Densities, Viscosities, and Refractive Indices of the Binary Mixtures of Bis(2-methoxyethyl) Ether with 1-Propanol, 1-Butanol, 2-Methyl-1-propanol, and 2-Methyl-2-propanol

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Densities, viscosities, and refractive indices of mixtures of bis(2-methoxyethyl) ether with 1-propanol, 1-butanol, 2-methyl-1-propanol, and 2-methyl-2-propanol are presented. From these results, the excess molar volumes, deviations in viscosity, and refractivity are calculated. These results are fitted to the Redlich–Kister polynomial to estimate the binary interaction parameters.

Introduction

As a part of an experimental program (*1–5*) on the physical properties of the binary mixtures containing bis-(2-methoxyethyl) ether (also called diglyme), we present here measurements on the density, viscosity, and refractive index for mixtures of diglyme with 1-propanol, 1-butanol, 2-methyl-1-propanol, and 2-methyl-2-propanol over the mole fraction range. From these results, the excess molar volumes, deviations in viscosity, and refractivity are calculated. These results are fitted to the Redlich–Kister polynomial to estimate the binary interaction parameters.

Experimental Section

Materials. Bis(2-methoxyethyl) ether was purchased from BDH, England. The analytical grade solvents 1-propanol, 1-butanol, 2-methyl-1-propanol, and 2-methyl-2-propanol were from S.D. Fine Chemicals, Bombay. All the solvents were used directly as received. The purity of these solvents was ascertained by comparing their density, ϱ, viscosity, η, and refractive index, n_D, with the available literature data (Table 1). The GLC analyses were made using a flame ionization detector (Nucon series, model 5700/5765, with fused silica columns) having a sensitivity better than 10^{-8} g of fatty acid/μL of solvent. The GLC purity analysis for each liquid is also included in Table 1.

Binary mixtures were prepared by mixing the calculated volumes of liquids in air-tight glass bottles. The weighings were done on a single-pan Mettler balance (Switzerland, model AE-240) to an accuracy of ±0.01 mg. The possible error in the mole fraction is around ±0.0001.

Measurements. Densities of liquids and their mixtures were measured using a pycnometer having a bulb volume of 15 cm^3 and a capillary with an internal diameter of 1 mm. Densities are considered to be accurate to ±0.0003 g·cm^{-3}. An average of triplicate measurements was taken into account, and these are generally reproducible within ±0.0002 g·cm^{-3}.

Viscosities were measured with a Cannon Fenske viscometer (size 100, Industrial Research Glassware Ltd., New Jersey). An electronic stopwatch with a precision of ±0.01 s was used for flow time measurements. Viscosities are accurate to ±0.001 mPa·s.

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Table 1. Comparison of Experimental Densities (ϱ), Viscosities (η), and Refractive Indices (n_D) of Pure Liquids with Literature Values at 298.15 K

	ϱ/(g·cm^{-3})		n_D	
liquid (mol % purity)	exptl	lit. (ref)	exptl	lit. (ref)
diglyme (>99.4)	0.9399	0.9397 (*7*) 0.9392 (*8*)	1.4058	1.4060 (*7*)
1-propanol (>99.0)	0.7996	0.7996 (*9*)	1.3830	1.3837 (*9*)
1-butanol (>99.2)	0.8059	0.8058 (*9*)	1.3975	1.3971 (*9*)
2-methyl-1-propanol (>99.6)	0.7979	0.7978 (*9*)	1.3934	1.3939 (*9*)
2-methyl-2-propanol (>99.0)	0.7807 0.7755	0.7812 (*9*) 0.7757[a] (*10*)	1.3849 1.3826	1.3852 (*9*) 1.3823[a] (*10*)

[a] Compared at 303.15 K.

Refractive indices were measured for the sodium-D line with a thermostated Abbe refractometer (Bellingham and Stanley Ltd., London). At least three independent readings were taken for each composition, and the average of these readings was used to calculate the refractive index. Refractive indices are accurate to ±0.0002 units.

The calibration procedure of the pycnometer, viscometer, and refractometer and other experimental details are the same as given earlier (*1–5*).

In all the property measurements, an INSREF, model 016 AP, thermostat was used at a constant digital temperature control of ±0.01 K at the desired temperature. The results of binary mixtures compiled in Table 2 are the averages of at least three independent measurements for each composition of the mixture.

The experimental data of all the mixtures except diglyme with 2-methyl-2-propanol were obtained at 298.15, 308.15, and 318.15 K. Due to the high volatility of 2-methyl-2-propanol, the experiments for its mixtures were carried out at 298.15, 303.15, and 308.15 K. The experimental values of ϱ, η, and n_D at 298.15 K are presented in Figure 1.

Results and Discussion

Excess molar volumes of the mixtures are calculated as

$$V^E/(\text{cm}^3\cdot\text{mol}^{-1}) = V_m - V_1^* x_1 - V_2^* x_2 \qquad (1)$$

where V_1^*, V_2^*, and V_m are the molar volumes of pure liquids 1 and 2 and of the mixture, respectively, x_1 and x_2 represent the mole fractions of components 1 and 2.

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Table 2. Experimental Densities, Viscosities, and Refractive Indices of the Binary Mixtures at Different Temperatures

x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D
Diglyme (1) + 1-Propanol (2)											
298.15 K											
0.0000	0.7996	1.898	1.3830	0.4025	0.8794	1.046	1.3967	0.8004	0.9247	0.971	1.4041
0.1011	0.8248	1.451	1.3882	0.5004	0.8924	1.010	1.3991	0.8974	0.9328	0.981	1.4049
0.1997	0.8457	1.243	1.3912	0.5992	0.9042	0.988	1.4007	1.0000	0.9405	0.983	1.4058
0.3029	0.8640	1.115	1.3944	0.6934	0.9145	0.975	1.4025				
308.15 K											
0.0000	0.7914	1.486	1.3791	0.4025	0.8700	0.878	1.3931	0.8004	0.9147	0.825	1.4005
0.1011	0.8163	1.173	1.3844	0.5004	0.8830	0.852	1.3955	0.8974	0.9229	0.836	1.4013
0.1997	0.8367	1.021	1.3880	0.5992	0.8946	0.838	1.3966	1.0000	0.9305	0.839	1.4014
0.3029	0.8547	0.927	1.3910	0.6934	0.9047	0.828	1.3986				
318.15 K											
0.0000	0.7832	1.174	1.3768	0.4025	0.8606	0.743	1.3892	0.8004	0.9049	0.709	1.3963
0.1011	0.8077	0.956	1.3809	0.5004	0.8735	0.729	1.3919	0.8974	0.9130	0.748	1.3976
0.1997	0.8279	0.847	1.3843	0.5992	0.8850	0.717	1.3929	1.0000	0.9204	0.721	1.3987
0.3029	0.8455	0.779	1.3871	0.6934	0.8949	0.709	1.3946				
Diglyme (1) + 1-Butanol (2)											
298.15 K											
0.0000	0.8059	2.506	1.3975	0.4029	0.8747	1.178	1.4008	0.7983	0.9216	0.998	1.4050
0.1051	0.8265	1.866	1.3980	0.5049	0.8883	1.103	1.4026	0.9023	0.9320	0.989	1.4053
0.2018	0.8438	1.542	1.3993	0.6017	0.9002	1.048	1.4031	1.0000	0.9405	0.983	1.4058
0.3019	0.8600	1.304	1.4002	0.7049	0.9120	1.019	1.4034				
308.15 K											
0.0000	0.7981	1.927	1.3934	0.4029	0.8658	0.983	1.3967	0.7983	0.9119	0.849	1.4003
0.1051	0.8185	1.480	1.3938	0.5049	0.8792	0.924	1.3979	0.9023	0.9222	0.842	1.4009
0.2018	0.8354	1.252	1.3952	0.6017	0.8907	0.883	1.3984	1.0000	0.9305	0.839	1.4014
0.3019	0.8513	1.074	1.3956	0.7049	0.9024	0.863	1.3993				
318.15 K											
0.0000	0.7902	1.493	1.3892	0.4029	0.8568	0.827	1.3925	0.7983	0.9024	0.730	1.3953
0.1051	0.8103	1.186	1.3899	0.5049	0.8700	0.782	1.3934	0.9023	0.9120	0.723	1.3967
0.2018	0.8270	1.028	1.3903	0.6017	0.8813	0.762	1.3943	1.0000	0.9204	0.721	1.3987
0.3019	0.8426	0.906	1.3913	0.7049	0.8929	0.740	1.3944				
Diglyme (1) + 2-Methyl-1-propanol											
298.15 K											
0.0000	0.7979	3.291	1.3934	0.4023	0.8704	1.231	1.3995	0.8023	0.9214	1.011	1.4035
0.1040	0.8190	2.146	1.3950	0.5027	0.8848	1.136	1.4005	0.9024	0.9318	0.995	1.4042
0.2048	0.8383	1.635	1.3961	0.6050	0.8980	1.076	1.4025	1.0000	0.9405	0.983	1.4058
0.3058	0.8553	1.377	1.3979	0.7019	0.9101	1.038	1.4028				
308.15 K											
0.0000	0.7902	2.382	1.3889	0.4023	0.8612	1.013	1.3950	0.8023	0.9115	0.856	1.3991
0.1040	0.8106	1.649	1.3904	0.5027	0.8753	0.947	1.3959	0.9024	0.9218	0.846	1.4000
0.2048	0.8297	1.302	1.3919	0.6050	0.8885	0.904	1.3970	1.0000	0.9305	0.839	1.4014
0.3058	0.8465	1.121	1.3933	0.7019	0.9003	0.876	1.3980				
318.15 K											
0.0000	0.7822	1.751	1.3849	0.4023	0.8519	0.845	1.3902	0.8023	0.9018	0.733	1.3950
0.1040	0.8022	1.284	1.3858	0.5027	0.8659	0.796	1.3914	0.9024	0.9120	0.726	1.3952
0.2048	0.8210	1.047	1.3871	0.6050	0.8790	0.780	1.3927	1.0000	0.9204	0.721	1.3987
0.3058	0.8377	0.938	1.3897	0.7019	0.8906	0.747	1.3941				
Diglyme (1) + 2-Methyl-2-propanol (2)											
298.15 K											
0.0000	0.7807	4.309	1.3849	0.4031	0.8593	1.259	1.3951	0.8058	0.9183	1.008	1.4026
0.1032	0.8033	2.377	1.3878	0.5025	0.8756	1.146	1.3975	0.8973	0.9297	0.995	1.4045
0.2054	0.8238	1.768	1.3902	0.6046	0.8909	1.073	1.3989	1.0000	0.9405	0.983	1.4058
0.3014	0.8419	1.453	1.3930	0.7072	0.9056	1.032	1.4007				
303.15 K											
0.0000	0.7755	3.238	1.3826	0.4031	0.8549	1.123	1.3928	0.8058	0.9134	0.921	1.4005
0.1032	0.7985	1.954	1.3855	0.5025	0.8707	1.033	1.3951	0.8973	0.9247	0.915	1.4025
0.2054	0.8192	1.523	1.3876	0.6046	0.8859	0.974	1.3968	1.0000	0.9374	0.923	1.4035
0.3014	0.8372	1.274	1.3905	0.7072	0.9006	0.943	1.3987				
308.15 K											
0.0000	0.7703	2.510	1.3798	0.4031	0.8496	1.009	1.3908	0.8058	0.9083	0.852	1.3980
0.1032	0.7935	1.625	1.3828	0.5025	0.8657	0.937	1.3926	0.8973	0.9197	0.844	1.4001
0.2054	0.8142	1.319	1.3853	0.6046	0.8808	0.888	1.3951	1.0000	0.9305	0.839	1.4014
0.3014	0.8322	1.130	1.3882	0.7072	0.8954	0.864	1.3968				

The deviations in viscosity, $\Delta\eta$, are calculated as

$$\Delta\eta = \eta_m - \eta_1 x_1 - \eta_2 x_2 \qquad (2)$$

where η_m refers to mixture viscosity and η_1 and η_2 are the viscosities of the pure liquids.

The results of V^E and $\Delta\eta$ are fitted to the Redlich–Kister (*6*) relation

$$\Delta\eta \text{ or } V^E = x_1 x_2 \sum_{i=0}^{4} a_i (x_2 - x_1)^i \qquad (3)$$

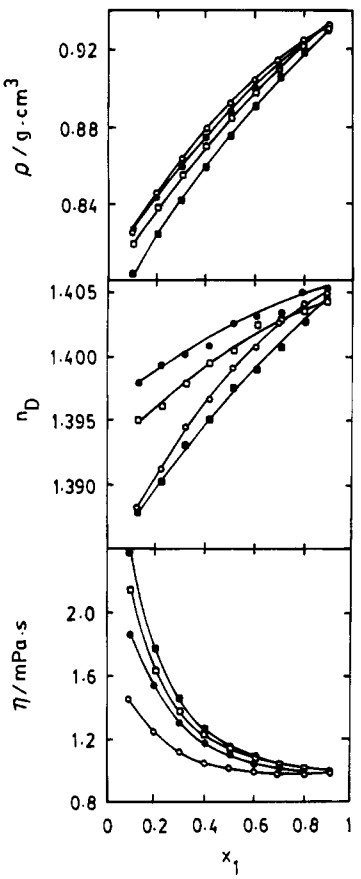

Figure 1. Density, ϱ, viscosity, η, and refractive index, n_D, versus mole fraction at 298.15 K for diglyme with (○) 1-propanol, (●) 1-butanol, (□) 2-methyl-1-propanol, and (■) 2-methyl-2-propanol.

to estimate the binary interaction coefficients, a_i, by the method of nonlinear least squares (Marquardt algorithm). The standard errors, σ, between the calculated and the experimental values are estimated by using

$$\sigma(\Delta\eta \text{ or } V^E) = [\sum_{i=1}^{m}\{(\Delta\eta \text{ or } V^E)_{expt} - (\Delta\eta \text{ or } V^E)_{calc}\}^2/(m-p)]^{1/2} \quad (4)$$

where m is the number of data points and p is the number of estimated parameters. The results of a_i and σ are presented in Table 3.

Table 3. Estimated Parameters of Excess Quantities for Binary Mixtures

quantity	T/K	a_0	a_1	a_2	a_3	a_4	σ
Diglyme (1) + 1-Propanol (2)							
V^E/(cm³·mol⁻¹)	298.15	−0.255	−0.099	−1.000	0.275	1.092	0.011
	308.15	−0.230	−0.045	−0.344	0.197	−0.169	0.007
	318.15	−0.168	0.071	−0.464	0.058	−0.156	0.011
$\Delta\eta$/(mPa·s)	298.15	−1.178	−1.174	−0.828	−0.902	−0.527	0.006
	308.15	−1.243	−0.844	−0.658	−0.563	−0.186	0.004
	318.15	−0.874	−0.523	−0.743	−0.723	0.704	0.008
Diglyme (1) + 1-Butanol (2)							
V^E/(cm³·mol⁻¹)	298.15	0.007	−0.121	0.064	0.683	−0.458	0.015
	308.15	0.038	−0.211	0.008	0.936	−0.739	0.015
	318.15	0.095	−0.056	−0.915	0.351	1.042	0.017
$\Delta\eta$/(mPa·s)	298.15	−2.577	−1.764	−0.994	−0.601	−0.365	0.009
	308.15	−1.842	−1.207	−0.579	−0.378	−0.337	0.008
	318.15	−1.293	−0.812	−0.214	−0.221	−0.469	0.006
Diglyme (1) + 2-Methyl-1-propanol (2)							
V^E/(cm³·mol⁻¹)	298.15	−0.017	0.099	−0.937	1.477	0.794	0.021
	308.15	0.167	0.076	−1.011	1.805	1.393	0.018
	318.15	0.244	0.065	−1.265	1.993	1.349	0.017
$\Delta\eta$/(mPa·s)	298.15	−3.995	−3.025	−2.296	−2.465	−1.627	0.004
	308.15	−2.649	−1.957	−1.421	−1.389	−1.912	0.003
	318.15	−1.733	−1.244	−0.802	−0.789	−0.664	0.010
Diglyme (1) + 2-Methyl-2-propanol (2)							
V^E/(cm³·mol⁻¹)	298.15	0.293	0.742	3.798	0.817	−6.517	0.104
	303.15	1.247	−0.033	−0.376	−0.677	1.317	0.018
	308.15	0.630	0.253	−0.331	0.971	−1.484	0.015
$\Delta\eta$/(mPa·s)	298.15	−6.027	−4.329	−2.700	−6.345	−6.577	0.028
	303.15	−4.209	−2.862	−1.650	−3.805	−4.281	0.021
	308.15	−2.970	−1.925	−0.892	−2.644	−3.021	0.015

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