Density, Speed of Sound, Isentropic Compressibility, and Excess Volume of (Monoethanolamine + 2-Amino-2-methyl-1-propanol), (Monoethanolamine + Triethanolamine), and (Monoethanolamine + *N*-Methyldiethanolamine) at Temperatures from (293.15 to 323.15) K

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Density and speed of sound of (monoethanolamine + 2-amino-2-methyl-1-propanol), (monoethanolamine + triethanolamine), and (monoethanolamine + *N*-methyldiethanolamine) 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

Natural, synthesis, and refinery gas streams contain H_2S and CO_2 that cause corrosion and fouling in pipelines and in processing plants. Therefore, to remove these acid gases aqueous solutions of one alkanolamine have traditionally been used. Some of the most important alkanolamines used in industrial processes include monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), 2-amino-2-methyl-1-propanol (AMP), and *N*-methyldiethanolamine (MDEA).

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.[1,2] Aqueous mixtures of alkanolamines combine the advantages of the individual amines to produce formulations of solvents with higher loading capacity, faster reaction rates, and lower energy required for regeneration. On the other hand, recent experimental studies[3,4] on the solubility of CO_2 and H_2S have shown that selected aqueous solutions of three alkanolamines (MDEA, DEA, and AMP) are more efficient than aqueous solutions of either one or two alkanolamines for the removal of those acid gases from hydrocarbon-rich streams. Other studies[5] have shown the use of nonaqueous solutions of alkanolamine causes an enhancement in the rate of absorption of CO_2.

It is well-known that to fully characterize the physicochemical behavior of new formulations of solvents it is important to create a reliable body of information on their different thermophysical properties that are relevant for the design, operation, and optimization of sour gas treatment plants. In this sense, we have measured the density, viscosity, and surface tension of binary or ternary aqueous solutions of alkanolamines[6,7] and, recently, published several papers on the physical properties of (alkanolamine + ethanol).[8,9]

This paper reports experimental data of density and ultrasonic velocity of {monoethanolamine (MEA) + 2-amino-2-methyl-1-propanol (AMP)}, {monoethanolamine + triethanolamine (TEA)}, and {monoethanolamine + *N*-methyldiethanolamine (MDEA)}. These data represent the continuation of previous experimental works on binary and ternary solutions of alkanolamines.

Experimental Section

All solutions were prepared by mass using an analytical balance with an uncertainty of ± 0.1 mg. The solutes were Merck reagents of nominal mass fraction purity > 0.95 for AMP (CAS registry No. 124-68-5), > 0.98 for MDEA (CAS registry No. 105-59-9), and > 0.99 for both MEA (CAS registry No. 141-43-5) and TEA (CAS registry No. 102-71-6).

The density, ρ, and speed of sound, u, of the pure alkanolamines and their mixtures were measured at temperature intervals of 5 K at temperatures between (293.15 and 323.15) K with an Anton Paar DSA 5000 densimeter with an uncertainty in density of $\pm\ 5\cdot10^{-5}\ g\cdot cm^{-3}$ and sound speed of $\pm\ 0.05\ m\cdot s^{-1}$. The apparatus temperature was controlled 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 are listed in Table 1 and are compared with values published by other authors.[10−18]

Finally, the isentropic compressibility, k_s, was calculated from the density, ρ, and speed of sound, u, values from

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$$k_s = \frac{1}{u^2\rho} \qquad (1)$$

Results and Discussion

Experimental densities and ultrasonic velocities of (monoethanolamine + 2-amino-2-methyl-1-propanol), (monoethanolamine + triethanolamine), and (monoethanolamine + *N*-methyldiethanolamine) at temperatures from (293.15 to 323.15) K are listed in Tables 2 to 4. In all systems, the density and speed of sound decreased linearly with increasing temperature for a mole fraction of monoethanolamine. For this reason, the experimental data (ρ or u) were correlated with the temperature T with

$$Y = K_0 - K_1 \cdot T \qquad (2)$$

where Y represents the density or the speed of sound and K_0 and K_1 are two adjustable parameters with values listed in Table 5.

Table 1. Review of the Literature Data for the Density, *ρ*, and Speed of Sound, *u*, of Monoethanolamine (MEA), 2-Amino-2-methyl-1-propanol (AMP), Triethanolamine (TEA), and *N*-Methyldiethanolamine (MDEA)

	ρ/kg·m^{-3}		u/m·s^{-1}		ρ/kg·m^{-3}		u/m·s^{-1}	
T/K	this work	lit. (ref)	this work	lit. (ref)	this work	lit. (ref)	this work	lit. (ref)
	Monoethanolamine				2-Amino-2-methyl-1-propanol			
293.15	1015.977		1735.46		936.751		1501.44	
298.15	1012.020	1011.80[a]	1719.23	1717.7[a]	932.596	929.9[e]	1483.44	
303.15	1008.002	1009.1[g] 1009.0[h]	1703.09		928.395	927.0[e]	1461.22	
308.15	1004.024	1004.67[a] 1004.45[b]	1686.79	1686.7[a]	924.174	923.5[e]	1442.40	
313.15	1000.037	1001.3[g] 999.9[h]	1670.54		919.945	919.65[f] 919.4[e]	1423.80	
318.15	996.029	998.17[a] 996.48[b]	1654.19	1653.5[a]	915.702		1405.28	
323.15	992.014	993.4[g] 991.8[h]	1637.86		911.431	911.24[f]	1386.93	
	Triethanolamine				*N*-Methyldiethanolamine			
293.15					1042.201	1041.604[d]	1585.48	
298.15	1120.820	1121.5[a]	1610.51		1038.290	1036.88[a] 1038.224[c] 1037.863[d]	1570.13	1568.3[a]
303.15	1118.061		1600.52		1034.358	1034.493[c]	1554.81	
308.15	1115.255	1115.6[a]	1595.45		1030.426	1030.749[c] 1030.322[d]	1539.47	1537.8[a]
313.15	1112.402	1112.3[i]	1586.99		1026.484	1026.993[c] 1023.523[d]	1524.19	
318.15	1109.604	1110.8[a]	1578.75		1022.535	1022.64[a] 1022.700[d]	1508.79	1507.0[a]
323.15	1106.778		1570.58		1018.576	1019.469[c] 1018.877[d]	1493.40	

[a] Ref 10. [b] Ref 11. [c] Ref 12. [d] Ref 13. [e] Ref 14. [f] Ref 15. [g] Ref 16. [h] Ref 17. [i] Ref 18.

Table 2. Density, *ρ*, Speed of Sound, *u*, and Isentropic Compressibility, *k*$_s$, for Monoethanolamine (1) + 2-Amino-2-methyl-1-propanol (2) Mixtures from *T* = (293.15 to 323.15) K

x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}
							T = 293.15 K								
0.0000	936.751	1501.44	4.7354	0.6869	984.969	1645.12	3.7513	0.3862	961.121	1574.05	4.1994	0.9268	1008.218	1712.56	3.3818
0.1410	944.932	1525.94	4.5449	0.7724	992.742	1668.25	3.6194	0.4939	969.165	1597.56	4.0428	1.0000	1015.977	1735.46	3.2680
0.2691	953.001	1550.21	4.3664	0.8532	1000.621	1690.99	3.4950	0.5933	977.051	1621.17	3.8943				
							T = 298.15 K								
0.0000	932.596	1483.44	4.8727	0.6869	980.811	1628.76	3.8433	0.3862	956.918	1557.14	4.3099	0.9268	1004.076	1696.48	3.4605
0.1410	940.731	1508.29	4.6727	0.7724	988.580	1651.96	3.7067	0.4939	964.959	1580.94	4.1463	1.0000	1012.020	1719.23	3.3430
0.2691	948.799	1532.96	4.4850	0.8532	996.465	1674.82	3.5777	0.5933	972.875	1604.68	3.9918				
							T = 303.15 K								
0.0000	928.395	1461.22	5.0447	0.6869	976.624	1610.55	3.9475	0.3862	952.718	1537.13	4.4424	0.9268	999.980	1679.89	3.5436
0.1410	936.493	1486.90	4.8298	0.7724	984.413	1634.32	3.8032	0.4939	960.768	1561.56	4.2684	1.0000	1008.002	1703.09	3.4203
0.2691	944.603	1512.28	4.6290	0.8532	992.305	1657.73	3.6671	0.5933	968.682	1585.92	4.1045				
							T = 308.15 K								
0.0000	924.174	1442.40	5.2009	0.6869	972.442	1593.80	4.0483	0.3862	948.482	1519.51	4.5663	0.9268	995.885	1663.60	3.6282
0.1410	932.236	1468.52	4.9741	0.7724	980.259	1617.68	3.8983	0.4939	956.545	1544.32	4.3835	1.0000	1004.024	1686.79	3.5005
0.2691	940.355	1494.36	4.7621	0.8532	988.206	1641.20	3.7569	0.5933	964.465	1569.02	4.2117				
							T = 313.15 K								
0.0000	919.945	1423.80	5.3622	0.6869	968.250	1576.93	4.1532	0.3862	944.248	1501.93	4.6948	0.9268	991.791	1647.30	3.7156
0.1410	927.969	1450.36	5.1229	0.7724	976.093	1600.95	3.9972	0.4939	952.319	1527.03	4.5032	1.0000	1000.037	1670.54	3.5832
0.2691	936.091	1476.45	4.9005	0.8532	984.066	1624.67	3.8499	0.5933	960.252	1551.94	4.3238				
							T = 318.15 K								
0.0000	915.702	1405.28	5.5299	0.6869	964.037	1559.90	4.2630	0.3862	940.009	1484.30	4.8286	0.9268	987.660	1630.81	3.8070
0.1410	923.687	1432.21	5.2779	0.7724	971.917	1584.06	4.1004	0.4939	948.077	1509.68	4.6279	1.0000	996.029	1654.19	3.6691
0.2691	931.816	1458.56	5.0445	0.8532	979.896	1608.01	3.9468	0.5933	956.017	1534.79	4.4405				
							T = 323.15 K								
0.0000	911.431	1386.93	5.7038	0.6869	959.804	1542.91	4.3766	0.3862	935.735	1466.73	4.9676	0.9268	983.527	1614.37	3.9013
0.1410	919.381	1414.22	5.4384	0.7724	967.721	1567.20	4.2073	0.4939	943.814	1492.35	4.7574	1.0000	992.014	1637.86	3.7578
0.2691	927.518	1440.79	5.1937	0.8532	975.738	1591.33	4.0471	0.5933	951.753	1517.66	4.5617				

Table 3. Density, ρ, Speed of Sound, u, and Isentropic Compressibility, k_s, for Monoethanolamine (1) + Triethanolamine (2) Mixtures from T = (298.15 to 323.15) K

x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}
T = 298.15 K															
0.0000	1120.820	1610.51	3.4398	0.6192	1080.560	1686.44	3.2539	0.3788	1101.520	1658.12	3.3020	0.9070	1035.531	1712.06	3.2946
0.1159	1116.381	1625.22	3.3913	0.7099	1069.500	1695.87	3.2511	0.4492	1096.350	1666.78	3.2832	0.9561	1023.915	1715.59	3.3182
0.2165	1111.374	1637.77	3.3545	0.7849	1058.490	1702.72	3.2586	0.5121	1091.139	1674.28	3.2694	1.0000	1012.020	1719.23	3.3427
0.3017	1106.520	1648.39	3.3260	0.8509	1046.990	1708.00	3.2740								
T = 303.15 K															
0.0000	1118.061	1600.52	3.4915	0.6192	1077.070	1675.27	3.3082	0.3788	1098.320	1648.27	3.3513	0.9070	1031.610	1697.12	3.3656
0.1159	1113.440	1615.20	3.4425	0.7099	1065.875	1683.36	3.3108	0.4492	1093.050	1656.70	3.3333	0.9561	1019.927	1700.26	3.3916
0.2165	1108.350	1627.99	3.4042	0.7849	1054.740	1689.12	3.3230	0.5121	1087.759	1663.93	3.3204	1.0000	1008.002	1703.09	3.4203
0.3017	1103.400	1638.71	3.3749	0.8509	1043.150	1693.54	3.3424								
T = 308.15 K															
0.0000	1115.255	1595.45	3.5226	0.6192	1073.560	1664.99	3.3601	0.3788	1095.080	1640.79	3.3919	0.9070	1027.720	1683.54	3.4330
0.1159	1110.420	1609.96	3.4744	0.7099	1062.260	1671.82	3.3681	0.4492	1089.750	1648.60	3.3763	0.9561	1015.985	1685.86	3.4631
0.2165	1105.255	1622.06	3.4388	0.7849	1051.010	1676.66	3.3846	0.5121	1084.390	1655.12	3.3663	1.0000	1004.024	1686.79	3.5005
0.3017	1100.250	1631.98	3.4125	0.8509	1039.310	1680.56	3.4068								
T = 313.15 K															
0.0000	1112.402	1586.99	3.5694	0.6192	1070.013	1654.58	3.4138	0.3788	1091.800	1631.91	3.4393	0.9070	1023.830	1668.96	3.5065
0.1159	1107.470	1601.84	3.5191	0.7099	1058.620	1661.14	3.4233	0.4492	1086.404	1639.19	3.4257	0.9561	1012.034	1669.96	3.5432
0.2165	1102.160	1613.92	3.4833	0.7849	1047.270	1665.14	3.4438	0.5121	1080.991	1645.22	3.4177	1.0000	1000.037	1670.54	3.5832
0.3017	1097.050	1623.58	3.4580	0.8509	1035.490	1667.58	3.4728								
T = 318.15 K															
0.0000	1109.604	1578.75	3.6158	0.6192	1066.473	1643.90	3.4698	0.3788	1088.580	1622.56	3.4893	0.9070	1019.920	1655.33	3.5782
0.1159	1104.530	1593.79	3.5642	0.7099	1054.940	1649.55	3.4837	0.4492	1083.063	1629.43	3.4776	0.9561	1008.071	1655.34	3.6202
0.2165	1099.150	1605.90	3.5278	0.7849	1043.540	1652.76	3.5081	0.5121	1077.570	1635.11	3.4710	1.0000	996.029	1654.19	3.6691
0.3017	1093.950	1614.84	3.5054	0.8509	1031.700	1654.57	3.5406								
T = 323.15 K															
0.0000	1106.778	1570.58	3.6628	0.6192	1062.920	1633.19	3.5272	0.3788	1085.310	1613.50	3.5392	0.9070	1016.001	1641.77	3.6516
0.1159	1101.560	1585.86	3.6096	0.7099	1051.260	1637.46	3.5477	0.4492	1079.760	1620.14	3.5283	0.9561	1004.089	1640.96	3.6985
0.2165	1096.030	1597.24	3.5763	0.7849	1039.740	1639.85	3.5766	0.5121	1074.180	1625.64	3.5227	1.0000	992.014	1637.86	3.7578
0.3017	1090.730	1605.88	3.5551	0.8509	1027.820	1641.32	3.6116								

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

x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}	x_1	ρ / kg·m^{-3}	u / m·s^{-1}	k_s·10^{10} / Pa^{-1}
T = 293.15 K															
0.0000	1042.201	1585.48	3.8239	0.8197	1026.389	1698.73	3.3809	0.5691	1034.198	1656.32	3.5327	0.9738	1018.272	1729.38	3.2836
0.1789	1040.322	1603.65	3.7444	0.8540	1024.997	1705.48	3.3591	0.6614	1031.812	1671.60	3.4773	1.0000	1015.977	1735.46	3.2680
0.3286	1038.487	1622.33	3.6658	0.8865	1023.480	1712.03	3.3385	0.7451	1029.170	1686.04	3.4273				
0.4560	1036.461	1640.01	3.5950	0.9461	1020.223	1723.26	3.3007								
T = 298.15 K															
0.0000	1038.290	1570.13	3.9140	0.8197	1022.321	1683.12	3.4579	0.5691	1030.158	1641.00	3.6133	0.9738	1014.198	1713.34	3.3588
0.1789	1036.351	1588.50	3.8310	0.8540	1020.835	1689.76	3.4358	0.6614	1027.724	1656.19	3.5564	1.0000	1012.020	1719.23	3.3430
0.3286	1034.460	1607.08	3.7502	0.8865	1019.333	1696.27	3.4147	0.7451	1025.098	1670.51	3.5052				
0.4560	1032.456	1624.69	3.6775	0.9461	1016.092	1707.34	3.3762								
T = 303.15 K															
0.0000	1034.358	1554.81	4.0070	0.8197	1018.166	1667.53	3.5373	0.5691	1026.074	1625.65	3.6967	0.9738	1009.954	1697.47	3.4363
0.1789	1032.335	1573.39	3.9203	0.8540	1016.658	1674.12	3.5148	0.6614	1023.608	1640.77	3.6383	1.0000	1008.002	1703.09	3.4203
0.3286	1030.414	1591.87	3.8373	0.8865	1015.146	1680.59	3.4931	0.7451	1020.956	1655.00	3.5858				
0.4560	1028.381	1609.40	3.7626	0.9461	1011.898	1691.52	3.4539								
T = 308.15 K															
0.0000	1030.426	1539.47	4.1031	0.8197	1014.032	1651.79	3.6197	0.5691	1022.010	1610.16	3.7831	0.9738	1005.910	1681.31	3.5168
0.1789	1028.359	1558.16	4.0129	0.8540	1012.554	1658.33	3.5966	0.6614	1019.552	1625.25	3.7230	1.0000	1004.024	1686.79	3.5005
0.3286	1026.407	1576.56	3.9275	0.8865	1011.030	1664.74	3.5746	0.7451	1016.859	1639.39	3.6693				
0.4560	1024.373	1594.02	3.8509	0.9461	1007.829	1675.47	3.5346								
T = 313.15 K															
0.0000	1026.484	1524.19	4.2021	0.8197	1009.917	1636.04	3.7048	0.5691	1017.964	1594.74	3.8722	0.9738	1001.868	1665.18	3.5997
0.1789	1024.364	1542.99	4.1083	0.8540	1008.436	1642.54	3.6811	0.6614	1015.469	1609.71	3.8106	1.0000	1000.037	1670.54	3.5832
0.3286	1022.379	1561.31	4.0205	0.8865	1006.906	1648.83	3.6586	0.7451	1012.763	1623.76	3.7555				
0.4560	1020.328	1578.66	3.9418	0.9461	1003.743	1659.48	3.6177								
T = 318.15 K															
0.0000	1022.535	1508.79	4.3051	0.8197	1005.810	1620.18	3.7932	0.5691	1013.887	1579.15	3.9649	0.9738	997.788	1648.95	3.6859
0.1789	1020.380	1527.69	4.2076	0.8540	1004.313	1626.61	3.7690	0.6614	1011.391	1594.07	3.9016	1.0000	996.029	1654.19	3.6691
0.3286	1018.352	1545.95	4.1172	0.8865	1002.793	1632.83	3.7460	0.7451	1008.661	1608.00	3.8451				
0.4560	1016.269	1563.20	4.0363	0.9461	999.607	1643.35	3.7043								
T = 323.15 K															
0.0000	1018.576	1493.40	4.4116	0.8197	1001.701	1604.31	3.8845	0.5691	1009.810	1563.58	4.0607	0.9738	993.693	1632.75	3.7749
0.1789	1016.376	1512.39	4.3102	0.8540	1000.209	1610.66	3.8598	0.6614	1007.306	1578.41	3.9956	1.0000	992.014	1637.86	3.7577
0.3286	1014.316	1530.61	4.2170	0.8865	998.693	1616.84	3.8364	0.7451	1004.572	1592.23	3.9378				
0.4560	1012.202	1547.73	4.1340	0.9461	995.464	1627.21	3.7939								

Table 5. Adjustable Parameters K_0 and K_1 (in Equation 2) with the Standard Deviations, σ_{st}, the Densities, and Ultrasonic Velocities[a]

	ρ/kg·m^{-3}			u/m·s^{-1}				ρ/kg·m^{-3}			u/m·s^{-1}		
	K_1	K_2		K_1	K_2			K_1	K_2		K_1	K_2	
x_1	kg·m^{-3}	kg·m^{-3}·K^{-1}	σ_{st}·10^3	m·s^{-1}	m·s^{-1}·K^{-1}	σ_{st}	x_1	kg·m^{-3}	kg·m^{-3}·K^{-1}	σ_{st}·10^3	m·s^{-1}	m·s^{-1}·K^{-1}	σ_{st}
Monoethanolamine (1) + 2-Amino-2-methyl-1-propanol (2)													
0.0000	1184.30	0.8443	0.043	2626.07	3.8376	1.202	0.6869	1230.86	0.8387	0.027	2646.04	3.4141	0.379
0.1410	1194.71	0.8519	0.039	2622.54	3.7419	1.056	0.7724	1237.13	0.8336	0.018	2657.38	3.3737	0.259
0.2691	1202.08	0.8495	0.045	2623.99	3.6635	0.883	0.8532	1243.57	0.8288	0.023	2666.20	3.3261	0.172
0.3862	1209.17	0.8460	0.032	2626.90	3.5917	0.747	0.9268	1249.21	0.8221	0.018	2672.76	3.2750	0.114
0.4939	1216.83	0.8448	0.033	2629.20	3.5191	0.629	1.0000	1250.17	0.7988	0.018	2689.17	3.2531	0.077
0.5933	1224.26	0.8431	0.037	2635.27	3.4592	0.496							
Monoethanolamine (1) + Triethanolamine (2)													
0.0000	1288.55	0.5625	0.028	2075.83	1.5624	1.061	0.6192	1291.06	0.7059	0.026	2317.90	2.1187	0.226
0.1159	1293.20	0.5931	0.027	2083.09	1.5380	1.002	0.7099	1287.00	0.7294	0.030	2382.98	2.3095	1.322
0.2165	1294.40	0.6138	0.028	2109.30	1.5832	0.858	0.7849	1281.84	0.7491	0.021	2443.14	2.4854	0.567
0.3017	1294.80	0.6314	0.031	2146.57	1.6718	0.711	0.8509	1275.31	0.7658	0.021	2496.67	2.6474	0.476
0.3788	1295.00	0.6489	0.030	2184.57	1.7663	0.570	0.9070	1268.27	0.7806	0.015	2548.77	2.8080	0.452
0.4492	1294.44	0.6643	0.024	2219.36	1.8538	0.471	0.9561	1260.13	0.7923	0.014	2607.83	2.9932	0.419
0.5121	1293.49	0.6786	0.022	2252.65	1.9403	0.357	1.0000	1250.17	0.7988	0.016	2689.17	3.2531	0.077
Monoethanolamine (1) + *N*-Methyldiethanolamine (2)													
0.0000	1273.10	0.7876	0.023	2484.92	3.0681	0.042	0.8197	1267.91	0.8238	0.019	2621.53	3.1474	0.133
0.1789	1274.33	0.7982	0.074	2495.33	3.0414	0.082	0.8540	1267.08	0.8259	0.015	2631.84	3.1596	0.131
0.3286	1274.60	0.8055	0.043	2518.54	3.0570	0.057	0.8865	1265.68	0.8263	0.027	2642.33	3.1729	0.144
0.4560	1273.52	0.8086	0.040	2541.65	3.0754	0.078	0.9461	1261.84	0.8243	0.049	2661.83	3.2012	0.128
0.5658	1272.53	0.8130	0.038	2562.78	3.0916	0.117	0.9738	1258.29	0.8189	0.013	2673.79	3.2211	0.134
0.6614	1271.19	0.8166	0.026	2582.32	3.1062	0.117	1.0000	1250.17	0.7988	0.022	2689.17	3.2531	0.077
0.7449	1269.69	0.8204	0.020	2602.66	3.1264	0.125							

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

Table 6. Adjustable Parameters a_i (in Equation 5) with the Standard Deviations, σ_{st}, for Excess Molar Volumes, V^E, and Isentropic Compressibility Deviations, Δk_s[a]

Y	T/K	a_0	a_1	a_2	a_3	a_4	σ_{st}·10
Monoethanolamine (1) + 2-Amino-2-methyl-1-propanol (2)							
V^E/cm^3·mol^{-1}	293.15	−0.7093	0.1561	0.2934	0.0489	−0.5833	0.004
	298.15	−0.6793	0.1644	0.2682	−0.0164	−0.4160	0.005
	303.15	−0.6677	0.1380	0.2760	0.0294	−0.3372	0.005
	308.15	−0.6435	0.1328	0.2554	0.0432	−0.2380	0.009
	313.15	−0.6233	0.1297	0.2834	0.0471	−0.1995	0.010
	318.15	−0.6029	0.1208	0.2883	0.0568	−0.1021	0.015
	323.15	−0.5794	0.1089	0.2863	0.0875	−0.0070	0.023
Δk_s	293.15	12.7968	2.5183	−6.4082	0.9768	7.1881	0.180
	298.15	11.5959	2.5001	−5.3970	1.8477	6.3992	0.155
	303.15	10.3394	2.4609	−5.6381	2.1352	6.5737	0.115
	308.15	8.8726	2.9372	−4.7855	1.8678	5.7523	0.133
	313.15	7.7646	3.0491	−3.3685	1.3230	2.9677	0.141
	318.15	6.7120	2.9894	−1.8802	1.0280	0.8594	0.117
	323.15	5.8026	3.0186	−1.0977	0.3768	−0.8707	0.176
Monoethanolamine (1) + Triethanolamine (2)							
V^E/cm^3·mol^{-1}	298.15	−1.8782	0.6638	−0.1686	−0.2771	−0.6052	0.012
	303.15	−1.8291	0.6666	−0.1871	−0.2449	−0.4818	0.011
	308.15	−1.7855	0.6679	−0.1492	−0.1602	−0.3763	0.008
	313.15	−1.7401	0.6982	−0.0993	−0.2424	−0.4886	0.010
	318.15	−1.6803	0.6575	−0.1528	−0.1528	−0.2740	0.016
	323.15	−1.6403	0.6828	−0.1950	−0.1950	−0.5203	0.015
Δk_s	298.15	−47.7473	22.5168	−7.9950	−4.3149	2.8542	0.348
	303.15	−53.3747	22.6085	−2.8054	−3.3497	−1.9190	0.225
	308.15	−57.5201	22.0778	0.6306	1.2711	−15.4807	0.622
	313.15	−62.9707	25.4661	−11.9916	−2.0121	2.2606	0.183
	318.15	−68.2449	26.8349	−15.3160	0.8567	−2.5979	0.792
	323.15	−74.8239	28.2280	−2.9019	3.8982	−30.5849	1.165
Monoethanolamine (1) + *N*-Methyldiethanolamine (2)							
V^E/cm^3·mol^{-1}	293.15	−0.6773	−0.3844	0.2154	−0.0491	−0.3027	0.494
	298.15	−0.7073	−0.3862	0.3014	−0.0767	−0.5361	0.329
	303.15	−0.7836	−0.3995	0.2713	−0.2351	−0.7389	0.132
	308.15	−0.7611	−0.3872	0.2967	−0.1884	−0.6708	0.018
	313.15	−0.7370	−0.3887	0.3560	−0.1314	−0.6940	0.016
	318.15	−0.7073	−0.3862	0.3014	−0.0767	−0.5361	0.014
	323.15	−0.6773	−0.3844	0.2154	−0.0491	−0.3027	0.018
Δk_s	293.15	9.6727	1.9708	5.8331	4.6791	−6.2219	0.029
	298.15	9.3223	2.2773	5.7058	3.8476	−6.8400	0.098
	303.15	9.0376	2.3532	5.4485	3.3283	−7.7849	0.095
	308.15	8.7739	2.4479	4.9892	3.2297	−7.8018	0.108
	313.15	8.4920	2.4675	5.0723	3.0294	−8.7950	0.135
	318.15	8.2499	2.4476	4.4599	3.0103	−8.3061	0.133
	323.15	7.9867	2.3454	3.7360	3.1088	−7.4530	0.140

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

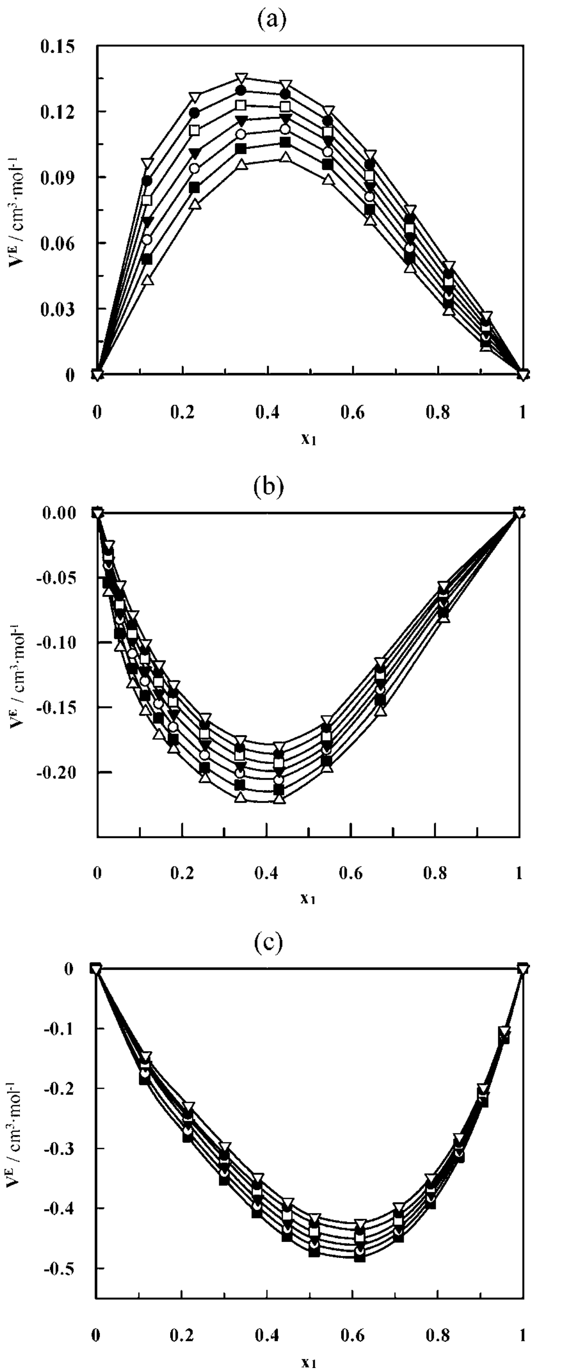

Figure 1. Excess molar volumes, V^E, for (a) 1-amino-2-propanol (1) + 2-amino-1-methyl-1-propanol (2), (b) monoethanolamine (1) + triethanolamine (2), and (c) monoethanolamine (1) + *N*-methyldiethanolamine (2): △, 293.15 K; ■, 298.15 K; ○, 303.15 K; ▼, 308.15 K; □, 313.15 K; ● 318.15 K; ▽, 323.15 K; —, Redlich−Kister fit curves.

With regard to the influence of the composition, it is observed that the ultrasonic velocity decreases as the mixture is enriched in monoethanolamine and that, for the mixtures of monoethanolamine with triethanolamine or *N*-methyldiethanolamine, the density decreases with the mole fraction of MEA. However, for the mixtures of monoethanolamine with 2-amino-2-methyl-1-propanol, the density increases with the concentration of MEA.

The excess molar volumes of mixtures V^E were calculated from density measurements by applying the following equation[19]

$$V^E = \sum_{i=1}^{2} x_i M_i \left(\frac{1}{\rho_m} - \frac{1}{\rho_i}\right) \tag{3}$$

where x_i represent the molar fraction of the component i in the mixture; ρ_i represents the density of the ith pure component; and ρ_m is the measured mixture density.

The isentropic compressibility listed in Tables 2 to 4 was used to obtain the isentropic compressibility deviations, Δk_s, defined by

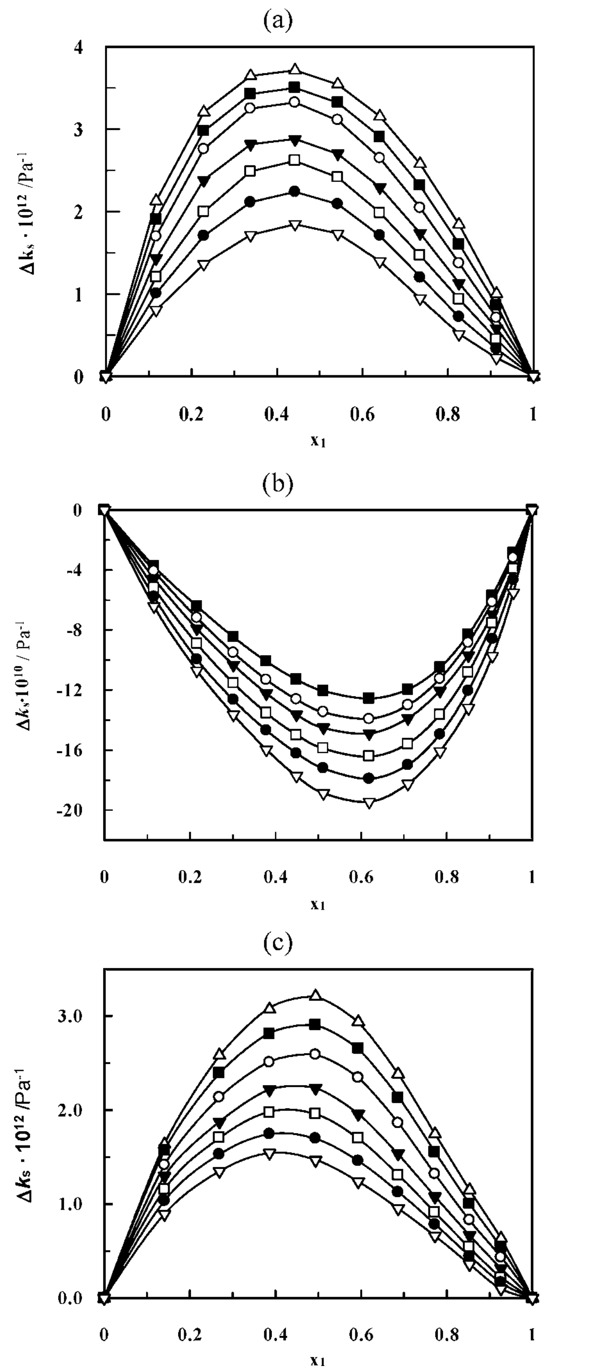

Figure 2. Isentropic compressibility deviations, Δk_s, for (a) 1-amino-2-propanol (1) + 2-amino-1-methyl-1-propanol (2), (b) monoethanolamine (1) + triethanolamine (2), and (c) monoethanolamine (1) + *N*-methyldiethanolamine (2): △, 293.15 K; ■, 298.15 K; ○, 303.15 K; ▼, 308.15 K; □, 313.15 K; ● 318.15 K; ▽, 323.15 K; —, Redlich−Kister fit curves.

$$\Delta k_s = k_{s,m} - \sum_{i=1}^{2} x_i k_{s,i} \quad (4)$$

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

A Redlich−Kister type equation was used to correlate the excess molar volume and the isentropic compressibility deviation. For a binary system, this equation has the following expression

$$Y = x_1 x_2 \sum_{i=0}^{4} a_i (1 - 2x_1)^i \quad (5)$$

where Y represents the isentropic compressibility deviation or the excess molar volume and x_1 and x_2 are the mole fraction of the monoethanolamine and (AMP, TEA, or MDEA), respectively. The coefficients a_i for the two functions, V^E and Δk_s, are listed in Table 6, with the standard deviation σ_{st} between the experimental and calculated values.

The excess molar volumes and the deviations in isentropic compressibility are shown in Figures 1 and 2.

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