Densities, Excess Molar Volumes, Viscosities, Speeds of Sound, Excess Isentropic Compressibilities, and Relative Permittivities for $C_mH_{2m+1}(OCH_2CH_2)_nOH$ ($m = 1$ or 2 or 4 and $n = 1$) + Benzene, + Toluene, + (*o*-, *m*-, and *p*-) Xylenes, + Ethylbenzene, and + Cyclohexane

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Measurements on densities, speeds of sound, viscosities, and relative permittivities for 21 binary mixtures of alkoxyethanols (2-methoxyethanol, 2-ethoxyethanol, and 2-butoxyethanol) + benzene, + toluene, + (*o*-, *m*-, and *p*-) xylenes, + ethylbenzene, and + cyclohexane at different temperatures are reported. The excess molar volumes, excess isentropic compressibilities, deviations in dynamic viscosities, speeds of sound, and relative permittivities have been calculated across the mole compositions. The compositional variation of excess and deviation functions has been expressed in terms of the Redlich−Kister equation.

Introduction

The molecules with the general formula $C_mH_{2m+1}(OCH_2CH_2)_nOH$ display a wide range of interesting properties and association patterns both in van der Waals clusters[1,2] and in the condensed phase.[3−7] These characteristics result from interplay of (i) the relative importance of the polar and nonpolar fragments, (ii) conformational degrees of freedom, (iii) the occurrence of intramolecular hydrogen bonding type interactions, and (iv) the extent of intermolecular interactions, hydrogen bonding included. The molecules with $m = 1$, 2, and 4 and $n = 1$ are widely used industrial solvents. Besides, these molecules act as model compounds for understanding the structural dynamics of poly(oxyethylene) crown ethers and related compounds.[8] There are several reports in the literature on the measurements of excess molar enthalpies, H_m^E,[9,10] excess molar volumes, V_m^E,[9−12] excess isentropic compressibilities, κ_s^E,[9−12] excess viscosities, η^E,[13] and vapor−liquid equilibria[9,10] for the lower alkoxyethanols + *n*-aliphatic alkanes. It is generally concluded that *n*-alkanes disrupt the self-associated structures of alkoxyethanols and such disruptions become more with the increase in the chain length of *n*-alkanes. Few available studies[14−16] on the thermodynamic behavior of alkoxyethanols + aromatic hydrocarbons in terms of calculated V_m^E and H_m^E suggested that aromatic hydrocarbons can form weak complexes with the former. With a view to understand the binary systems of alkoxyethanols + aromatic hydrocarbons further, the present study reports various excess and deviation functions, namely, V_m^E, viscosity deviations, $\delta\eta$, deviations in speeds of sound, δv, κ_s^E, and deviations in relative permittivities, $\delta\epsilon_r$, as calculated from the measured densities, ρ, dynamic viscosities, η, speed of sound, v, and relative permittivities, ϵ_r, for 2-methoxyethanol, 2-ethoxyethanol, or 2-butoxyethanol + aromatic hydrocarbons (benzene, toluene, *o*-, *m*-, *p*-xylenes, ethylbenzene) or + cyclohexane mixtures at different temperatures.

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Experimental Section

Materials. 2-Methoxyethanol, 2-ethoxyethanol, and 2-butoxyethanol were Chiti-Chem, India, products with a stated purity of 99.5% on a mole basis. These chemicals were dried over 4 Å molecular sieves and three times fractionally distilled through a 15 plate column under vacuum with temperature maintained at 100 °C. This procedure reduced the various initial impurities such as water, free acid (as CH_3COOH), and carbonyl compounds. A reagent grade benzene was acquired locally and purified by a standard procedure.[17] Toluene and *o*-, *m*-, and *p*-xylenes obtained from Chiti-Chem, India, were further purified by successive shaking with concentrated sulfuric acid, sodium hydroxide solutions, and mercury. They were dried over phosphorus pentoxide and then finally fractionally distilled over a 1 m column. Ethylbenzene procured from Chiti-Chem, India, was of analytical reagent (AR) quality with 99.5% purity (on a mole basis). It was further purified by shaking with concentrated sulfuric acid until the acid layer became colorless and then with sodium carbonate solution and water. Afterward, it was dried over anhydrous magnesium sulfate and fractionally distilled. Cyclohexane was of AR grade from Chiti-Chem, India. It was washed several times in the cold with a mixture of concentrated nitric and sulfuric acids to nitrate any benzene that may have been present. After repeated washings with distilled water, it was fractionally distilled over sodium metal.

Methods. The binary solutions were prepared by mass in hermetically sealed glass vials. The solutions of each composition were prepared fresh, and all the properties were measured the same day. The mass measurements, accurate to ±0.01 mg, were made on a single pan analytical balance (Dhona 100 DS, India). The estimated accuracy in the mole fraction was ±0.0001.

Densities of the pure liquids and their mixtures were measured with a high precision vibrating tube digital density meter (Anton Paar, DMA 5000). The instrument has a built-in thermostat for maintaining desired temperatures in the range 0 to 90 °C. The repeatability of the

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Table 1. Densities, ρ, Viscosities, η, Speeds of Sound, v, and Relative Permittivities, ϵ_r, at T = (298.15 to 313.15) K and Physicochemical Properties[a] at T = (298.15 and 308.15) K for the Pure Components

	T = 298.15 K		T = 303.15 K		T = 308.15 K		T = 313.15 K	
	exp	lit.	exp	lit.	exp	lit.	exp	lit.
				2-Methoxyethanol				
ρ/g·cm^{-3}	0.960 25(6)	0.960 24[17]	0.955 71(0)	0.955 77[15]	0.953 56(1)	0.953 56[24]	0.946 34(4)	0.946 34[26]
η/mPa·s	1.592	1.60[17]			1.242	1.256[24]		
v/m·s^{-1}	1339	1339.89[23]			1328	1327[25]		
ϵ_r	17.011				16.219			
				2-Ethoxyethanol				
ρ/g·cm^{-3}	0.925 20(1)	0.925 20[17]	0.921 17(8)	0.921 18[27]	0.917 96(9)	0.917 97[25]	0.911 59(7)	0.9116[12]
η/mPa·s	1.850	1.85[17]			1.407			
v/m·s^{-1}	1298	1301.99[11]			1266	1266[25]		
ϵ_r	13.219				12.269			
				2-Butoxyethanol				
ρ/g·cm^{-3}	0.896 24(8)	0.896 25[17]	0.892 02(6)	0.8924[29]	0.888 91(0)	0.888 73[25]	0.883 40(1)	0.8836[34]
η/mPa·s	2.782	2.786[28]			2.206	2.193[25]		
v/m·s^{-1}	1304	1304.40[23]			1285	1283[25]		
ϵ_r	9.446				8.352			
				Benzene				
ρ/g·cm^{-3}	0.873 60(9)	0.873 60[17]	0.868 28(9)	0.868 29[17]	0.862 95(8)	0.862 96[31]	0.857 97(1)	0.857 99[34]
η/mPa·s	0.602	0.6028[17]			0.526	0.528[32]		
v/m·s^{-1}	1299	1300.45[30]			1260			
ϵ_r	2.271	2.274[17]			2.250	2.2540[33]		
				Toluene				
ρ/g·cm^{-3}	0.862 19(9)	0.862 19[17]	0.857 54(5)	0.857 54[17]	0.852 85(8)	0.8527[35]	0.848 15(8)	
η/mPa·s	0.550	0.5525[17]			0.498	0.498[32]		
v/m·s^{-1}	1304	1304[32]			1262			
ϵ_r	2.408	2.3807[17]			2.381			
				o-Xylene				
ρ/g·cm^{-3}	0.875 93(8)	0.875 94[17]	0.871 71(2)	0.871 74[17]	0.867 38(1)	0.867 39[37]	0.863 16(7)	
η/mPa·s	0.759	0.756[17]			0.658	0.659[37]		
v/m·s^{-1}	1348				1322			
ϵ_r	2.551	2.56[36]			2.352	2.35[36]		
				m-Xylene				
ρ/g·cm^{-3}	0.859 99(9)	0.860 09[17]	0.855 79(7)	0.855 81[17]	0.851 57(7)		0.846 69(2)	
η/mPa·s	0.582	0.581[17]			0.499			
v/m·s^{-1}	1320				1283			
ϵ_r	2.360				2.310			
				p-Xylene				
ρ/g·cm^{-3}	0.856 61(8)	0.856 61[17]	0.852 24(5)	0.852 25[17]	0.847 87(7)	0.8479[39]	0.843 64(1)	
η/mPa·s	0.613	0.610[17]			0.540	0.539[40]		
v/m·s^{-1}	1308				1276	1272[41]		
ϵ_r	2.268	2.260[38]			2.119			
				Ethylbenzene				
ρ/g·cm^{-3}	0.862 52(8)	0.862 53[17]	0.858 31(3)	0.858 34[34]	0.854 15(2)	0.854 16[42]	0.849 44(8)	
η/mPa·s	0.638	0.637[17]			0.534	0.531[43]		
v/m·s^{-1}	1318	1312[42]			1276	1276[42]		
ϵ_r	2.374				2.319			
				Cyclohexane				
ρ/g·cm^{-3}	0.773 85(8)	0.773 89[17]	0.768 44(2)	0.768 45[17]	0.764 46(4)	0.764 47[44]	0.759 40(2)	0.7594[45]
η/mPa·s	0.898	0.898[17]			0.749	0.7483[45]		
v/m·s^{-1}	1253	1256.07[30]			1212			
ϵ_r	1.989				1.886			

	V_T/cm^3·mol^{-1}	V_0/cm^3·mol^{-1}	V_a/cm^3·mol^{-1}	L_f/Å	Y	S	B/cm^3·mol^{-1}
			T = 298.15 K				
2-methoxyethanol	79.244	63.753	15.491	0.475	65.16	3.361	19.731
2-ethoxyethanol	97.408	78.553	18.855	0.504	74.90	3.257	24.260
2-butoxyethanol	131.855	108.794	23.061	0.496	93.06	3.271	32.855
benzene	89.417	71.315	18.102	0.516	70.22	3.262	22.254
toluene	108.864	86.635	20.229	0.506	79.95	3.273	26.609
o-xylene	121.217	100.147	21.071	0.479	88.06	3.382	30.198
m-xylene	123.464	101.311	22.153	0.499	88.74	3.312	30.754
p-xylene	123.926	101.627	22.299	0.502	88.92	3.282	30.868
ethylbenzene	123.074	100.700	22.374	0.506	88.38	3.307	30.657
cyclohexane	108.755	86.230	22.525	0.565	79.70	3.146	27.069
			T = 308.15 K				
2-methoxyethanol	79.801		16.047	0.493		3.334	19.867
2-ethoxyethanol	98.194		19.622	0.526		3.178	24.451
2-butoxyethanol	132.836		24.150	0.517		3.224	33.095
benzene	90.518		19.203	0.523		3.165	22.522
toluene	108.037		21.402	0.535		3.168	26.896
o-xylene	122.377		22.253	0.505		3.317	30.483
m-xylene	124.671		23.360	0.527		3.220	31.050
p-xylene	125.215		23.588	0.531		3.202	31.184
ethylbenzene	124.330		23.595	0.535		3.202	30.964
cyclohexane	110.092		23.861	0.599		3.044	27.396

[a] V_T = molar volume, V_0 = molar volume at absolute zero, V_a = available volume, L_f = free length, Y = surface area, S = collision factor, B = actual volume per mole.

Table 2. Densities, ρ, for Alkoxyethanols (1) + Aromatic Hydrocarbons (2) and + Cyclohexane (2) at T = (298.15 to 313.15) K

	ρ/g·cm^{-3}					ρ/g·cm^{-3}			
x_1	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K	x_1	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
	2-Methoxyethanol (1) + Benzene (2)					2-Methoxyethanol (1) + Toluene (2)			
0.0543	0.877 11(2)	0.871 63(9)	0.866 32(5)	0.861 18(3)	0.0586	0.866 02(5)	0.861 22(1)	0.856 54(8)	0.851 74(1)
0.1499	0.883 76(2)	0.878 21(8)	0.873 02(0)	0.867 61(1)	0.1696	0.873 92(5)	0.868 96(1)	0.864 38(3)	0.859 29(4)
0.2235	0.889 28(8)	0.883 78(3)	0.878 73(9)	0.873 12(2)	0.2421	0.879 54(4)	0.874 53(9)	0.870 06(7)	0.864 75(0)
0.3508	0.899 62(7)	0.894 22(0)	0.889 54(0)	0.883 55(0)	0.3513	0.888 69(2)	0.883 68(1)	0.879 42(6)	0.873 72(5)
0.4496	0.908 25(9)	0.902 86(1)	0.898 52(8)	0.892 23(5)	0.4555	0.898 18(9)	0.893 20(4)	0.889 20(9)	0.883 12(5)
0.4961	0.912 47(9)	0.907 05(3)	0.902 89(5)	0.896 45(9)	0.4987	0.902 34(7)	0.897 37(4)	0.893 50(2)	0.887 26(0)
0.5462	0.917 12(1)	0.911 64(2)	0.907 68(1)	0.901 09(2)	0.5515	0.907 60(6)	0.902 64(8)	0.898 93(3)	0.892 50(6)
0.6455	0.926 55(0)	0.920 92(1)	0.917 36(7)	0.910 48(9)	0.6515	0.918 10(0)	0.913 16(4)	0.909 77(7)	0.903 02(7)
0.7524	0.936 89(3)	0.931 12(9)	0.928 02(6)	0.920 89(1)	0.7487	0.928 97(8)	0.924 06(1)	0.921 02(1)	0.914 01(8)
0.8509	0.946 40(4)	0.940 70(8)	0.938 03(1)	0.930 74(9)	0.8495	0.940 97(2)	0.936 09(3)	0.933 44(3)	0.926 26(5)
0.9558	0.956 26(0)	0.951 11(1)	0.948 89(9)	0.941 61(6)	0.9558	0.954 41(9)	0.949 65(0)	0.947 44(4)	0.940 20(7)
	2-Methoxyethanol (1) + *o*-Xylene (2)					2-Methoxyethanol (1) + *m*-Xylene (2)			
0.0517	0.877 85(5)	0.873 31(9)	0.869 04(6)	0.864 67(6)	0.0519	0.862 40(5)	0.857 98(5)	0.853 64(3)	0.848 65(7)
0.1491	0.882 30(0)	0.877 45(2)	0.873 23(5)	0.868 58(9)	0.1498	0.867 96(6)	0.863 28(9)	0.858 88(1)	0.853 65(6)
0.2491	0.887 92(1)	0.882 99(8)	0.878 80(7)	0.873 86(6)	0.2504	0.874 92(5)	0.870 13(9)	0.865 82(5)	0.860 30(9)
0.3509	0.894 66(1)	0.889 79(0)	0.885 63(2)	0.880 35(2)	0.3476	0.882 70(6)	0.877 91(5)	0.873 78(3)	0.867 96(6)
0.4485	0.902 02(9)	0.897 23(0)	0.893 14(5)	0.887 49(0)	0.4520	0.892 10(5)	0.887 36(7)	0.883 47(4)	0.877 33(5)
0.4919	0.905 58(0)	0.900 80(2)	0.896 77(0)	0.890 93(2)	0.4991	0.896 68(0)	0.891 97(2)	0.888 19(1)	0.881 91(3)
0.5537	0.910 92(3)	0.906 15(1)	0.902 22(3)	0.896 11(1)	0.5538	0.902 24(8)	0.897 57(5)	0.893 92(3)	0.887 49(1)
0.6432	0.919 25(8)	0.914 44(0)	0.910 72(9)	0.904 20(7)	0.6476	0.912 44(7)	0.907 82(0)	0.904 38(3)	0.897 71(5)
0.7525	0.930 41(9)	0.925 48(0)	0.922 15(3)	0.915 16(2)	0.7504	0.924 64(6)	0.920 03(3)	0.916 84(4)	0.909 96(2)
0.8492	0.941 25(8)	0.936 23(7)	0.933 36(0)	0.926 06(9)	0.8491	0.937 54(1)	0.932 90(5)	0.930 02(3)	0.922 98(3)
0.9547	0.954 25(1)	0.949 36(1)	0.947 07(5)	0.939 73(5)	0.9558	0.953 14(9)	0.948 47(2)	0.946 12(7)	0.938 95(8)
	2-Methoxyethanol (1) + *p*-Xylene (2)					2-Methoxyethanol (1) + Ethylbenzene (2)			
0.0528	0.859 41(0)	0.854 99(8)	0.850 64(4)	0.846 26(5)	0.0558	0.865 14(7)	0.860 77(8)	0.856 53(2)	0.851 73(7)
0.1469	0.865 14(8)	0.860 67(0)	0.856 36(0)	0.851 72(4)	0.1525	0.870 63(8)	0.866 09(2)	0.861 80(0)	0.856 78(7)
0.2507	0.872 58(5)	0.868 04(0)	0.863 80(0)	0.858 87(9)	0.2511	0.877 35(2)	0.872 71(7)	0.868 48(3)	0.863 19(4)
0.3484	0.880 62(2)	0.876 02(3)	0.871 86(9)	0.866 67(6)	0.3504	0.885 12(7)	0.880 46(5)	0.876 36(5)	0.870 77(3)
0.4499	0.890 02(4)	0.885 38(0)	0.881 33(8)	0.875 86(0)	0.4525	0.894 08(4)	0.889 43(5)	0.885 52(8)	0.879 62(4)
0.4999	0.895 04(8)	0.890 38(7)	0.886 41(1)	0.880 79(1)	0.5021	0.898 77(1)	0.894 13(4)	0.890 33(7)	0.884 28(6)
0.5542	0.900 79(9)	0.896 12(3)	0.892 23(1)	0.886 45(5)	0.5522	0.903 72(6)	0.899 10(3)	0.895 42(4)	0.889 23(2)
0.6493	0.911 61(9)	0.906 92(5)	0.903 22(0)	0.897 16(4)	0.6499	0.914 04(2)	0.909 44(1)	0.906 01(4)	0.899 57(0)
0.7508	0.924 23(7)	0.919 53(8)	0.916 11(6)	0.909 74(9)	0.7500	0.925 58(7)	0.920 99(0)	0.917 85(8)	0.911 18(7)
0.8478	0.937 37(2)	0.932 67(6)	0.929 64(8)	0.922 96(9)	0.8530	0.938 68(9)	0.934 07(0)	0.931 30(7)	0.924 42(4)
0.9556	0.953 27(8)	0.948 59(0)	0.946 21(8)	0.939 16(6)	0.9546	0.953 16(2)	0.948 49(9)	0.946 21(6)	0.939 11(4)
	2-Methoxyethanol (1) + Cyclohexane (2)					2-Ethoxyethanol (1) + Benzene (2)			
0.0540	0.779 60(7)	0.774 21(5)	0.770 01(0)	0.764 53(1)	0.0585	0.875 67(4)	0.870 69(3)	0.865 67(1)	0.860 78(4)
0.1506	0.791 26(1)	0.785 84(0)	0.781 46(3)	0.775 56(1)	0.1533	0.879 82(4)	0.875 37(2)	0.870 76(9)	0.865 96(8)
0.2513	0.804 98(3)	0.799 48(2)	0.795 15(2)	0.789 09(7)	0.2518	0.884 90(3)	0.880 92(2)	0.876 66(6)	0.871 86(8)
0.3532	0.820 23(6)	0.814 65(8)	0.810 51(2)	0.804 43(7)	0.3637	0.891 24(8)	0.887 65(2)	0.883 70(3)	0.878 82(1)
0.4508	0.836 01(0)	0.830 40(2)	0.826 48(8)	0.820 39(6)	0.4521	0.896 46(0)	0.893 03(4)	0.889 27(5)	0.884 27(2)
0.4955	0.843 61(7)	0.838 01(8)	0.834 21(2)	0.828 08(9)	0.5048	0.899 57(9)	0.896 19(8)	0.892 53(3)	0.887 44(0)
0.5513	0.853 47(8)	0.847 91(4)	0.844 24(0)	0.838 04(4)	0.5525	0.902 38(2)	0.899 00(4)	0.895 41(6)	0.890 23(0)
0.6490	0.871 88(0)	0.866 44(2)	0.862 98(4)	0.856 55(9)	0.6521	0.908 09(2)	0.904 62(7)	0.901 17(1)	0.895 76(3)
0.7493	0.892 72(5)	0.887 49(4)	0.884 25(8)	0.877 48(5)	0.7508	0.913 45(5)	0.909 81(4)	0.906 45(7)	0.900 80(1)
0.8496	0.916 39(7)	0.911 41(7)	0.908 47(5)	0.901 33(7)	0.8521	0.918 56(2)	0.914 71(0)	0.911 43(0)	0.905 49(5)
0.9529	0.945 13(3)	0.940 38(4)	0.937 97(9)	0.930 66(9)	0.9547	0.923 27(2)	0.919 26(8)	0.916 04(2)	0.909 80(7)
	2-Ethoxyethanol (1) + Toluene (2)					2-Ethoxyethanol (1) + *o*-Xylene (2)			
0.0560	0.864 63(3)	0.859 92(9)	0.855 21(5)	0.850 33(0)	0.0533	0.876 92(5)	0.872 50(7)	0.868 19(8)	0.863 82(7)
0.1494	0.869 40(0)	0.864 59(8)	0.859 89(6)	0.854 77(1)	0.1508	0.879 61(3)	0.875 01(7)	0.870 75(2)	0.866 13(6)
0.2493	0.875 23(3)	0.870 35(7)	0.865 73(3)	0.860 42(5)	0.2502	0.883 34(4)	0.878 69(8)	0.874 47(7)	0.869 65(0)
0.3539	0.881 87(4)	0.877 00(1)	0.872 51(6)	0.867 07(0)	0.3516	0.887 97(5)	0.883 32(3)	0.879 14(2)	0.874 12(3)
0.4490	0.888 18(0)	0.883 40(2)	0.879 08(3)	0.873 53(7)	0.4528	0.893 23(1)	0.888 55(2)	0.884 41(0)	0.879 20(9)
0.5019	0.891 74(0)	0.887 05(5)	0.882 83(9)	0.877 24(2)	0.5042	0.896 08(3)	0.891 37(3)	0.887 25(2)	0.881 95(8)
0.5488	0.894 90(8)	0.890 32(5)	0.886 20(6)	0.880 56(2)	0.5530	0.898 87(5)	0.894 12(5)	0.890 02(8)	0.884 64(3)
0.6514	0.901 83(0)	0.897 51(5)	0.893 61(7)	0.887 86(3)	0.6472	0.904 42(8)	0.899 58(3)	0.895 54(7)	0.889 98(1)
0.7465	0.908 19(8)	0.904 14(1)	0.900 44(9)	0.894 57(0)	0.7494	0.910 56(4)	0.905 64(8)	0.901 72(4)	0.895 94(5)
0.8514	0.915 18(1)	0.911 32(1)	0.907 84(6)	0.901 79(5)	0.8486	0.916 49(1)	0.911 65(2)	0.907 91(4)	0.901 91(0)
0.9527	0.921 97(1)	0.918 08(2)	0.914 79(5)	0.908 53(5)	0.9540	0.922 61(5)	0.918 21(5)	0.914 80(5)	0.908 54(7)
	2-Ethoxyethanol (1) + *m*-Xylene (2)					2-Ethoxyethanol (1) + *p*-Xylene (2)			
0.0531	0.861 88(5)	0.857 42(7)	0.853 03(2)	0.848 04(3)	0.0551	0.858 94(3)	0.854 55(9)	0.850 10(0)	0.845 67(5)
0.1513	0.866 18(4)	0.861 41(3)	0.856 91(6)	0.851 71(6)	0.1489	0.863 43(1)	0.859 02(3)	0.854 55(5)	0.849 89(1)
0.2482	0.871 30(5)	0.866 38(5)	0.861 95(3)	0.856 53(4)	0.2499	0.868 99(5)	0.864 55(7)	0.860 20(7)	0.855 35(5)
0.3528	0.877 62(5)	0.872 67(2)	0.868 37(0)	0.862 71(6)	0.3507	0.875 27(0)	0.870 79(6)	0.866 61(8)	0.861 60(7)
0.4512	0.884 15(5)	0.879 25(2)	0.875 04(5)	0.869 18(6)	0.4514	0.882 19(6)	0.877 68(6)	0.873 67(7)	0.868 49(7)
0.5053	0.887 93(2)	0.883 07(9)	0.878 89(8)	0.872 93(6)	0.5001	0.885 75(4)	0.881 22(9)	0.877 29(0)	0.872 01(7)
0.5473	0.890 93(8)	0.886 13(0)	0.881 95(5)	0.875 91(9)	0.5497	0.889 49(9)	0.884 96(2)	0.881 08(2)	0.875 70(7)
0.6494	0.898 45(1)	0.893 77(3)	0.889 57(0)	0.883 38(2)	0.6526	0.897 58(4)	0.893 04(2)	0.889 24(8)	0.883 63(0)
0.7510	0.906 12(0)	0.901 59(1)	0.897 36(4)	0.891 06(8)	0.7513	0.905 58(6)	0.901 08(3)	0.897 34(7)	0.891 47(0)
0.8492	0.913 62(6)	0.909 26(2)	0.905 14(4)	0.898 78(7)	0.8499	0.913 60(0)	0.909 20(5)	0.905 56(1)	0.899 43(0)
0.9554	0.921 77(7)	0.917 63(6)	0.914 01(8)	0.907 64(1)	0.9549	0.921 84(7)	0.917 67(9)	0.914 27(8)	0.907 94(8)

Table 2. (Continued)

x_1	ρ/g·cm^{-3} T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
	2-Ethoxyethanol (1) + Ethylbenzene (2)			
0.0573	0.864 51(6)	0.860 19(2)	0.855 98(5)	0.851 18(3)
0.1487	0.868 36(6)	0.863 91(3)	0.859 68(4)	0.854 70(5)
0.2498	0.873 45(9)	0.868 92(6)	0.864 73(3)	0.859 54(4)
0.3527	0.879 37(9)	0.874 82(7)	0.870 72(4)	0.865 32(0)
0.4489	0.885 44(6)	0.880 92(8)	0.876 94(6)	0.871 34(9)
0.4998	0.888 82(2)	0.884 34(0)	0.880 43(2)	0.874 73(9)
0.5485	0.892 14(2)	0.887 70(3)	0.883 87(0)	0.878 09(1)
0.6501	0.899 29(3)	0.894 96(5)	0.891 29(6)	0.885 35(6)
0.7484	0.906 42(4)	0.902 21(6)	0.898 70(5)	0.892 62(9)
0.8508	0.913 99(8)	0.909 90(2)	0.906 53(8)	0.900 34(1)
0.9547	0.921 78(2)	0.917 75(4)	0.914 50(8)	0.908 19(1)
	2-Butoxyethanol (1) + Benzene (2)			
0.0553	0.874 30(5)	0.869 03(8)	0.863 89(8)	0.858 82(1)
0.1496	0.876 28(2)	0.871 10(7)	0.866 19(2)	0.860 98(6)
0.2488	0.879 00(8)	0.873 93(1)	0.869 18(5)	0.863 87(4)
0.3504	0.882 07(4)	0.877 10(4)	0.872 51(4)	0.867 12(7)
0.4555	0.885 22(0)	0.880 36(6)	0.875 95(6)	0.870 52(2)
0.4995	0.886 47(3)	0.881 67(0)	0.877 34(6)	0.871 90(1)
0.5504	0.887 85(4)	0.883 11(0)	0.878 89(6)	0.873 44(1)
0.6482	0.890 26(2)	0.885 63(5)	0.881 65(5)	0.876 19(3)
0.7535	0.892 46(2)	0.887 96(2)	0.884 26(1)	0.878 79(7)
0.8483	0.894 11(1)	0.889 72(2)	0.886 27(2)	0.880 80(4)
0.9556	0.895 67(0)	0.891 40(1)	0.888 20(2)	0.882 71(1)
	2-Butoxyethanol (1) + *o*-Xylene (2)			
0.0549	0.875 83(5)	0.871 65(1)	0.867 29(9)	0.862 92(4)
0.1475	0.876 80(6)	0.872 55(7)	0.868 23(9)	0.863 54(7)
0.2508	0.878 94(6)	0.874 52(2)	0.870 30(8)	0.865 35(1)
0.3485	0.881 54(2)	0.876 95(1)	0.872 86(4)	0.867 70(6)
0.4527	0.884 51(1)	0.879 80(9)	0.875 86(1)	0.870 54(1)
0.5000	0.885 84(0)	0.881 12(1)	0.877 23(4)	0.871 85(8)
0.5489	0.887 16(9)	0.882 45(8)	0.878 63(0)	0.873 20(6)
0.6483	0.889 66(1)	0.885 03(7)	0.881 32(5)	0.875 83(4)
0.7518	0.891 90(6)	0.887 44(7)	0.883 85(6)	0.878 33(3)
0.8493	0.893 72(0)	0.889 42(6)	0.885 97(4)	0.880 44(6)
0.9524	0.895 45(2)	0.891 25(0)	0.888 00(5)	0.882 48(8)
	2-Butoxyethanol (1) + *p*-Xylene (2)			
0.0541	0.858 20(8)	0.853 81(6)	0.849 44(4)	0.845 15(1)
0.1518	0.861 90(7)	0.857 46(7)	0.853 12(2)	0.848 55(1)
0.2496	0.865 97(9)	0.861 49(6)	0.857 21(4)	0.852 27(0)
0.3502	0.870 43(0)	0.865 91(9)	0.861 73(0)	0.856 40(4)
0.4510	0.874 96(0)	0.870 44(7)	0.866 37(5)	0.860 74(4)
0.5028	0.877 26(3)	0.872 76(1)	0.868 75(7)	0.863 01(5)
0.5533	0.879 47(1)	0.874 98(6)	0.871 05(3)	0.865 23(7)
0.6489	0.883 50(6)	0.879 07(1)	0.875 28(5)	0.869 42(1)
0.7493	0.887 49(0)	0.883 12(5)	0.879 50(7)	0.873 71(0)
0.8519	0.891 26(9)	0.886 97(8)	0.883 55(0)	0.877 89(2)
0.9561	0.894 82(2)	0.890 58(8)	0.887 37(4)	0.881 84(4)
	2-Butoxyethanol (1) + Cyclohexane (2)			
0.0557	0.780 53(0)	0.774 84(4)	0.771 17(8)	0.765 44(0)
0.1501	0.792 14(6)	0.786 38(5)	0.782 85(7)	0.776 71(4)
0.2504	0.804 78(0)	0.799 25(3)	0.795 54(6)	0.789 54(2)
0.3543	0.818 03(1)	0.812 87(3)	0.808 84(8)	0.803 16(7)
0.4488	0.830 10(3)	0.825 26(1)	0.820 97(5)	0.815 49(1)
0.5025	0.836 93(2)	0.832 23(1)	0.827 84(6)	0.822 38(1)
0.5493	0.842 84(7)	0.838 24(1)	0.833 80(8)	0.828 29(8)
0.6485	0.855 22(8)	0.850 72(5)	0.846 33(5)	0.840 55(8)
0.7494	0.867 52(4)	0.863 02(4)	0.858 87(2)	0.852 71(5)
0.8511	0.879 52(7)	0.875 01(9)	0.871 26(1)	0.864 88(1)
0.9556	0.891 37(8)	0.887 00(3)	0.883 70(9)	0.877 70(9)

x_1	ρ/g·cm^{-3} T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
	2-Ethoxyethanol (1) + Cyclohexane (2)			
0.0542	0.779 45(6)	0.773 87(7)	0.769 63(2)	0.764 48(3)
0.1507	0.790 32(8)	0.784 68(7)	0.780 34(1)	0.775 04(0)
0.2541	0.803 24(7)	0.797 74(6)	0.793 57(0)	0.788 10(9)
0.3508	0.816 47(9)	0.811 19(4)	0.807 22(2)	0.801 61(6)
0.4520	0.831 44(6)	0.826 39(3)	0.822 52(5)	0.816 77(3)
0.5000	0.838 91(6)	0.833 95(8)	0.830 07(5)	0.824 25(7)
0.5497	0.846 88(1)	0.842 00(6)	0.838 06(1)	0.832 17(7)
0.6534	0.864 16(4)	0.859 41(4)	0.855 21(9)	0.849 20(3)
0.7527	0.881 37(9)	0.876 70(9)	0.872 24(4)	0.866 11(2)
0.8492	0.898 48(2)	0.893 92(3)	0.889 41(5)	0.883 18(0)
0.9552	0.917 32(9)	0.913 07(1)	0.909 21(1)	0.902 87(7)
	2-Butoxyethanol (1) + Toluene (2)			
0.0550	0.863 84(6)	0.859 17(3)	0.854 65(1)	0.849 76(8)
0.1509	0.867 24(8)	0.862 55(5)	0.858 08(1)	0.852 99(5)
0.2513	0.871 21(9)	0.866 52(5)	0.861 96(0)	0.856 75(6)
0.3489	0.875 19(9)	0.870 52(3)	0.865 88(4)	0.860 60(5)
0.4511	0.879 27(0)	0.874 63(4)	0.870 03(4)	0.864 68(1)
0.5015	0.881 19(2)	0.876 58(3)	0.872 06(1)	0.866 66(8)
0.5525	0.883 06(2)	0.878 48(5)	0.874 08(2)	0.868 64(6)
0.6512	0.886 44(1)	0.881 93(6)	0.877 86(3)	0.872 33(7)
0.7494	0.889 48(6)	0.885 06(1)	0.881 39(1)	0.875 78(7)
0.8498	0.892 31(7)	0.887 97(8)	0.884 68(9)	0.879 04(7)
0.9541	0.895 06(2)	0.890 80(7)	0.887 71(9)	0.882 13(6)
	2-Butoxyethanol (1) + *m*-Xylene (2)			
0.0560	0.861 44(5)	0.857 06(3)	0.852 68(1)	0.847 76(8)
0.1520	0.864 52(2)	0.859 92(4)	0.855 46(7)	0.850 37(8)
0.2496	0.868 18(9)	0.863 47(2)	0.859 11(0)	0.853 77(2)
0.3506	0.872 30(4)	0.867 54(8)	0.863 37(7)	0.857 79(7)
0.4512	0.876 51(3)	0.871 78(5)	0.867 82(9)	0.862 08(3)
0.5022	0.878 63(4)	0.873 93(8)	0.870 08(6)	0.864 29(7)
0.5529	0.880 70(9)	0.876 05(5)	0.872 29(8)	0.866 49(3)
0.6487	0.884 49(2)	0.879 93(4)	0.876 32(7)	0.870 56(6)
0.7505	0.888 25(5)	0.883 81(0)	0.880 32(6)	0.874 68(4)
0.8511	0.891 68(0)	0.887 34(2)	0.883 96(8)	0.878 45(6)
0.9549	0.894 92(0)	0.890 67(0)	0.887 45(3)	0.881 98(6)
	2-Butoxyethanol (1) + Ethylbenzene (2)			
0.0546	0.863 76(5)	0.859 41(8)	0.855 27(3)	0.850 44(5)
0.1505	0.866 73(9)	0.862 26(0)	0.858 07(9)	0.853 05(0)
0.2513	0.870 23(5)	0.865 73(1)	0.861 49(5)	0.856 31(9)
0.3501	0.873 92(7)	0.869 44(7)	0.865 19(8)	0.859 92(7)
0.4528	0.877 85(6)	0.873 40(9)	0.869 23(1)	0.863 90(5)
0.4982	0.879 58(3)	0.875 14(7)	0.871 03(1)	0.865 69(2)
0.5500	0.881 52(6)	0.877 09(8)	0.873 07(6)	0.867 72(8)
0.6497	0.885 14(7)	0.880 72(0)	0.876 93(6)	0.871 58(3)
0.7511	0.888 62(3)	0.884 19(1)	0.880 68(8)	0.875 33(1)
0.8507	0.891 81(5)	0.887 40(6)	0.884 15(4)	0.878 77(2)
0.9614	0.895 13(4)	0.890 83(6)	0.887 73(0)	0.882 26(8)

temperature has been found to be ±0.003 and ±0.002 °C for a given session and two different sessions, respectively. The accuracy in the temperature during the measurements, however, is ±0.01 °C because Pt 100 measuring sensors were used. The instrument was calibrated with air and with four times distilled and freshly degassed water at T = (293.15, 313.15, and 333.15) K during every session. The repeatabilities in the densities for the distilled water and freshly distilled pure liquids and prepared binary mixtures have been found to be better than 3×10^{-6} g·cm^{-3}. We have estimated the accuracy in densities of the seven pure liquids used in the study by comparing our data at different temperatures with the literature values, as listed in Table 1. This comparison gave a mean absolute deviation of 2.9×10^{-5} g·cm^{-3}. Hence, the precision and accuracies of the densities reported in the present work are 3×10^{-6} and 2.9×10^{-5} g·cm^{-3}, respectively. The viscosities, η, of pure liquids and liquid mixtures were determined using a Ubbelohde suspended-level viscometer. The viscometer was suspended in a thermostated water bath maintained to ±0.01 °C. Four sets of readings for the flow times were taken using a Racer stopwatch that can register time to

Table 3. Parameters of Eq 2 for the Mathematical Representation of V_m^E/cm³ ·mol⁻¹ for Alkoxyethanols (1) + Aromatic Hydrocarbons (2) and + Cyclohexane (2) at T = (298.15 to 313.15) K

T/K	a_0	a_1	a_2	σ/cm³·mol⁻¹	a_0	a_1	a_2	σ/cm³·mol⁻¹	a_0	a_1	a_2	σ/cm³·mol⁻¹
	Methoxyethanol (1) + Benzene (2)				Methoxyethanol (1) + Toluene (2)				Methoxyethanol (1) + *o*-Xylene (2)			
298.15	0.548	−1.083	−0.187	0.001	0.608	−0.526	0.041	0.001	1.333	−1.192	0.406	0.001
303.15	0.697	−0.829	0.381	0.001	0.738	−0.621	0.191	0.001	1.511	−1.401	1.000	0.001
308.15	0.809	−0.970	0.439	0.001	0.844	−0.719	0.223	0.001	1.771	−1.326	0.857	0.001
313.15	0.994	−0.837	0.526	0.001	1.079	−0.525	0.184	0.001	2.034	−1.049	1.097	0.001
	Methoxyethanol (1) + *m*-Xylene (2)				Methoxyethanol (1) + *p*-Xylene (2)				Methoxyethanol (1) + Ethylbenzene (2)			
298.15	1.098	−1.178	0.861	0.001	0.899	−1.269	0.201	0.001	1.007	−1.024	0.797	0.001
303.15	1.252	−1.483	1.090	0.001	0.982	−1.301	0.190	0.001	1.125	−1.232	0.914	0.001
308.15	1.424	−1.618	1.453	0.001	1.199	−1.193	0.264	0.001	1.328	−1.363	1.067	0.001
313.15	1.692	−1.541	1.362	0.001	1.349	−1.221	0.251	0.001	1.533	−1.302	0.946	0.001
	Methoxyethanol (1) + Cyclohexane (2)				Ethoxyethanol (1) + Benzene (2)				Ethoxyethanol (1) + Toluene (2)			
298.15	3.576	0.902	2.249	0.001	0.504	−1.573	0.454	0.001	0.289	−1.082	0.766	0.001
303.15	3.798	0.912	2.027	0.001	−0.030	−1.423	0.706	0.001	0.440	−1.417	0.462	0.001
308.15	4.060	0.715	2.517	0.001	−0.280	−1.347	0.697	0.001	0.538	−1.559	0.492	0.001
313.15	4.213	0.461	3.318	0.001	−0.542	−1.272	0.681	0.001	0.603	−1.751	0.549	0.001
	Ethoxyethanol (1) + *o*-Xylene (2)				Ethoxyethanol (1) + *m*-Xylene (2)				Ethoxyethanol (1) + *p*-Xylene (2)			
298.15	0.997	−2.001	0.390	0.001	0.596	−1.677	0.468	0.001	0.525	−1.765	−0.295	0.001
303.15	1.287	−1.836	0.936	0.001	0.968	−1.964	0.650	0.001	0.677	−1.650	−0.242	0.001
308.15	1.433	−1.706	1.022	0.001	1.172	−1.838	1.336	0.001	0.713	−1.718	0.131	0.001
313.15	1.519	−1.810	1.091	0.001	1.411	−1.802	1.298	0.001	0.788	−1.783	0.368	0.001
	Ethoxyethanol (1) + Ethylbenzene (2)				Ethoxyethanol (1) + Cyclohexane (2)				Butoxyethanol (1) + Benzene (2)			
298.15	0.683	−1.470	0.424	0.001	3.170	−2.211	−0.379	0.001	0.305	−1.463	0.778	0.001
303.15	0.862	−1.667	0.394	0.001	3.255	−2.371	0.167	0.001	0.373	−1.495	0.768	0.001
308.15	0.946	−1.839	0.405	0.001	3.388	−2.029	1.466	0.001	0.527	−1.458	0.596	0.001
313.15	1.096	−1.836	0.354	0.001	3.511	−2.051	1.483	0.001	0.611	−1.533	0.576	0.001
	Butoxyethanol (1) + Toluene (2)				Butoxyethanol (1) + *o*-Xylene (2)				Butoxyethanol (1) + *m*-Xylene (2)			
298.15	−0.069	−1.031	0.854	0.001	0.388	−2.116	1.487	0.001	0.102	1.487	0.667	0.001
303.15	0.032	−1.077	0.840	0.001	0.678	−2.096	1.026	0.001	0.387	−1.719	0.691	0.001
308.15	0.412	−1.161	0.091	0.001	0.789	−2.124	1.219	0.001	0.506	−1.993	1.047	0.001
313.15	0.558	−1.155	0.348	0.001	1.089	−2.202	1.210	0.001	0.862	−2.021	0.588	0.001
	Butoxyethanol (1) + *p*-Xylene (2)				Butoxyethanol (1) + Ethylbenzene (2)				Butoxyethanol (1) + Cyclohexane (2)			
298.15	−0.055	−1.333	0.635	0.001	0.183	−1.197	0.605	0.001	2.481	−1.553	0.191	0.001
303.15	0.064	−1.385	0.555	0.001	0.313	−1.261	0.868	0.001	2.436	−1.906	1.056	0.001
308.15	0.225	−1.431	0.586	0.001	0.599	−1.442	0.486	0.001	2.944	−1.232	0.306	0.001
313.15	0.746	−1.269	0.098	0.001	0.740	−1.626	0.447	0.001	3.067	−1.295	2.436	0.001

Table 4. Comparison of Excess Molar Volumes at Equimolar Composition $(V_m^E)_{x=0.5}$ with Literature Values for Alkoxyethanols + Aromatic Hydrocarbons and + Cyclohexane

	$(V_m^E)_{x=0.5}$/cm³·mol⁻¹							
	T = 298.15 K		T = 303.15 K		T = 308.15 K		T = 313.15 K	
	present study	lit.	present study	lit.	present study	lit.	present study	lit.
methoxyethanol +								
benzene	0.137		0.174	0.174[15]	0.202		0.249	
toluene	0.152	0.1509[46]	0.185	0.185[15]	0.211		0.270	
o-xylene	0.333		0.378		0.443		0.509	
m-xylene	0.275		0.313		0.356		0.423	
p-xylene	0.225		0.246		0.300		0.337	
ethylbenzene	0.252		0.281		0.332		0.383	
cyclohexane	0.894	0.9099[19]	0.950	0.9510[19]	1.015		1.053	
ethoxyethanol +								
benzene	0.126		−0.008	−0.0073[14]	−0.070		−0.136	−0.1356[14]
toluene	0.082	0.0823[46]	0.110		0.135		0.151	
o-xylene	0.249		0.322		0.358		0.380	
m-xylene	0.149		0.242		0.293		0.353	
p-xylene	0.131		0.170		0.178		0.197	
ethylbenzene	0.171		0.216		0.237		0.274	
cyclohexane	0.793	0.795[12]	0.814	0.815[12]	0.847	0.844[12]	0.878	0.878[12]
butoxyethanol +								
benzene	0.076		0.093		0.132		0.153	
toluene	−0.017	−0.0056[46]	0.008		0.103		0.140	
o-xylene	0.097		0.170		0.197		0.272	
m-xylene	0.026		0.097		0.127		0.216	
p-xylene	−0.014		0.016		0.056		0.187	
ethylbenzene	0.046		0.078		0.150		0.185	
cyclohexane	0.620		0.609		0.726		0.767	

±0.1 s, and the arithmetic mean was taken for the calculation of the viscosity. The estimated accuracy and precision in viscosity measurements were found to be ±0.002 and ±0.001 mPa·s, respectively. The speeds of

sound, v, were measured using an ultrasonic interferometer (Mittal Enterprises, New Delhi, India) operating at a fixed frequency of 2 MHz. The measured speeds of sound have a precision of ±0.8 m·s^{-1} and an accuracy better than ±1.9 m·s^{-1}. The relative permittivities of the individual pure components and binary mixtures were calculated from the capacitance measurements with an universal dielectrometer, type OH-301 of Radelkis, Hungary. The procedure used in the calibration of dielectric cells was the same as that described in detail elsewhere.[18] The measured relative permittivities have an estimated precision and accuracy of ±0.001 and ±0.004, respectively. The desired temperatures accurate to ±0.01 °C during the v and ϵ_r measurements were maintained using an INSREF, India, circulator (model 020A).

Results and Discussion

Densities, ρ, and Excess Molar Volumes, V_m^E. The experimental data on ρ at T = (298.15, 303.15, 308.15, and 313.15) K for the 21 mixtures of methoxyethanol, ethoxyethanol, and butoxyethanol + benzene, + toluene, + *o*-xylene, + *m*-xylene, + *p*-xylene, + ethylbenzene, and + cyclohexane are listed in Table 2. The V_m^E values were calculated using the relation

$$V_m^E/\mathrm{cm}^3\cdot\mathrm{mol}^{-1} = \frac{x_1M_1 + x_2M_2}{\rho_{12}} - \left\{\frac{x_1M_1}{\rho_1} + \frac{x_2M_2}{\rho_2}\right\} \quad (1)$$

The compositional variation of V_m^E was mathematically represented through the equation of the type

$$A^E = x_1(1 - x_1)\sum_{i=0}^{i=n} a_i(2x_1 - 1)^i \quad (2)$$

where $A^E = V_m^E$ and a_i are the fitting coefficients and x_1 is the alkoxyethanol mole fraction. The values of a_i were estimated by a least-squares method using multiple regression analysis. The summary of a_i and σ, the standard deviations between experimental and fitted V_m^E values, is given in Table 3. The graphical variation of V_m^E as a function of mole fraction of the alkoxyethanols for the binary systems of methoxyethanol, ethoxyethanol, and butoxyethanol + aromatic hydrocarbons and + cyclohexane at T = 298.15 K is shown in Figure 1. The V_m^E profiles of alkoxyethanols + aromatic hydrocarbons are characterized by initial positive values followed by small but negative values in the alkoxyethanol rich compositions. The binary mixtures containing cyclohexane as one of the components have, however, been characterized by large and positive values across the mole composition. The comparison of V_m^E values of the mixtures containing different alkoxyethanols + aromatic hydrocarbons and + cyclohexane showed that the positive magnitudes decreased on one hand and while the negative magnitudes increased on the other from methoxyethanol to butoxyethanol containing mixtures. The rise in the temperature from 298.15 to 313.15 K has always increased the overall magnitude of V_m^E values with an exception in ethoxyethanol + benzene mixtures. A comparison of our calculated equimolar V_m^E values with the literature data is presented in Table 4, and we noticed a close agreement of our data with the literature values.

The recent detailed ab initio calculations and a few matrix isolation infrared spectroscopy measurements have revealed that alkoxyethanol molecules in their pure monomeric (gas phase) state prefer the formation of five membered rings through CH···O and/or O···H−O contacts between the methylene hydrogen and etheric oxygens or/and between the etheric oxygen and the hydrogen of the hydroxyl group of the same molecule.[8−11,19] The binary systems of 1-alcohols + cyclohexane[20] exhibited large and positive volume expansions, and it has been reported that the heteroassociated structures of 1-alcohols were ruptured in the presence of cyclohexane. The molecular skeletons of methoxy-, ethoxy-, and butoxyethanols can be made structurally equivalent to 1-butanol, 1-pentanol, and 1-heptanol

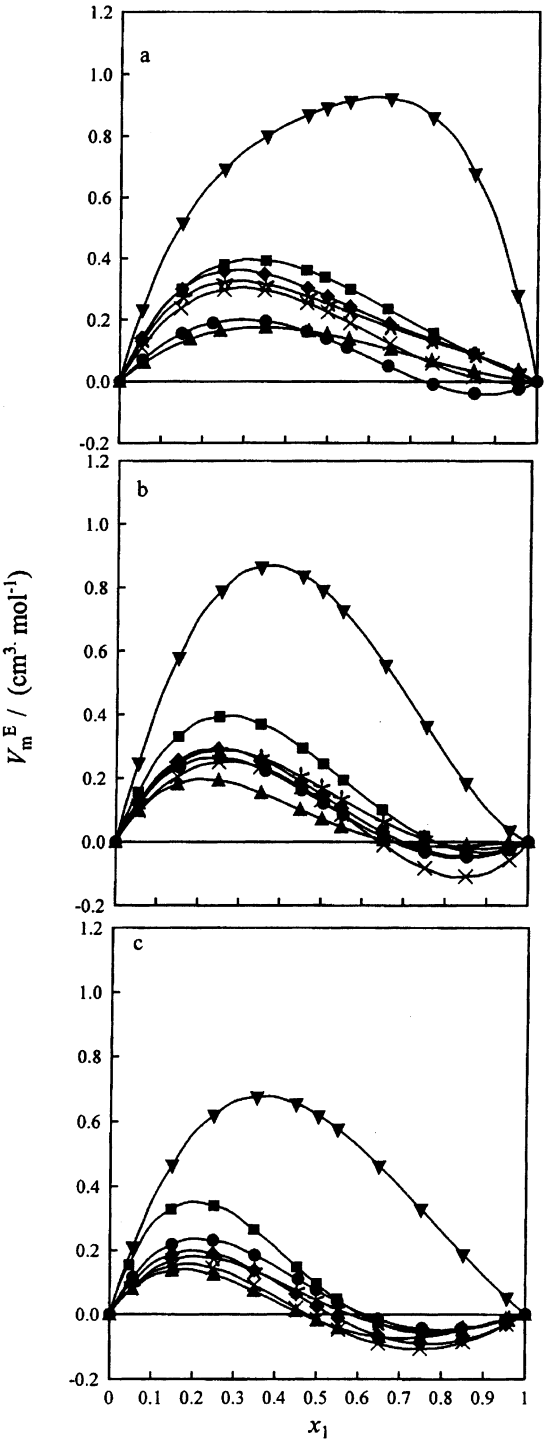

Figure 1. Variation of excess molar volumes, V_m^E, with alkoxyethanol mole fraction for the binary mixtures of methoxyethanol (a), ethoxyethanol (b), and butoxyethanol (c) + aromatic hydrocarbons and + cyclohexane at 298.15 K: ●, benzene; ▲, toluene; ■, *o*-xylene; ◆, *m*-xylene; ×, *p*-xylene; ∗, ethylbenzene; ▼, cyclohexene. Solid lines are fitted values calculated using coefficients from Table 3 and eq 2.

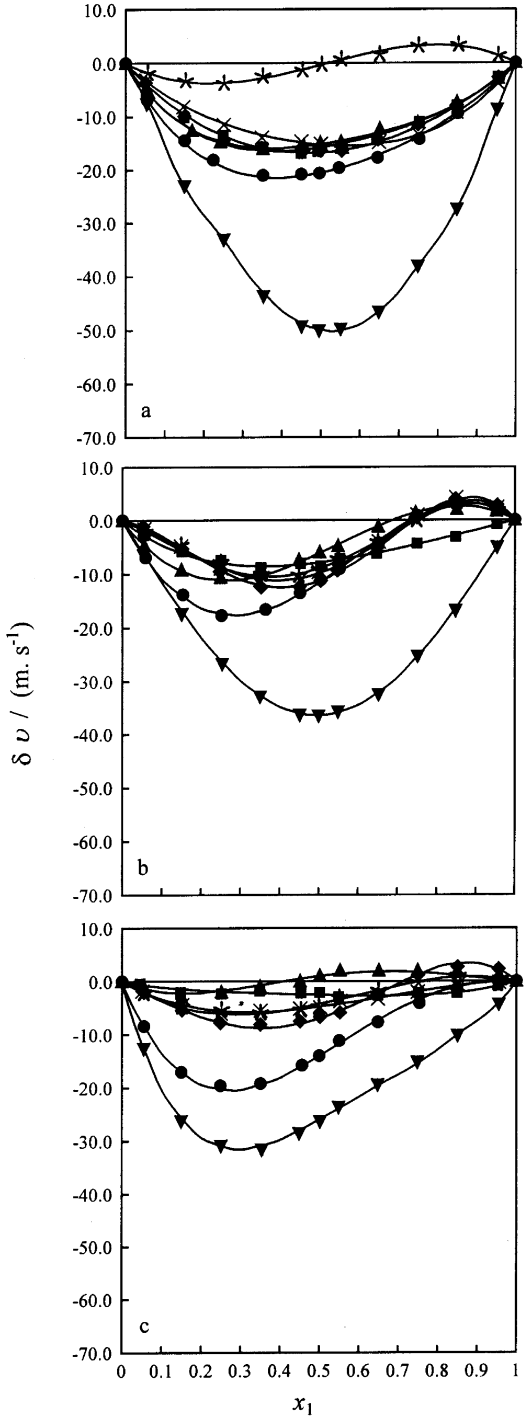

Figure 2. Variation of deviation in speeds of found, δv, with alkoxyethanol mole fraction for the binary mixtures of methoxyethanol (a), ethoxyethanol (b), and butoxyethanol (c) + aromatic hydrocarbons and + cyclohexane at 298.15 K. (The symbols are the same as those in Figure 1.) Solid lines are fitted values calculated using coefficients from Table 6 and eq 2.

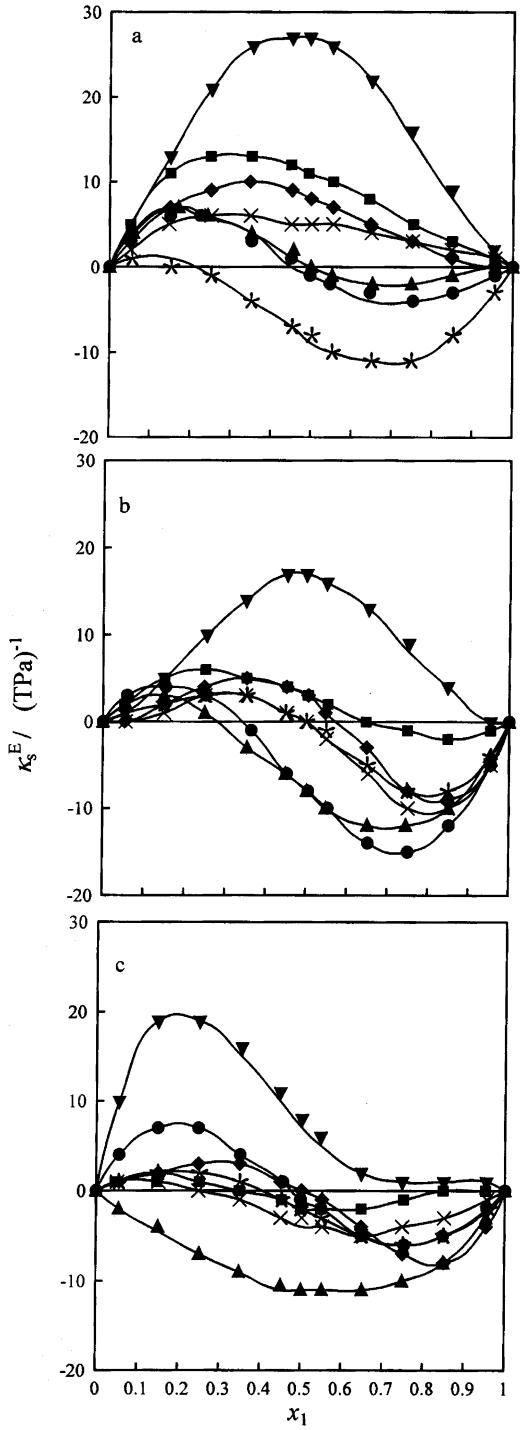

Figure 3. Variation of excess isentropic compressibilities, κ_s^E, with alkoxyethanol mole fraction for the binary mixtures of methoxyethanol (a), ethoxyethanol (b), and butoxyethanol (c) + aromatic hydrocarbons and + cyclohexane at 298.15 K. (The symbols are the same as those in Figure 1.) Solid lines are fitted values calculated using coefficients from Table 6 and eq 2.

(the difference being the presence of an −O− group in the place of $-CH_2-$). Our equimolar V_m^E values of 0.950, 0.814, and 0.609 for cyclohexane + methoxy-, + ethoxy-, and + butoxyethanols at $T = 303.15$ K are interestingly found to be smaller than 1.5355, 1.4668, and 1.3912 for cyclohexane + 1-butanol, + pentanol, and + 1-heptanol mixtures at the same temperature.[21] Thus, we attribute the observed positive V_m^E values of alkoxyethanols + cyclohexane mixtures to the disruptions in the self-associated structures of the former. The smaller V_m^E values for alkoxyethanols + cyclohexane vis-à-vis those of 1-alcohols + cyclohexane indicate that the self-associate ring structures in the alkoxyethanols resist the structure disruption. The observed less positive or even negative V_m^E values for the alkoxyethanols + aromatic hydrocarbons in general indicate that, besides structure disruptions, weak interactions between the π electrons of the aromatic ring system and the etheric oxygen as well as the −OH group of the respective alkoxyethanols also exist. The presence of one

Table 5. Dynamic Viscosities, η, Speeds of Sound, v, and Relative Permittivities, ϵ_r, for Alkoxyethanols (1) + Aromatic Hydrocarbons (2) and + Cyclohexane (2) at T = (298.15 and 308.15) K

	η/mPa·s		v/m·s^{-1}		ϵ_r			η/mPa·s		v/m·s^{-1}		ϵ_r	
x_1	298.15 K	308.15 K	298.15 K	308.15 K	298.15 K	308.15 K	x_1	298.15 K	308.15 K	298.15 K	308.15 K	298.15 K	308.15 K
2-Methoxyethanol (1) + Benzene (2)							2-Methoxyethanol (1) + Toluene (2)						
0.0543	0.624	0.541	1294	1258	2.652	2.674	0.0586	0.571	0.512	1300	1261	2.824	2.735
0.1499	0.669	0.571	1290	1256	3.308	3.462	0.1696	0.617	0.545	1296	1260	3.570	3.524
0.2235	0.708	0.598	1289	1256	3.886	4.153	0.2421	0.654	0.571	1296	1260	4.136	4.164
0.3508	0.788	0.654	1291	1258	5.216	5.604	0.3513	0.719	0.618	1298	1261	5.241	5.356
0.4496	0.862	0.707	1295	1263	6.614	6.983	0.4555	0.796	0.674	1302	1265	6.658	6.766
0.4961	0.902	0.735	1297	1265	7.389	7.703	0.4987	0.833	0.700	1304	1266	7.356	7.426
0.5462	0.947	0.768	1300	1269	8.296	8.534	0.5515	0.882	0.736	1306	1269	8.289	8.285
0.6455	1.049	0.842	1306	1277	10.290	10.292	0.6515	0.990	0.814	1312	1277	10.265	10.045
0.7524	1.180	0.938	1314	1289	12.584	12.265	0.7487	1.118	0.905	1317	1287	12.338	11.858
0.8509	1.323	1.043	1323	1302	14.633	14.028	0.8495	1.279	1.021	1325	1300	14.466	13.736
0.9558	1.505	1.177	1334	1319	16.448	15.661	0.9558	1.490	1.170	1334	1317	16.392	15.556
2-Methoxyethanol (1) + *o*-Xylene (2)							2-Methoxyethanol (1) + *m*-Xylene (2)						
0.0517	0.769	0.666	1342	1314	2.864	2.821	0.0519	0.598	0.513	1317	1279	2.702	2.269
0.1491	0.795	0.686	1337	1303	3.544	3.466	0.1498	0.635	0.543	1312	1275	3.366	3.197
0.2491	0.830	0.714	1333	1298	4.393	4.276	0.2504	0.681	0.580	1309	1273	4.183	3.910
0.3509	0.877	0.749	1330	1295	5.440	5.262	0.3476	0.737	0.624	1309	1273	5.179	4.852
0.4485	0.934	0.790	1328	1295	6.633	6.373	0.4520	0.810	0.680	1310	1275	6.526	6.219
0.4919	0.963	0.811	1328	1295	7.227	6.922	0.4991	0.848	0.709	1311	1277	7.233	6.960
0.5537	1.009	0.845	1328	1295	8.140	7.764	0.5538	0.897	0.746	1312	1279	8.120	7.910
0.6432	1.088	0.901	1329	1297	9.606	9.114	0.6476	0.996	0.819	1316	1285	9.827	9.721
0.7525	1.206	0.983	1331	1301	11.618	10.985	0.7504	1.127	0.915	1321	1293	11.881	11.852
0.8492	1.334	1.070	1333	1308	13.595	12.858	0.8491	1.282	1.026	1327	1304	13.950	13.852
0.9547	1.506	1.185	1337	1320	15.944	15.150	0.9558	1.491	1.172	1335	1320	16.152	15.663
2-Methoxyethanol (1) + *p*-Xylene (2)							2-Methoxyethanol (1) + Ethylbenzene (2)						
0.0528	0.626	0.549	1306	1273	2.625	2.424	0.0558	0.650	0.548	1317	1273	2.731	2.610
0.1469	0.654	0.570	1303	1270	3.246	3.032	0.1525	0.679	0.577	1317	1269	3.305	3.195
0.2507	0.696	0.601	1302	1268	4.034	3.881	0.2511	0.717	0.612	1318	1269	3.988	3.966
0.3484	0.746	0.639	1302	1269	4.989	4.908	0.3504	0.766	0.655	1321	1269	4.902	4.977
0.4499	0.812	0.688	1304	1270	6.267	6.240	0.4525	0.831	0.708	1324	1271	6.168	6.292
0.4999	0.850	0.716	1305	1272	7.012	6.997	0.5021	0.869	0.738	1326	1273	6.914	7.030
0.5542	0.897	0.750	1306	1273	7.909	7.886	0.5522	0.911	0.771	1328	1274	7.750	7.839
0.6493	0.994	0.820	1310	1278	9.671	9.588	0.6499	1.008	0.844	1331	1279	9.602	9.568
0.7508	1.122	0.913	1315	1285	11.766	11.547	0.7500	1.131	0.933	1335	1286	11.726	11.491
0.8478	1.274	1.021	1323	1297	13.868	13.458	0.8530	1.291	1.043	1338	1298	13.833	13.520
0.9556	1.488	1.170	1333	1317	16.146	15.469	0.9546	1.488	1.175	1339	1317	16.153	15.436
2-Methoxyethanol (1) + Cyclohexane (2)							2-Ethoxyethanol (1) + Benzene (2)						
0.0540	0.905	0.750	1249	1205	2.283	2.175	0.0585	0.632	0.548	1292	1258	2.698	2.546
0.1506	0.923	0.757	1240	1194	2.785	2.800	0.1533	0.686	0.587	1285	1255	3.362	3.173
0.2513	0.950	0.773	1237	1195	3.664	3.819	0.2518	0.752	0.635	1281	1252	4.115	4.011
0.3532	0.989	0.797	1234	1196	4.679	4.965	0.3637	0.841	0.700	1282	1250	5.148	5.168
0.4508	1.037	0.829	1236	1200	5.900	6.219	0.4521	0.923	0.760	1285	1250	6.132	6.206
0.4955	1.062	0.847	1239	1203	6.543	6.844	0.5048	0.979	0.800	1287	1250	6.789	6.862
0.5513	1.098	0.873	1244	1207	7.424	7.664	0.5525	1.034	0.839	1289	1251	7.426	7.467
0.6490	1.172	0.926	1256	1218	9.166	9.215	0.6521	1.164	0.931	1294	1254	8.847	8.756
0.7493	1.264	0.994	1274	1236	11.196	10.967	0.7508	1.317	1.039	1299	1257	10.305	9.983
0.8496	1.377	1.079	1295	1250	13.480	12.818	0.8521	1.505	1.170	1301	1261	11.713	11.105
0.9529	1.518	1.185	1325	1303	15.872	15.118	0.9547	1.734	1.328	1300	1265	12.862	11.931
2-Ethoxyethanol (1) + Toluene (2)							2-Ethoxyethanol (1) + *o*-Xylene (2)						
0.0560	0.576	0.517	1299	1258	2.840	2.820	0.0533	0.777	0.674	1343	1315	2.862	2.826
0.1494	0.627	0.554	1294	1255	3.553	3.556	0.1508	0.817	0.708	1336	1304	3.468	3.378
0.2493	0.690	0.601	1292	1253	4.374	4.404	0.2502	0.867	0.750	1330	1294	4.187	3.981
0.3539	0.771	0.660	1292	1254	5.358	5.373	0.3516	0.931	0.800	1324	1286	5.082	4.774
0.4490	0.859	0.723	1294	1256	6.390	6.344	0.4528	1.009	0.858	1320	1281	6.154	5.672
0.5019	0.915	0.763	1295	1257	7.019	6.918	0.5042	1.056	0.892	1317	1278	6.765	6.228
0.5488	0.969	0.802	1296	1258	7.609	7.445	0.5530	1.104	0.926	1316	1277	7.383	6.703
0.6514	1.107	0.899	1299	1260	8.972	8.637	0.6472	1.211	1.001	1312	1274	8.549	7.914
0.7465	1.261	1.007	1301	1262	10.275	9.751	0.7494	1.353	1.096	1308	1272	10.100	9.224
0.8514	1.468	1.149	1301	1263	11.655	10.920	0.8486	1.520	1.204	1304	1270	11.471	10.505
0.9527	1.716	1.317	1300	1265	12.795	11.896	0.9540	1.739	1.340	1300	1268	12.756	11.794
2-Ethoxyethanol (1) + *m*-Xylene (2)							2-Ethoxyethanol (1) + *p*-Xylene (2)						
0.0531	0.608	0.521	1318	1279	2.701	2.602	0.0551	0.632	0.555	1306	1270	2.590	2.570
0.1513	0.663	0.566	1312	1273	3.335	3.205	0.1489	0.672	0.584	1302	1268	3.125	3.244
0.2482	0.727	0.618	1306	1268	4.040	3.904	0.2499	0.725	0.625	1297	1258	3.781	3.950
0.3528	0.809	0.682	1301	1265	4.967	4.795	0.3507	0.792	0.674	1294	1256	4.610	4.730
0.4512	0.900	0.752	1299	1265	6.027	5.768	0.4514	0.875	0.735	1293	1257	5.656	5.646
0.5053	0.957	0.795	1299	1265	6.686	6.356	0.5001	0.922	0.769	1294	1258	6.245	6.146
0.5473	1.006	0.831	1300	1266	7.233	6.834	0.5497	0.975	0.808	1295	1259	6.894	6.695
0.6494	1.140	0.928	1302	1268	8.658	8.064	0.6526	1.106	0.900	1298	1261	8.373	7.944
0.7510	1.300	1.040	1305	1270	10.143	9.371	0.7513	1.262	1.010	1302	1263	9.889	9.241
0.8492	1.487	1.168	1306	1270	11.529	10.569	0.8499	1.456	1.143	1304	1265	11.377	10.542
0.9554	1.731	1.330	1302	1268	12.804	11.804	0.9549	1.717	1.319	1301	1266	12.752	11.808

Table 5. (Continued)

	η/mPa·s		v/m·s^{-1}		ϵ_r			η/mPa·s		v/m·s^{-1}		ϵ_r	
x_1	298.15 K	308.15 K	298.15 K	308.15 K	298.15 K	308.15 K	x_1	298.15 K	308.15 K	298.15 K	308.15 K	298.15 K	308.15 K
	2-Ethoxyethanol (1) + Ethylbenzene (2)							2-Ethoxyethanol (1) + Cyclohexane (2)					
0.0573	0.658	0.557	1315	1272	2.778	2.713	0.0542	0.903	0.755	1249	1204	2.341	2.251
0.1487	0.696	0.597	1311	1267	3.288	3.292	0.1507	0.920	0.775	1242	1195	3.016	2.943
0.2498	0.749	0.648	1306	1265	3.839	3.955	0.2541	0.952	0.805	1237	1191	3.829	3.758
0.3527	0.817	0.708	1302	1264	4.558	4.739	0.3508	0.996	0.841	1235	1193	4.695	4.596
0.4489	0.895	0.773	1300	1264	5.467	5.619	0.4520	1.057	0.888	1236	1198	5.725	5.557
0.4998	0.944	0.812	1300	1264	6.053	6.149	0.5000	1.093	0.915	1238	1202	6.258	6.046
0.5485	0.995	0.852	1301	1264	6.682	6.695	0.5497	1.135	0.945	1241	1206	6.840	6.572
0.6501	1.121	0.945	1302	1264	8.174	7.944	0.6534	1.240	1.019	1249	1217	8.155	7.742
0.7484	1.273	1.050	1304	1264	9.763	9.242	0.7527	1.368	1.105	1260	1229	9.517	8.945
0.8508	1.469	1.178	1305	1264	11.399	10.591	0.8492	1.524	1.206	1274	1242	10.925	10.193
0.9547	1.721	1.331	1301	1265	12.784	11.822	0.9552	1.741	1.341	1294	1259	12.532	11.638
	2-Butoxyethanol (1) + Benzene (2)							2-Butoxyethanol (1) + Toluene (2)					
0.0553	0.648	0.562	1291	1255	2.887	2.764	0.0550	0.593	0.531	1303	1261	2.977	2.817
0.1496	0.736	0.631	1283	1250	3.844	3.575	0.1509	0.678	0.597	1301	1260	3.879	3.536
0.2488	0.845	0.717	1281	1249	4.746	4.350	0.2513	0.784	0.679	1302	1261	4.730	4.242
0.3504	0.978	0.821	1282	1250	5.579	5.074	0.3489	0.909	0.775	1303	1262	5.497	4.887
0.4555	1.144	0.949	1286	1254	6.360	5.757	0.4511	1.066	0.896	1304	1264	6.256	5.527
0.4995	1.223	1.011	1288	1256	6.666	6.025	0.5015	1.156	0.965	1305	1265	6.618	5.830
0.5504	1.323	1.088	1291	1258	7.006	6.323	0.5525	1.257	1.042	1306	1267	6.974	6.128
0.6482	1.543	1.258	1295	1262	7.622	6.857	0.6512	1.483	1.215	1306	1270	7.639	6.682
0.7535	1.830	1.479	1299	1268	8.231	7.378	0.7494	1.759	1.425	1306	1273	8.255	7.200
0.8483	2.143	1.718	1302	1273	8.735	7.795	0.8498	2.105	1.689	1306	1277	8.815	7.695
0.9556	2.575	2.048	1304	1281	9.251	8.205	0.9541	2.551	2.030	1305	1282	9.287	8.763
	2-Butoxyethanol (1) + *o*-Xylene (2)							2-Butoxyethanol (1) + *m*-Xylene (2)					
0.0549	0.797	0.686	1345	1314	2.838	2.852	0.0560	0.625	0.534	1317	1279	2.670	2.618
0.1475	0.891	0.756	1339	1303	3.513	3.387	0.1520	0.711	0.602	1312	1275	3.248	3.181
0.2508	1.004	0.840	1334	1295	4.248	3.995	0.2496	0.813	0.686	1308	1272	3.875	3.776
0.3485	1.129	0.933	1330	1291	4.975	4.572	0.3506	0.941	0.786	1306	1270	4.553	4.400
0.4527	1.286	1.052	1325	1288	5.769	5.186	0.4512	1.095	0.908	1305	1270	5.248	5.014
0.5000	1.366	1.113	1323	1287	6.131	5.463	0.5022	1.185	0.979	1305	1270	5.606	5.320
0.5489	1.457	1.182	1320	1286	6.504	5.749	0.5529	1.284	1.056	1305	1270	5.965	5.622
0.6483	1.666	1.341	1316	1278	7.248	6.327	0.6487	1.501	1.225	1307	1271	6.653	6.186
0.7518	1.925	1.540	1312	1282	7.985	6.924	0.7505	1.781	1.442	1309	1273	7.407	6.782
0.8493	2.216	1.765	1308	1281	8.622	7.484	0.8511	2.122	1.704	1309	1277	8.186	7.385
0.9524	2.586	2.053	1305	1283	9.211	8.077	0.9549	2.560	2.037	1307	1282	9.048	8.046
	2-Butoxyethanol (1) + *p*-Xylene (2)							2-Butoxyethanol (1) + Ethylbenzene (2)					
0.0541	0.647	0.566	1306	1273	2.588	2.515	0.0546	0.678	0.568	1315	1274	2.659	2.616
0.1518	0.725	0.625	1303	1268	3.246	3.207	0.1505	0.769	0.643	1311	1272	3.289	3.166
0.2496	0.817	0.695	1301	1266	3.922	3.868	0.2513	0.877	0.732	1309	1270	3.977	3.780
0.3502	0.933	0.784	1301	1265	4.661	4.525	0.3501	1.003	0.835	1307	1270	4.671	4.391
0.4510	1.076	0.894	1301	1265	5.439	5.165	0.4528	1.161	0.961	1306	1271	5.391	5.020
0.5028	1.162	0.961	1301	1266	5.850	5.489	0.4982	1.240	1.025	1306	1271	5.706	5.293
0.5533	1.256	1.033	1302	1266	6.256	5.801	0.5500	1.339	1.103	1307	1272	6.064	5.602
0.6489	1.465	1.194	1302	1268	7.025	6.380	0.6497	1.560	1.277	1307	1274	6.747	6.190
0.7493	1.739	1.404	1303	1272	7.813	6.975	0.7511	1.831	1.487	1307	1276	7.454	6.783
0.8519	2.092	1.676	1304	1276	8.561	7.561	0.8507	2.156	1.736	1307	1279	8.186	7.379
0.9561	2.551	2.029	1304	1282	9.215	8.125	0.9614	2.601	2.071	1305	1283	9.095	8.087
	2-Butoxyethanol (1) + Cyclohexane (2)												
0.0557	0.950	0.790	1244	1206	2.372	2.238							
0.1501	1.046	0.866	1236	1202	3.018	2.869							
0.2504	1.162	0.958	1237	1202	3.704	3.556							
0.3543	1.300	1.066	1242	1206	4.419	4.260							
0.4488	1.443	1.178	1250	1212	5.080	4.885							
0.5025	1.532	1.248	1255	1216	5.461	5.228							
0.5493	1.616	1.313	1260	1220	5.799	5.521							
0.6485	1.813	1.465	1269	1229	6.534	6.127							
0.7494	2.043	1.642	1278	1241	7.313	6.733							
0.8511	2.311	1.848	1287	1255	8.140	7.354							
0.9556	2.631	2.091	1298	1275	9.043	8.037							

or two $-CH_3$ groups and the CH_3-CH_2- group on the aromatic ring system affects the balance between the above-mentioned opposing effects due to steric hindrance.

Dynamic Viscosities, η. The experimentally measured η values for the 21 mixtures at T = (298.15 and 308.15) K are listed in Table 5. The one parameter Grunberg−Nissan

Table 6. Parameters of Eq 2 for the Mathematical Representation of Various Excess and Deviation Functions for Alkoxyethanols (1) + Aromatic Hydrocarbons (2) and + Cyclohexane (2) at T = (298.15 and 308.15) K

	T = 298.15 K				T = 308.15 K				T = 298.15 K				T = 308.15 K			
	a_0	a_1	a_2	σ	a_0	a_1	a_2	σ	a_0	a_1	a_2	σ	a_0	a_1	a_2	σ
	Methoxyethanol (1) + Benzene (2)								Methoxyethanol (1) + Toluene (2)							
δv/m·s^{-1}	−81.9	31.0	−25.3	0.4	−104.3	−12.1	−14.6	0.5	−60.3	21.1	−30.2	0.4	−91.1	−41.4	−28.0	0.3
κ_s^E/TPa^{-1}	−5	−39	47	1.0	12	1	11	0.1	0.4	−34	35	0.5	31	18	14	0.9
$\delta\epsilon_r$	−6.962	5.652	6.966	0.001	−4.106	4.429	4.017	0.001	−4.995	5.248	7.054	0.001	−3.254	4.486	3.329	0.001
	Methoxyethanol (1) + *o*-Xylene (2)								Methoxyethanol (1) + *m*-Xylene (2)							
δv/m·s^{-1}	−62.9	21.9	−25.8	0.4	−118.0	−0.0	−65.6	0.4	−66.7	8.9	−3.7	0.4	−94.3	−5.9	−24.3	0.3
κ_s^E/TPa^{-1}	45	−36	18	1.0	106	−18	55	0.6	31	−28	14	0.8	61	−19	7	0.5
$\delta\epsilon_r$	−3.700	0.947	0.980	0.001	−3.623	0.227	0.192	0.001	−3.375	3.342	3.975	0.002	−3.052	6.600	7.289	0.001
	Methoxyethanol (1) + *p*-Xylene (2)								Methoxyethanol (1) + Ethylbenzene (2)							
δv /m·s^{-1}	−60.9	−11.5	−18.6	0.4	−99.1	−44.3	−45.4	0.4	−1.4	36.6	1.2	0.3	−96.3	−40.9	−46.5	0.4
κ_s^E/TPa^{-1}	18	−14	13	0.7	60	9	29	0.7	35	−50	14	0.5	60	2	39	0.6
$\delta\epsilon_r$	−4.017	3.307	4.979	0.001	−2.438	4.640	3.778	0.001	−4.950	3.396	5.767	0.001	−3.022	4.469	3.636	0.002
	Methoxyethanol (1) + Cyclohexane (2)								Ethoxyethanol (1) + Benzene (2)							
δv/m·s^{-1}	−199.6	−26.1	41.1	0.3	−230.7	79.0	99.3	0.4	−46.4	94.8	7.2	0.3	−51.7	12.7	25.4	0.3
κ_s^E/TPa^{-1}	108	−22	−59	1.6	146	−7	87	1.3	−32	−94	2	0.1	−28	5	−28	0.1
$\delta\epsilon_r$	−6.845	1.251	2.129	0.001	−4.041	0.756	−1.257	0.001	−5.007	3.866	4.577	0.001	−2.547	4.830	0.701	0.001
	Ethoxyethanol (1) + Toluene (2)								Ethoxyethanol (1) + *o*-Xylene (2)							
δv/m·s^{-1}	−24.6	66.9	−3.1	0.3	−27.8	32.3	−23.7	0.3	−31.5	18.4	−6.4	0.4	−74.6	32.0	17.4	0.4
κ_s^E/TPa^{-1}	−33	−71	10	0.1	−25	−44	28	0.4	13	−35	−2	0.5	62	−41	−25	0.1
$\delta\epsilon_r$	−2.268	2.906	3.216	0.001	−0.769	2.393	2.073	0.001	−2.437	3.348	3.139	0.001	−2.817	2.236	2.971	0.001
	Ethoxyethanol (1) + *m*-Xylene (2)								Ethoxyethanol (1) + *p*-Xylene (2)							
δv/m·s^{-1}	−44.8	50.0	81.4	0.3	−41.6	53.7	31.2	0.3	−39.4	47.4	65.6	0.5	−55.3	55.9	−12.4	0.2
κ_s^E/TPa^{-1}	12	−63	−85	0.1	15	−60	−38	0.5	−1	64	−70	0.1	25	−68	15	0.4
$\delta\epsilon_r$	−2.121	3.739	3.879	0.001	−1.603	2.592	1.705	0.001	−3.375	3.581	4.461	0.001	−1.740	1.341	3.882	0.001
	Ethoxyethanol (1) + Ethylbenzene (2)								Ethoxyethanol (1) + Cyclohexane (2)							
δv/m·s^{-1}	−35.7	46.3	50.2	0.4	−30.7	19.1	−26.7	0.2	−145.4	2.7	32.9	0.4	−144.0	56.7	−14.9	0.4
κ_s^E/TPa^{-1}	0	−59	−46	0.4	2	−31	34	0.5	67	−7	−70	0.4	66	−97	29	0.4
$\delta\epsilon_r$	−4.438	3.105	6.953	0.001	−2.234	2.058	3.722	0.001	−4.147	0.441	0.908	0.001	−2.945	0.048	0.345	0.001
	Butoxyethanol (1) + Benzene (2)								Butoxyethanol (1) + Toluene (2)							
δv/m·s^{-1}	−56.0	89.0	−29.9	0.4	−76.9	33.7	−35.4	0.3	4.1	18.4	−17.1	0.4	−37.3	2.7	−15.3	0.4
κ_s^E/TPa^{-1}	−3	−69	22	0.4	20	0	29	0.4	−42	−26	−1	0.1	16	0	−19	0.1
$\delta\epsilon_r$	0.489	−0.177	0.288	0.001	0.590	0.187	0.214	0.001	1.245	0.268	1.098	0.001	0.459	0.088	0.203	0.001
	Butoxyethanol (1) + *o*-Xylene (2)								Butoxyethanol (1) + *m*-Xylene (2)							
δv/m·s^{-1}	−9.9	−3.5	−7.6	0.4	−63.0	27.4	−52.2	0.2	−27.7	47.6	41.3	0.4	−56.5	3.9	−18.0	
κ_s^E/TPa^{-1}	−6	−10	22	0.4	56	−36	57	0.5	1	−56	−46	0.4	40	−8	14	0.1
$\delta\epsilon_r$	−0.052	1.525	0.208	0.001	−0.395	0.086	−0.121	0.001	−1.719	−0.080	−0.593	0.001	−0.484	−0.091	−0.724	0.001
	Butoxyethanol (1) + *p*-Xylene (2)								Butoxyethanol (1) + Ethylbenzene (2)							
δv/m·s^{-1}	−19.0	19.3	−2.6	0.3	−60.7	6.8	−9.0	0.4	−16.9	31.6	1.8	0.4	−36.8	4.6	−12.6	0.4
κ_s^E/TPa^{-1}	−14	−24	14	0.4	39	0	32	0.5	−8	−41	−9	0.1	15	−10	22	0.4
$\delta\epsilon_r$	−0.561	1.631	0.776	0.001	0.570	−0.028	0.262	0.001	−1.251	−0.287	−1.264	0.001	−0.530	−0.054	−0.803	0.001
	Butoxyethanol (1) + Cyclohexane (2)															
δv/m·s^{-1}	−103.7	82.6	−78.8	0.4	−144.5	15.8	−54.6	0.3								
κ_s^E/TPa^{-1}	30	−98	98	0.4	81	−32	82	0.4								
$\delta\epsilon_r$	−2.530	−0.458	−0.060	0.001	−0.842	−0.145	−0.961	0.001								

(GN), two parameter McAllister (Mc), and three parameter Auslander (A) equations were employed to correlate the dynamic and kinematic viscosities, η, ν, and viscosity ratios.

$$\ln \eta_{12} = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 G_{12} \quad (3)$$

$$\ln \nu_{12} = x_1^3 \ln \nu_1 + 3x_1^2 x_2 \ln M_{12} + 3x_1 x_2^2 \ln M_{21} + x_2^3 \ln \nu_2 - \ln\left(x_1 + \frac{x_2 M_2}{M_1}\right) + 3x_1^2 x_2 \ln\left(\frac{2}{3} + \frac{M_2}{3M_1}\right) + 3x_1 x_2^2 \ln\left(\frac{1}{3} + \frac{2M_2}{3M_1}\right) + x_2^3 \ln\left(\frac{M_2}{M_1}\right) \quad (4)$$

$$x_1(x_1 + B_{12}x_2)(\eta_{12} - \eta_1) + A_{21}x_2(B_{21}x_1 + x_2)(\eta_{12} - \eta_2) = 0 \quad (5)$$

These equations are particularly selected because the characteristic constant parameter G_{12} of eq 3 allows for the positive and negative deviations from the additivity rule, eq 4 is based on Eyring theory on absolute reaction rates with a three body model, and eq 5 involves three parameters. The Grunberg−Nissan and McAllister equations correlated the viscosities excellently with maximum σ values of 0.001 mPa·s. However, the application of the Auslander equation has yielded σ values ranging from 0.013 to 0.146.

Speeds of Sound, v, and Excess Isentropic Compressibilities, κ_s^E. The data of experimental speeds of sound are listed in Table 5. The speeds of sound were also calculated using free length theory (FLT) and collision factor theory (CFT) approaches and Nomoto and Junjie equations.[22] The various thermophysical quantities of pure liquids needed for the calculation of speeds of sound have been listed in Table 1. The standard percentage deviation, σ/%, for the experimental and predicted values ranged from 0.4 to 13.4 for different approaches. Hence, it is stated that the above four approaches fail to predict the speeds of sound in these mixtures.

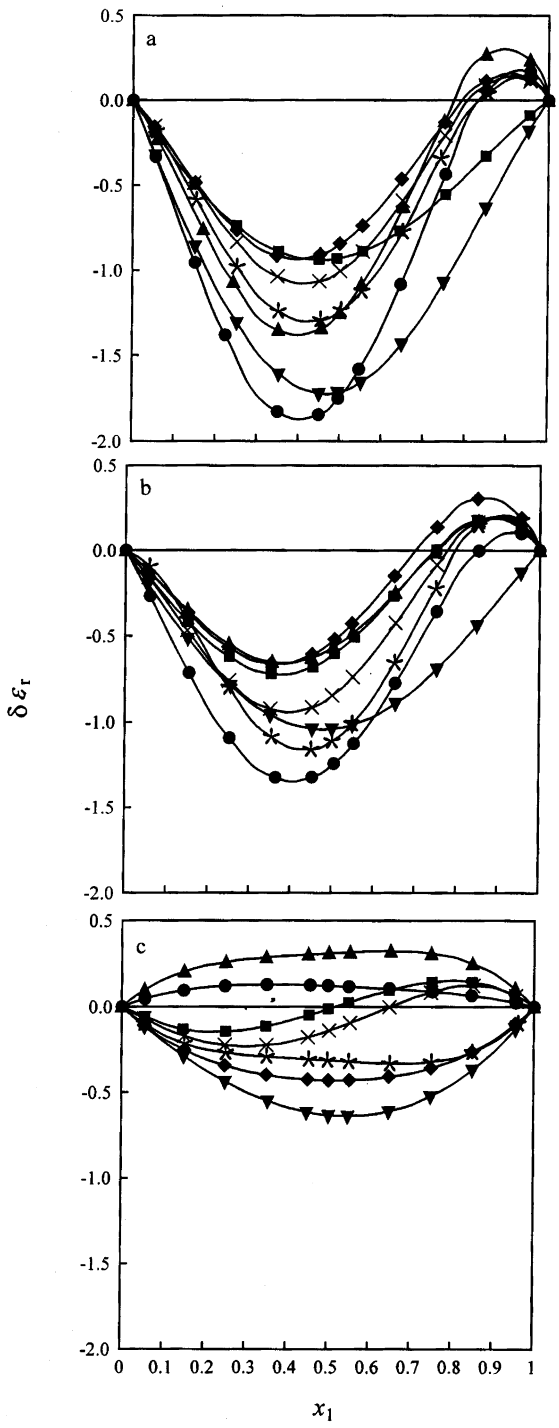

Figure 4. Variation of relative permittivity deviations, $\delta\epsilon_r$, with alkoxyethanol mole fraction for the binary mixtures of methoxyethanol (a), ethoxyethanol (b), and butoxyethanol (c) + aromatic hydrocarbons and + cyclohexane at 298.15 K. (The symbols are the same as those in Figure 1.) Solid lines are fitted values calculated using coefficients from Table 6 and eq 2.

The deviations in speed of sound, δv, and excess isentropic compressibilities, κ_s^E, were calculated using the relations

$$\delta v/\mathrm{m\cdot s^{-1}} = v_{12} - (\phi_1 v_1 + \phi_2 v_2) \quad (6)$$

$$\kappa_s^E/\mathrm{TPa^{-1}} = \kappa_s - \kappa_s^{id} \quad (7)$$

where κ_s is the isentropic compressibility and was calculated using the Laplace equation, that is, $\kappa_s = 1/(v^2\rho)$, and κ_s^{id} was calculated from the relation

$$\kappa_s^{id} = \sum_{i=1}^{2}\phi_i[\kappa_{s,i} + TV_i(\alpha_i^2)/C_{p,i}] - \{T(\sum_{i=1}^{2}x_iV_i)(\sum_{i=1}^{2}\phi_i\alpha_i)^2/\sum_{i=1}^{2}x_iC_{p,i}\} \quad (8)$$

and the ϕ_i is the ideal state volume fraction and is defined by the relation

$$\phi_i = x_iV_i/(\sum_{i=1}^{2}x_iV_i) \quad (9)$$

The δv and κ_s^E are also smoothed through use of eq 2. The summary of the smoothing coefficients, a_i, and σ values is given in Table 6. The maximum uncertainties in δv and κ_s^E values have been found to be 0.5 $\mathrm{m\cdot s^{-1}}$ and 0.9 $\mathrm{TPa^{-1}}$. The variation of δv as a function of alkoxyethanol mole fraction for the binary mixtures at $T = 298.15$ K is shown in Figure 2. It can be seen from the figure that, for methoxyethanol containing mixtures, the δv values in general are large and negative except for the case of methoxyethanol + ethylbenzene, in which the profile showed an initial negative trend followed by positive points. Except in benzene containing mixtures, the δv values at equimole composition (i.e. $x_1 = 0.5$) have been found to be shifted to lesser negative magnitudes from methoxyethanol to ethoxyethanol to butoxyethanol. The rise in the temperature in general, however, tends to increase the negative δv values.The graphical variation of κ_s^E as a function of alkoxyethanol mole fraction for the binary mixtures at $T = 298.15$ K is shown in Figure 3. The κ_s^E values in cyclohexane containing mixtures at $T = 298.15$ K have been found to be large and positive in methoxyethanol and ethoxyethanol containing mixtures. The κ_s^E values, however, become less positive in the 2-butoxyethanol rich regions. The positive κ_s^E values indicate that the mixed species are overall more compressible and hence have large volumes due to the structure disruption effect of cyclohexane. The κ_s^E values in methoxyethanol + benzene, + toluene, + ethylbenzene and in ethoxyethanol and butoxyethanol + six aromatics have been found to be negative, especially in the alkoxyethanol rich region and at $T = 298.15$ K. The rise in the temperature from $T = (298.15$ to $308.15)$ K increased the magnitude of κ_s^E values in these mixtures. The negative κ_s^E values indicate the dominance of weak but structure making n···π, −OH···π, and −CH···π interactions at $T = 298.15$ K, and the same get further weakened at elevated temperatures due to enhanced thermal motion.

Deviations in Relative Permittivities, $\delta\epsilon_r$. The $\delta\epsilon_r$ values are calculated using $\epsilon_{r,i}$ and $\epsilon_{r,12}$ values as listed in Tables 1 and 5 through the relation

$$\delta\epsilon_r = \epsilon_{r,12} - (\phi_1\epsilon_{r,1} + \phi_2\epsilon_{r,2}) \quad (10)$$

The values of the coefficients a_i needed for the mathematical representation of $\delta\epsilon_r$ and σ between the experimental and fitted values are listed in Table 6. The graphical representations of $\delta\epsilon_r$ as a function of alkoxyethanol mole fractions for the binary mixtures at $T = 298.15$ K are shown in Figure 4. The profiles showed that $\delta\epsilon_r$ values in methoxyethanol containing mixtures are largely negative except a few small but positive points to the right of the figure.

The magnitude of $\delta\epsilon_r$ values, however, was found to become less negative with the lengthening of alkyl chain in ethoxyethanol and butoxyethanol and also with the rise in the temperature. We did not, however, find any definite trend in $(\delta\epsilon_r)_{0.5}$ values among different aromatics for a given alkoxyethanol.

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