = 298.15							
0.0000	932.596	1483.44	4.8727	0.6406	946.322	1517.71	4.5876
0.1176	934.492	1487.84	4.8341	0.7346	949.017	1524.21	4.5356
0.2292	936.540	1493.03	4.7900	0.8260	951.728	1530.79	4.4839
0.3381	938.766	1498.93	4.7411	0.9131	954.391	1537.31	4.4335
0.4424	941.139	1505.06	4.6907	1.0000	957.114	1544.07	4.3823
0.5422	943.637	1511.25	4.6400				
T/K = 303.15							
0.0000	928.395	1461.22	5.0447	0.6406	942.102	1499.74	4.7192
0.1176	930.214	1466.73	4.9971	0.7346	944.816	1506.82	4.6615
0.2292	932.272	1472.61	4.9463	0.8260	947.545	1513.88	4.6049
0.3381	934.526	1479.06	4.8914	0.9131	950.222	1520.81	4.5501
0.4424	936.909	1485.80	4.8348	1.0000	952.980	1527.85	4.4953
0.5422	939.416	1492.63	4.7779				
T/K = 308.15							
0.0000	924.174	1442.40	5.2009	0.6406	937.874	1483.16	4.8471
0.1176	925.918	1448.70	5.1460	0.7346	940.595	1490.40	4.7862
0.2292	927.995	1455.04	5.0898	0.8260	943.346	1497.57	4.7267
0.3381	930.264	1461.85	5.0302	0.9131	946.036	1504.53	4.6697
0.4424	932.667	1468.87	4.9694	1.0000	948.828	1511.56	4.7355
0.5422	935.180	1475.89	4.9090				
T/K = 313.15							
0.0000	919.945	1423.80	5.3622	0.6406	933.636	1466.47	4.9805
0.1176	921.613	1430.76	5.3005	0.7346	936.363	1473.84	4.9165
0.2292	923.688	1437.59	5.2385	0.8260	939.126	1481.09	4.8541
0.3381	925.995	1444.56	5.1751	0.9131	941.837	1488.14	4.7944
0.4424	928.422	1451.68	5.1111	1.0000	944.656	1495.14	4.6128
0.5422	930.949	1458.95	5.0465				
T/K = 318.15							
0.0000	915.702	1405.28	5.5299	0.6406	929.375	1449.69	5.1199
0.1176	917.294	1412.82	5.4616	0.7346	932.111	1457.24	5.0521
0.2292	919.386	1420.01	5.3941	0.8260	934.886	1464.59	4.9866
0.3381	921.710	1427.31	5.3256	0.9131	937.610	1471.68	4.9244
0.4424	924.148	1434.66	5.2573	1.0000	940.462	1478.68	4.8631
0.5422	926.686	1442.05	5.1893				
T/K = 323.15							
0.0000	911.431	1386.93	5.7038	0.6406	925.091	1432.92	5.2647
0.1176	912.954	1394.99	5.6287	0.7346	927.832	1440.55	5.1937
0.2292	915.059	1402.56	5.5553	0.8260	930.614	1448.00	5.1250
0.3381	917.403	1410.12	5.4819	0.9131	933.355	1455.10	5.0602
0.4424	919.860	1417.64	5.4094	1.0000	936.244	1462.09	4.9965
0.5422	922.397	1425.17	5.3376				

Table 3. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for MIPA (1) + DEA (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
T/K = 293.15							
0.0000	1097.250	1736.54	3.0222	0.6771	1014.995	1631.66	3.7006
0.1179	1084.985	1721.26	3.1109	0.7642	1001.715	1614.36	3.8305
0.2586	1069.676	1702.22	3.2264	0.8483	988.016	1596.24	3.9723
0.3754	1055.966	1684.35	3.3380	0.9250	974.656	1578.41	4.1182
0.4835	1042.201	1666.32	3.4557	1.0000	961.223	1560.07	4.2745
0.5836	1028.501	1648.89	3.5761				
T/K = 298.15							
0.0000	1094.019	1723.96	3.0755	0.6771	1011.241	1616.74	3.7832
0.1179	1081.705	1708.16	3.1684	0.7642	997.886	1599.11	3.9189
0.2586	1066.319	1688.78	3.2883	0.8483	984.110	1580.57	4.0675
0.3754	1052.495	1670.43	3.4050	0.9250	970.627	1562.45	4.2202
0.4835	1038.585	1651.99	3.5281	1.0000	957.114	1544.07	4.3823
0.5836	1024.808	1634.31	3.6533				
T/K = 303.15							
0.0000	1090.788	1711.55	3.1295	0.6771	1007.474	1601.81	3.8685
0.1179	1078.457	1695.20	3.2267	0.7642	994.025	1583.65	4.0113
0.2586	1062.898	1675.24	3.3524	0.8483	980.171	1564.85	4.1663
0.3754	1049.010	1656.68	3.4733	0.9250	966.599	1546.56	4.3253
0.4835	1035.015	1638.13	3.6004	1.0000	952.980	1527.85	4.4953
0.5836	1021.153	1619.89	3.7320				
T/K = 308.15							
0.0000	1087.508	1698.70	3.1866	0.6771	1003.686	1586.89	3.9565
0.1179	1075.207	1682.25	3.2864	0.7642	990.147	1568.36	4.1059
0.2586	1059.484	1662.08	3.4167	0.8483	976.205	1549.12	4.2686
0.3754	1045.473	1643.11	3.5429	0.9250	962.572	1530.51	4.4350
0.4835	1031.412	1624.05	3.6759	1.0000	948.828	1511.56	4.6128
0.5836	1017.463	1605.36	3.8136				
T/K = 313.15							
0.0000	1084.199	1686.13	3.2442	0.6771	999.894	1572.18	4.0461
0.1179	1071.893	1669.22	3.3483	0.7642	986.251	1553.39	4.2019
0.2586	1056.049	1648.57	3.4842	0.8483	972.199	1533.70	4.3728
0.3754	1041.915	1629.53	3.6145	0.9250	958.506	1514.46	4.5487
0.4835	1027.763	1610.06	3.7534	1.0000	944.656	1495.14	4.7355
0.5836	1013.753	1591.03	3.8968				
T/K = 318.15							
0.0000	1080.862	1673.76	3.3025	0.6771	996.072	1557.37	4.1393
0.1179	1068.576	1656.33	3.4111	0.7642	982.326	1537.99	4.3036
0.2586	1052.601	1635.18	3.5531	0.8483	968.193	1518.00	4.4822
0.3754	1038.372	1615.63	3.6895	0.9250	954.443	1498.45	4.6662
0.4835	1024.141	1595.86	3.8340	1.0000	940.462	1478.68	4.8631
0.5836	1010.016	1576.59	3.9832				
T/K = 323.15							
0.0000	1077.491	1660.36	3.3665	0.6771	992.230	1542.21	4.2374
0.1179	1065.187	1643.05	3.4775	0.7642	978.393	1522.69	4.4082
0.2586	1049.093	1621.82	3.6239	0.8483	964.204	1502.38	4.5948
0.3754	1034.766	1601.88	3.7661	0.9250	950.392	1482.42	4.7880
0.4835	1020.496	1581.55	3.9176	1.0000	936.244	1462.09	4.9965
0.5836	1006.284	1561.72	4.0745				

Table 4. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for MIPA (1) + TEA (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
T/K = 293.15							
0.0000	1123.540	1617.81	3.4006	0.7489	1028.026	1618.07	3.7154
0.1163	1114.179	1624.93	3.3992	0.8224	1012.093	1601.62	3.8518
0.3329	1092.744	1640.28	3.4013	0.8877	996.169	1587.10	3.9853
0.4604	1077.073	1650.70	3.4074	0.9470	979.341	1573.57	4.1238
0.5705	1060.733	1647.85	3.4718	1.0000	961.223	1560.07	4.2745
0.6645	1044.451	1635.18	3.5808				
T/K = 298.15							
0.0000	1120.820	1610.51	3.4398	0.7489	1024.173	1605.91	3.7860
0.1163	1111.225	1617.78	3.4384	0.8224	1008.087	1588.95	3.9290
0.3329	1089.489	1631.02	3.4503	0.8877	992.033	1573.68	4.0704
0.4604	1073.660	1641.45	3.4568	0.9470	975.140	1559.20	4.2182
0.5705	1057.160	1638.09	3.5252	1.0000	957.114	1544.07	4.3823
0.6645	1040.702	1624.25	3.6422				
T/K = 303.15							
0.0000	1118.061	1600.52	3.4915	0.7489	1020.249	1592.62	3.8643
0.1163	1108.259	1608.00	3.4897	0.8224	1004.052	1574.68	4.0166
0.3329	1086.217	1620.37	3.5063	0.8877	987.898	1559.14	4.1642
0.4604	1070.191	1630.93	3.5129	0.9470	970.952	1544.17	4.3193
0.5705	1053.544	1626.79	3.5866	1.0000	952.980	1527.85	4.4953
0.6645	1036.962	1611.63	3.7128				
T/K = 308.15							
0.0000	1115.255	1595.45	3.5226	0.7489	1016.349	1580.78	3.9374
0.1163	1105.177	1603.21	3.5204	0.8224	1000.002	1562.12	4.0980
0.3329	1082.896	1614.56	3.5425	0.8877	983.731	1545.68	4.2548
0.4604	1066.685	1623.42	3.5571	0.9470	966.734	1529.35	4.4226
0.5705	1049.885	1617.56	3.6403	1.0000	948.828	1511.56	4.6128
0.6645	1033.171	1600.98	3.7762				
T/K = 313.15							
0.0000	1112.402	1586.99	3.5694	0.7489	1012.379	1567.40	4.0207
0.1163	1102.065	1594.93	3.5670	0.8224	995.914	1548.32	4.1885
0.3329	1079.555	1605.35	3.5943	0.8877	979.528	1531.07	4.3550
0.4604	1063.143	1612.92	3.6156	0.9470	962.491	1514.02	4.5325
0.5705	1046.181	1605.76	3.7071	1.0000	944.656	1495.14	4.7355
0.6645	1029.340	1588.24	3.8513				
T/K = 318.15							
0.0000	1109.604	1578.75	3.6158	0.7489	1008.404	1554.84	4.1020
0.1163	1098.991	1585.79	3.6184	0.8224	991.792	1535.70	4.2753
0.3329	1076.201	1596.23	3.6468	0.8877	975.304	1517.90	4.4501
0.4604	1059.618	1602.16	3.6765	0.9470	958.211	1499.55	4.6411
0.5705	1042.485	1593.70	3.7767	1.0000	940.462	1478.68	4.8631
0.6645	1025.508	1575.87	3.9266				
T/K = 323.15							
0.0000	1106.778	1570.58	3.6628	0.7489	1004.395	1541.38	4.1906
0.1163	1095.881	1577.65	3.6662	0.8224	987.654	1522.10	4.3703
0.3329	1072.832	1587.21	3.7000	0.8877	971.044	1504.09	4.5521
0.4604	1056.038	1591.39	3.7391	0.9470	953.905	1484.73	4.7555
0.5705	1038.752	1581.16	3.8507	1.0000	936.244	1462.09	4.9965
0.6645	1021.640	1562.39	4.0098				

Table 5. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for AP (1) + AMP (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
T/K = 293.15							
0.0000	936.751	1501.44	4.7354	0.6398	967.714	1650.74	3.7922
0.1175	941.523	1528.15	4.5482	0.7346	973.519	1672.47	3.6723
0.2294	946.417	1554.37	4.3733	0.8257	979.428	1692.67	3.5635
0.3374	951.472	1579.86	4.2108	0.9130	985.339	1710.89	3.4671
0.4419	956.712	1604.48	4.0602	1.0000	991.349	1727.44	3.3804
0.5434	962.166	1628.28	3.9200				
T/K = 298.15							
0.0000	932.596	1483.44	4.8727	0.6398	963.512	1632.52	3.8943
0.1175	937.236	1509.74	4.6811	0.7346	969.368	1654.46	3.7688
0.2294	942.095	1535.65	4.5011	0.8257	975.324	1675.04	3.6543
0.3374	947.136	1561.11	4.3323	0.9130	981.303	1694.11	3.5507
0.4419	952.399	1585.87	4.1749	1.0000	987.421	1712.25	3.4543
0.5434	957.904	1609.87	4.0281				
T/K = 303.15							
0.0000	928.395	1461.22	5.0447	0.6398	959.244	1611.80	4.0128
0.1175	932.936	1487.33	4.8454	0.7346	965.136	1634.38	3.8789
0.2294	937.757	1513.20	4.6571	0.8257	971.149	1655.86	3.7555
0.3374	942.799	1538.85	4.4791	0.9130	977.194	1676.18	3.6423
0.4419	948.086	1564.04	4.3118	1.0000	983.399	1696.24	3.5342
0.5434	953.616	1588.55	4.1555				
T/K = 308.15							
0.0000	924.174	1442.40	5.2009	0.6398	954.870	1593.12	4.1263
0.1175	928.617	1468.26	4.9952	0.7346	960.831	1616.05	3.9851
0.2294	933.354	1493.96	4.8004	0.8257	966.919	1638.02	3.8545
0.3374	938.365	1519.60	4.6150	0.9130	973.041	1659.23	3.7330
0.4419	943.647	1544.91	4.4400	1.0000	979.316	1680.79	3.6145
0.5434	949.199	1569.63	4.2761				
T/K = 313.15							
0.0000	919.945	1423.80	5.3622	0.6398	950.485	1574.27	4.2452
0.1175	924.304	1449.36	5.1503	0.7346	956.533	1597.56	4.0962
0.2294	928.957	1474.88	4.9487	0.8257	962.693	1619.99	3.9581
0.3374	933.920	1500.47	4.7559	0.9130	968.853	1641.95	3.8284
0.4419	939.182	1525.76	4.5738	1.0000	975.191	1664.67	3.7004
0.5434	944.749	1550.60	4.4023				
T/K = 318.15							
0.0000	915.702	1405.28	5.5299	0.6398	946.108	1555.36	4.3691
0.1175	919.962	1430.53	5.3117	0.7346	952.221	1578.97	4.2122
0.2294	924.564	1455.93	5.1025	0.8257	958.435	1601.97	4.0656
0.3374	929.450	1481.38	4.9028	0.9130	964.652	1624.71	3.9271
0.4419	934.683	1506.63	4.7133	1.0000	971.043	1648.51	3.7895
0.5434	940.295	1531.50	4.5342				
T/K = 323.15							
0.0000	911.431	1386.93	5.7038	0.6398	941.701	1536.84	4.4960
0.1175	915.614	1411.91	5.4786	0.7346	947.873	1560.90	4.3301
0.2294	920.054	1437.30	5.2613	0.8257	954.128	1584.43	4.1749
0.3374	924.883	1462.67	5.0538	0.9130	960.386	1607.72	4.0284
0.4419	930.131	1487.83	4.8568	1.0000	966.881	1632.43	3.8811
0.5434	935.813	1512.73	4.6697				

Table 6. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for AP (1) + DEA (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
			T/K = 293.15				
0.0000	1097.250	1736.54	2.9515	0.6764	1034.735	1730.83	3.1978
0.1363	1086.751	1735.40	2.9896	0.7646	1023.844	1729.68	3.2444
0.2594	1076.525	1734.15	3.0287	0.8483	1012.817	1728.68	3.2915
0.3748	1066.246	1733.35	3.0686	0.9257	1002.090	1727.99	3.3366
0.4833	1055.822	1732.49	3.1101	1.0000	991.349	1727.44	3.3804
0.5828	1045.420	1731.82	3.1529				
			T/K = 298.15				
0.0000	1094.019	1723.96	3.0020	0.6764	1031.145	1717.36	3.2597
0.1363	1083.525	1722.99	3.0410	0.7646	1020.192	1715.96	3.3087
0.2594	1073.229	1721.48	3.0823	0.8483	1009.118	1714.72	3.3581
0.3748	1062.864	1720.57	3.1238	0.9257	998.332	1713.65	3.4061
0.4833	1052.359	1719.57	3.1671	1.0000	987.421	1712.25	3.4543
0.5828	1041.882	1718.65	3.2122				
			T/K = 303.15				
0.0000	1090.788	1711.55	3.0532	0.6764	1027.492	1703.91	3.3234
0.1363	1080.293	1710.56	3.0938	0.7646	1016.465	1702.12	3.3754
0.2594	1069.906	1709.06	3.1364	0.8483	1005.333	1700.23	3.4290
0.3748	1059.436	1707.92	3.1800	0.9257	994.491	1698.40	3.4814
0.4833	1048.869	1706.67	3.2256	1.0000	983.399	1696.24	3.5342
0.5828	1038.318	1705.49	3.2732				
			T/K = 308.15				
0.0000	1087.508	1698.70	3.1074	0.6764	1023.787	1690.76	3.3877
0.1363	1076.997	1697.80	3.1492	0.7646	1012.692	1688.44	3.4436
0.2594	1066.528	1696.34	3.1931	0.8483	1001.530	1685.96	3.5011
0.3748	1055.948	1695.29	3.2377	0.9257	990.643	1683.55	3.5575
0.4833	1045.285	1694.02	3.2849	1.0000	979.316	1680.79	3.6145
0.5828	1034.675	1692.70	3.3345				
			T/K = 313.15				
0.0000	1084.199	1686.13	3.1620	0.6764	1020.021	1676.50	3.4585
0.1363	1073.675	1685.13	3.2058	0.7646	1008.866	1673.97	3.5170
0.2594	1063.132	1683.74	3.2508	0.8483	997.642	1671.12	3.5779
0.3748	1052.459	1682.23	3.2987	0.9257	986.668	1668.11	3.6387
0.4833	1041.701	1680.35	3.3498	1.0000	975.191	1664.67	3.7004
0.5828	1030.991	1678.64	3.4027				
			T/K = 318.15				
0.0000	1080.862	1673.76	3.2170	0.6764	1016.229	1662.17	3.5316
0.1363	1070.323	1672.62	3.2630	0.7646	1005.027	1659.38	3.5931
0.2594	1059.682	1671.24	3.3095	0.8483	993.745	1656.15	3.6576
0.3748	1048.919	1669.25	3.3609	0.9257	982.692	1652.61	3.7227
0.4833	1038.068	1666.77	3.4162	1.0000	971.043	1648.51	3.7895
0.5828	1027.274	1664.60	3.4727				
			T/K = 323.15				
0.0000	1077.491	1660.36	3.2774	0.6764	1012.416	1647.54	3.6082
0.1363	1066.950	1659.72	3.3233	0.7646	1001.137	1644.36	3.6735
0.2594	1056.219	1657.78	3.3737	0.8483	989.811	1640.81	3.7415
0.3748	1045.329	1655.45	3.4281	0.9257	978.714	1636.96	3.8101
0.4833	1034.404	1652.80	3.4860	1.0000	966.881	1632.43	3.8811
0.5828	1023.542	1650.35	3.5457				

Table 7. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for AP (1) + TEA (2) Mixtures from T = (293.15 to 323.15) K

x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}	x_1	ρ / $kg \cdot m^{-3}$	u / $m \cdot s^{-1}$	$k_s \cdot 10^{10}$ / Pa^{-1}
			T/K = 293.15				
0.0000	1123.540	1617.81	3.4006	0.7482	1043.841	1729.50	3.2028
0.1830	1110.658	1645.79	3.3241	0.8215	1030.235	1734.19	3.2275
0.3320	1097.902	1669.16	3.2692	0.8877	1016.673	1734.56	3.2692
0.4606	1084.631	1688.69	3.2331	0.9466	1003.711	1731.81	3.3219
0.5698	1071.221	1705.78	3.2083	1.0000	991.349	1727.44	3.3804
0.6654	1057.509	1719.90	3.1968				
			T/K = 298.15				
0.0000	1120.820	1610.51	3.4398	0.7482	1040.156	1717.21	3.2603
0.1830	1107.682	1637.97	3.3649	0.8215	1026.428	1721.98	3.2856
0.3320	1094.767	1660.16	3.3142	0.8877	1012.778	1722.27	3.3288
0.4606	1081.377	1678.52	3.2822	0.9466	999.774	1718.72	3.3860
0.5698	1067.828	1694.50	3.2615	1.0000	987.421	1712.25	3.4543
0.6654	1053.965	1707.86	3.2529				
			T/K = 303.15				
0.0000	1118.061	1600.52	3.4915	0.7482	1036.404	1703.17	3.3262
0.1830	1104.671	1627.53	3.4175	0.8215	1022.568	1708.50	3.3502
0.3320	1091.589	1648.60	3.3706	0.8877	1008.833	1709.32	3.3926
0.4606	1078.054	1666.32	3.3407	0.9466	995.773	1705.23	3.4536
0.5698	1064.356	1681.34	3.3235	1.0000	983.399	1696.24	3.5342
0.6654	1050.348	1693.90	3.3181				
			T/K = 308.15				
0.0000	1115.255	1595.45	3.5226	0.7482	1032.586	1690.94	3.3870
0.1830	1101.604	1621.51	3.4525	0.8215	1018.641	1696.31	3.4117
0.3320	1088.348	1640.67	3.4134	0.8877	1004.851	1697.28	3.4545
0.4606	1074.659	1657.51	3.3870	0.9466	991.742	1692.47	3.5201
0.5698	1060.824	1671.23	3.3751	1.0000	979.316	1680.79	3.6145
0.6654	1046.660	1682.42	3.3754				
			T/K = 313.15				
0.0000	1112.402	1586.99	3.5694	0.7482	1028.734	1677.50	3.4544
0.1830	1098.491	1612.44	3.5014	0.8215	1014.688	1683.12	3.4789
0.3320	1085.071	1630.86	3.4650	0.8877	1000.814	1684.45	3.5215
0.4606	1071.226	1647.08	3.4410	0.9466	987.651	1678.99	3.5917
0.5698	1057.250	1659.51	3.4345	1.0000	975.191	1664.67	3.7005
0.6654	1042.938	1669.43	3.4404				
			T/K = 318.15				
0.0000	1109.604	1578.75	3.6158	0.7482	1024.888	1664.56	3.5215
0.1830	1095.428	1603.65	3.5497	0.8215	1010.742	1670.40	3.5458
0.3320	1081.828	1621.36	3.5163	0.8877	996.791	1671.81	3.5894
0.4606	1067.823	1636.77	3.4956	0.9466	983.567	1665.48	3.6654
0.5698	1053.685	1647.91	3.4948	1.0000	971.043	1648.51	3.7895
0.6654	1039.221	1656.83	3.5054				
			T/K = 323.15				
0.0000	1106.778	1570.58	3.6628	0.7482	1021.021	1650.93	3.5934
0.1830	1092.338	1594.93	3.5988	0.8215	1006.770	1657.21	3.6167
0.3320	1078.561	1611.85	3.5687	0.8877	992.746	1659.08	3.6595
0.4606	1064.417	1626.33	3.5520	0.9466	979.466	1652.13	3.7404
0.5698	1050.105	1635.97	3.5581	1.0000	966.881	1632.43	3.8811
0.6654	1035.492	1643.55	3.5751				

Table 8. Adjustable Parameters a_i (in Equation 4) with the Standard Deviations, σ_{st}, for Excess Molar Volumes (V^E)[a]

T/K	a_0	a_1	a_2	$a_3 \cdot 10$	a_4	$\sigma_{st} \cdot 10$
			MIPA (1) + AMP (2)			
293.15	0.3753	0.2236	−0.1568	−1.1201	0.0190	0.003
298.15	0.4038	0.2274	−0.1684	−0.4815	0.1337	0.004
303.15	0.4274	0.2303	−0.1438	0.1510	0.1881	0.003
308.15	0.4494	0.2354	−0.1183	0.7040	0.2407	0.002
313.15	0.4656	0.2465	−0.0321	1.2363	0.2124	0.002
318.15	0.4876	0.2527	−0.0051	1.7689	0.2688	0.002
323.15	0.5077	0.2550	0.0316	2.2855	0.3193	0.002
			MIPA (1) + DEA (2)			
293.15	−1.2770	0.1941	−0.1774	2.7083	0.6348	0.053
298.15	−1.3016	0.1796	−0.3363	2.9567	0.8382	0.055
303.15	−1.3464	0.2038	−0.2491	2.2722	0.6287	0.063
308.15	−1.3901	0.2241	−0.2077	1.2892	0.4172	0.059
313.15	−1.4322	0.2453	−0.2301	0.4197	0.3691	0.049
318.15	−1.4872	0.2388	−0.1793	0.0816	0.1753	0.048
323.15	−1.5465	0.2568	−0.0731	−0.0012	−0.1107	0.042
			MIPA (1) + TEA (2)			
293.15	−3.1904	0.6649	0.8456	18.1841	−3.4352	0.018
298.15	−3.1489	0.6799	0.9112	17.5813	−3.2826	0.014
303.15	−3.0994	0.6927	0.9417	16.8264	−3.1663	0.008
308.15	−3.0447	0.7008	0.8944	17.0402	−2.8147	0.011
313.15	−2.9901	0.6807	0.8484	17.4297	−2.4720	0.010
318.15	−2.9308	0.6955	0.8791	17.1794	−2.2246	0.007
323.15	−2.8631	0.6939	0.8282	17.2526	−1.8410	0.009
			AP (1) + AMP (2)			
293.15	0.4148	0.0786	−0.1367	1.1766	−0.0310	0.002
298.15	0.4992	0.1356	−0.1297	0.9573	0.0392	0.006
303.15	0.5663	0.1579	−0.0606	1.1187	−0.0071	0.006
308.15	0.6679	0.1962	−0.0662	1.0716	0.0614	0.003
313.15	0.7755	0.2488	−0.1790	0.7835	0.0614	0.004
318.15	0.8841	0.3111	−0.3130	0.3570	0.2060	0.007
323.15	1.0000	0.4509	−0.2953	−1.9002	0.1087	0.005
			AP (1) + DEA (2)			
293.15	−1.1884	0.3604	0.3676	−36250	−0.1511	0.009
298.15	−1.2266	0.3533	0.3341	−32675	−0.2481	0.013
303.15	−1.2706	0.3575	0.3670	−32714	−0.4578	0.021
308.15	−1.3066	0.3536	0.3461	−25492	−0.6447	0.034
313.15	−1.3483	0.3324	0.3074	−20390	−0.7038	0.032
318.15	−1.3852	0.3292	0.2785	−16571	−0.8231	0.031
323.15	−1.4233	0.3280	0.2829	−15769	−1.0197	0.044
			AP (1) + TEA (2)			
293.15	−1.7474	0.1153	0.4920	−5.7776	0.4978	0.003
298.15	−1.7213	0.1254	0.6381	−6.4611	0.4443	0.014
303.15	−1.6902	0.1202	0.7248	−6.6368	0.4335	0.004
308.15	−1.6560	0.1175	0.8661	−6.8098	0.2883	0.002
313.15	−1.6226	0.1116	0.9515	−6.7941	0.2726	0.001
318.15	−1.5882	0.0984	1.0470	−6.5555	0.1971	0.001
323.15	−1.5600	0.0866	1.1840	−6.4101	0.0764	0.004

[a] $\sigma_{st} = [\sum(V^E_{cal} - V^E_{exp})^2/(N - n)]^{1/2}$, where N is the number of data and n is the number of parameters.

Table 9. Adjustable Parameters a_i (in Equation 4) with the Standard Deviations, σ_{st}, for Isentropic Compressibility Deviations (Δk_s)[a]

T/K	a_0	a_1	a_2	a_3	a_4	$\sigma_{st} \cdot 10$
			MIPA (1) + AMP (2)			
293.15	14.5651	3.9697	3.6575	2.2229	−0.5101	0.128
298.15	13.6937	4.3304	1.9760	1.3402	−0.9150	0.212
303.15	12.9267	5.1399	−0.3357	−0.5933	0.1453	0.212
308.15	11.2361	4.6076	−0.8957	−0.6139	−0.1547	0.203
313.15	10.1290	4.2558	−3.9323	−0.9903	2.6898	0.097
318.15	8.7394	3.6173	−4.5223	−0.2196	2.8860	0.086
323.15	7.2520	2.9049	−5.3241	0.4536	3.7015	0.096
			MIPA (1) + DEA (2)			
293.15	−31.4497	4.6268	−3.4891	4.7272	2.3238	0.054
298.15	−29.3631	5.0602	0.3597	2.0124	0.9901	0.024
303.15	−27.1730	5.3917	3.6975	0.0198	−0.4649	0.048
308.15	−24.9178	5.2613	6.2390	−1.9160	−1.3075	0.021
313.15	−22.5613	5.0193	6.7875	−2.5489	−0.3138	0.090
318.15	−19.8470	4.2094	6.5599	−2.0452	1.2727	0.073
323.15	−17.3370	3.9398	3.9104	−1.6305	6.1732	0.017
			MIPA (1) + TEA (2)			
293.15	−69.4559	18.0828	−13.8635	4.9553	14.5700	0.295
298.15	−72.4162	19.0529	−16.3103	4.2202	19.7770	0.275
303.15	−76.4492	20.2505	−11.0267	4.1239	12.5266	0.231
308.15	−80.7905	20.5371	−12.4277	4.1761	14.3748	0.215
313.15	−85.5091	22.7760	−13.7962	4.1537	16.5271	0.642
318.15	−90.1686	24.9188	−12.8353	3.4555	14.0240	0.340
323.15	−95.6867	24.6867	−16.2666	7.2747	15.3154	0.444
			AP (1) + AMP (2)			
293.15	−19.5845	3.0985	4.2697	−4.4692	−1.6635	0.030
298.15	−21.5494	3.6007	5.6571	−4.0207	−6.1909	0.020
303.15	−24.1736	4.6637	3.7863	−3.8407	−3.4131	0.056
308.15	−27.2691	6.1568	5.3568	−4.9819	−4.6761	0.012
313.15	−29.1608	5.5159	0.7726	−1.8104	1.1836	0.011
318.15	−31.1722	4.6645	−2.8992	1.5056	5.6456	0.018
323.15	−33.4684	5.2377	−1.4297	−1.3741	0.0815	0.032
			AP (1) + DEA (2)			
293.15	−165.9913	76.3991	112.4226	−29.5061	−132.1069	0.028
298.15	−175.2855	83.8578	125.4910	−34.4065	−159.9528	0.030
303.15	−185.2613	88.1762	140.5055	−36.1735	−185.0638	0.031
308.15	−196.0235	88.2728	139.2181	−29.3510	−190.2433	0.021
313.15	−205.3856	89.0092	137.7648	−24.3113	−193.9618	0.017
318.15	−214.6149	89.2748	128.5296	−4.2914	−191.2081	0.026
323.15	−223.9923	86.5231	123.4409	13.9004	−199.0477	0.016
			AP (1) + TEA (2)			
293.15	−66.8533	43.6659	−41.5684	4.0498	37.9631	0.037
298.15	−69.2532	43.1117	−42.8068	11.7287	26.3062	0.038
303.15	−71.7247	42.5116	−37.5876	20.7629	−0.8123	0.023
308.15	−74.8707	43.2800	−27.6726	25.1213	−36.8902	0.031
313.15	−79.1642	41.7035	−18.0804	37.5180	−68.6886	0.047
318.15	−83.6767	40.3027	−13.4350	51.9721	−93.8216	0.024
323.15	−88.0043	36.7770	−4.1696	69.0641	−128.6137	0.035

[a] $\sigma_{st} = [\sum(\Delta k_{s,cal} - \Delta k_{s,exp})^2/(N - n)]^{1/2}$, where N is the number of data and n is the number of parameters.

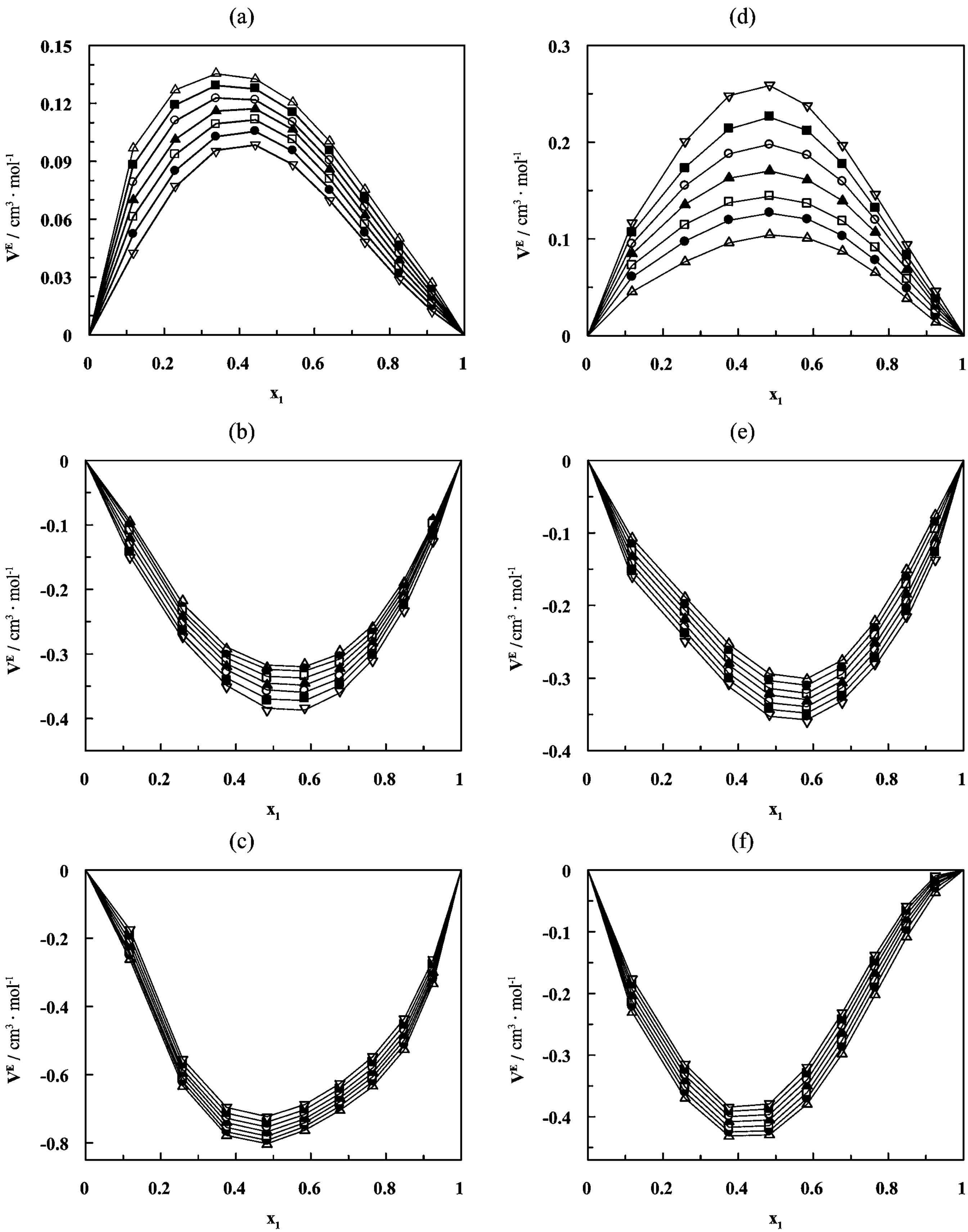

Figure 1. Excess molar volumes, V^E, for (a) MIPA (1) + AMP (2), (b) MIPA (1) + DEA (2), (c) MIPA (1) + TEA (2), (d) AP (1) + AMP (2), (e) AP (1) + DEA (2), and (f) AP (1) + TEA (2). △, 293.15 K; ●, 298.15 K; □ 303.15 K; ▲, 308.15 K; ○, 313.15 K; ■, 318.15 K; ▽, 323.15 K; —, Redlich−Kister fit curves.

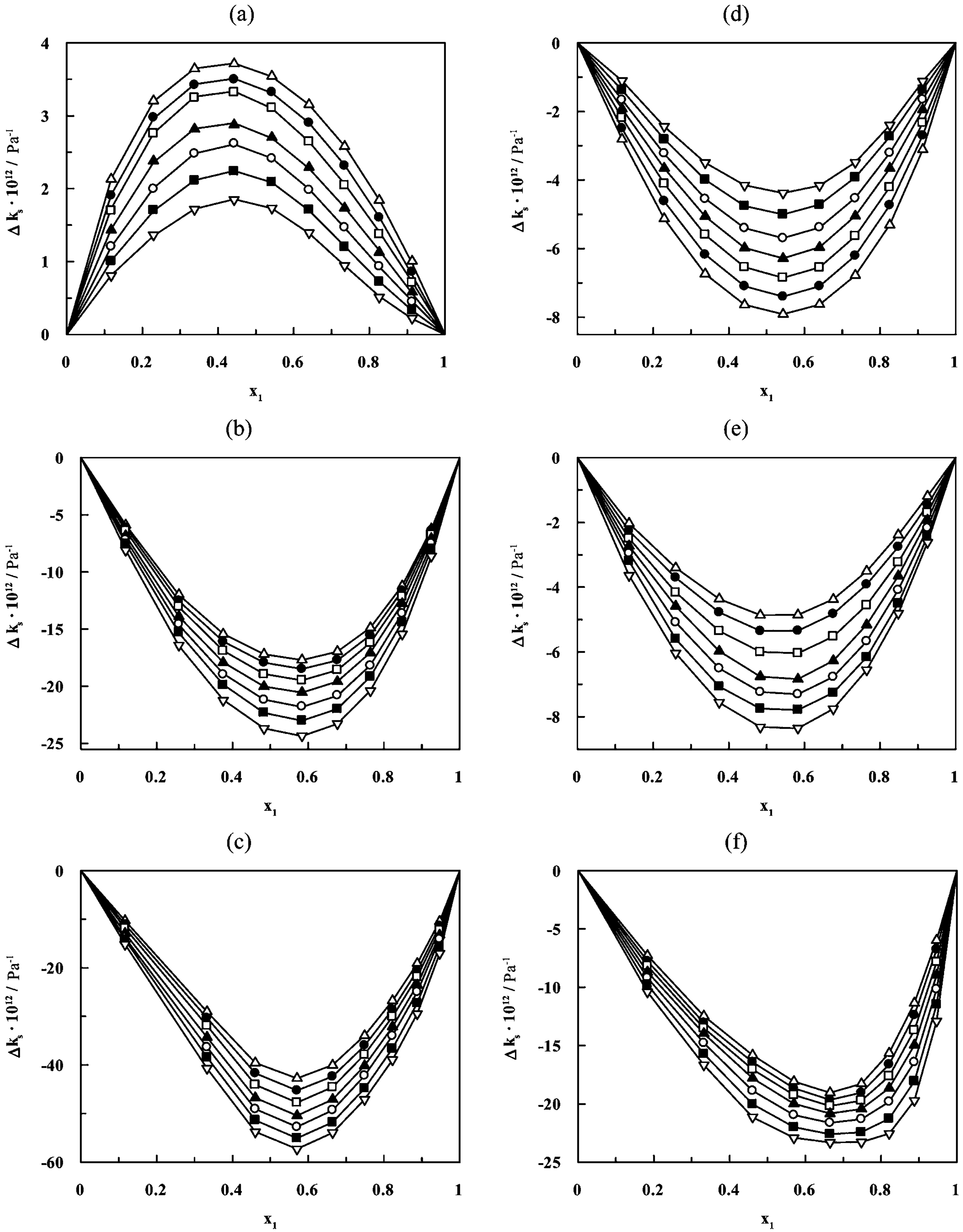

Figure 2. Isentropic compressibility deviations, Δk_s, for (a) MIPA (1) + AMP (2), (b) MIPA (1) + DEA (2), (c) MIPA (1) + TEA (2), (d) AP (1) + AMP (2), (e) AP (1) + DEA (2), and (f) AP (1) + TEA (2). △, 293.15 K; ●, 298.15 K; □, 303.15 K; ▲, 308.15 K; ○, 313.15 K; ■, 318.15 K; ▽, 323.15 K; —, Redlich−Kister fit curves.

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