Densities, Shear Viscosities, Refractive Indices, and Speeds of Sound of Bis(2-methoxyethyl) Ether with Hexane, Heptane, Octane, and 2,2,4-Trimethylpentane in the Temperature Interval 298.15-318.15 K

Tejraj M. Aminabhavi,* Mrityunjaya I. Aralaguppi, Bindu Gopalakrishna, and Rajashekhar S. Khinnavar

Department of Chemistry, Karnatak University, Dharwad 580 003, India

Densities, shear viscosities, refractive indices, and speeds of sound for the mixtures of bis(2-methoxyethyl) ether with hexane, heptane, octane, and 2,2,4-trimethylpentane have been measured in the temperature interval of 298.15-318.15 K. The experimental values of pure liquids and their mixtures are used to calculate the changes in molar volume V^E and deviations in viscosity $\Delta\eta$ and speeds of sound Δu for the mixing processes. These results are fitted to the Redlich-Kister polynomial relation to estimate the binary interaction parameters. Refractive index results are analyzed using different refractive index mixing rules.

Introduction

Over the past decade, we have been involved in the accumulation of extensive thermodynamic, hydrodynamic, and optical data on binary mixtures of organic liquids (*1-6*). In continuation of this program, we now present some new and useful experimental data on density ρ, shear viscosity η, refractive index n_D, and speed of sound u for the mixtures of bis(2-methoxyethyl) ether with hexane, heptane, octane, and 2,2,4-trimethylpentane over the whole range of mole fractions in the temperature interval of 298.15-318.15 K. The reason for selecting bis(2-methoxyethyl) ether, also called diethylene glycol dimethyl ether or simply "diglyme", is that many of the polyalkylene glycol ethers have been used as monomers in polymerization processes and in a variety of engineering applications including underwater research (*7*). The particular alkanes were chosen in view of their importance in hydrocarbon processing industries. Moreover, to the best of our knowledge, the physical properties of these organic mixtures have not been measured previously. Additionally, from a fundamental viewpoint, it would be interesting to know the behavior of diglyme in an environment of alkanes (C_6-C_8). The experimental results of ρ, η, n_D, and u have been used to calculate the mixing properties, namely, changes in molar volume V^E and deviations in shear viscosity $\Delta\eta$ and speeds of sound Δu, from a mole fraction average of the mixtures. An attempt has also been made to analyze the experimental refractive index data using the refractive index mixing rules.

Experimental Section

Materials. Bis(2-methoxyethyl) ether and 2,2,4-trimethylpentane were purchased from B.D.H., England. The other solvents, viz., hexane, heptane, and octane, were from S.D. Fine Chemicals, Bombay. All the solvents were used directly as received. The purities of these solvents were ascertained by comparing their ρ, η, n_D, and u values with the available literature data (see 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 appropriate volumes of liquids in specially designed ground-glass air-tight bottles and weighed in a single-pan Mettler balance (Switzerland, model AE-240) to an accuracy of ±0.01 mg. Preferential evaporation losses of solvents from the mixtures were kept to a minimum as evidenced by a repeated measurement of the physical properties over an interval of 2-3 days during which time no changes in the physical properties were observed. The possible error in the mole fractions is estimated to be around ±0.0001.

Measurements. The densities of pure liquids and their binary mixtures in the mole fraction range of 0.1-0.9 were measured using a pycnometer having a bulb volume of 15 cm^3 and a capillary with an internal diameter of 1 mm. The details of the measurements are the same as given earlier (*1-6*). Densities at 298.15, 303.15, 308.15, 313.15, and 318.15 K are considered significant to four figures. An average of triplicate measurements was taken into account, and these were generally reproducible within ±0.0002 g·cm^{-3}.

The shear viscosities were measured with a Cannon Fenske viscometer (size 100) supplied by the industrial Research Glassware Ltd., New Jersey. An electronic stopwatch with a precision of ±0.01 s was used to measure the flow times. Triplicate measurements of flow times were reproducible within ±0.01 s. The calibration methods of the viscometers and the experimental details are the same as given earlier (*1-6*). Shear viscosities are accurate to ±0.001 mPa·s.

The refractive index values for the sodium-D line were measured with a thermostated Abbe refractometer (Bellingham and Stanley Ltd., London) with an error of less than 0.0001 unit. The refractometer was frequently calibrated by using the glass test piece of known refractive index supplied by the manufacturer. Water was circulated into the instrument through a thermostatically controlled bath. The mixtures were directly injected into the prism assembly of the instrument using an air-tight hypodermic syringe, and the refractive index measurements were done after the liquid mixtures attained the constant temperature of the refractometer. This procedure was repeated at least three times, and the average of these readings was taken for the calculation of refractive index values.

The speed of sound data were obtained by using a variable-path single-crystal interferometer (Mittal Enterprises, New Delhi, model M-84) as per the experimental details given

* To whom correspondence should be addressed.

0021-9568/94/1739-0522$04.50/0

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

	ρ/(g·cm^{-3})		η/(mPa·s)		n_D		u/(m·s^{-1})	
liquid (mol % purity)	expt	lit. (ref)	expt	lit. (ref)	expt	lit. (ref)	expt	lit. (ref)
diglyme (>99.4)	0.9399	0.9397 (*21*)	0.991	0.990 (*22*)	1.4058	1.4060 (*21*)	1284	1280 (*21*)
hexane (>99.6)	0.6612	0.6552 (*23*)	0.298	0.292 (*24*)	1.3755	1.3721 (*23*)	1074	1076 (*25*)
heptane (>99.5)	0.6793	0.6795 (*26*)	0.388	0.387 (*27*)	1.3857	1.3855 (*28*)	1137	1131 (*29*)
octane (>99.2)	0.6984	0.6985 (*26*)	0.506	0.519 (*30*)	1.3956	1.3955 (*28*)	1172	1172 (*25*)
2,2,4-trimethylpentane (>99.7)	0.6877	0.6878 (*1*)	0.478	0.474 (*1*)	1.3892	1.3883 (*1*)	1084	1077 (*1*)

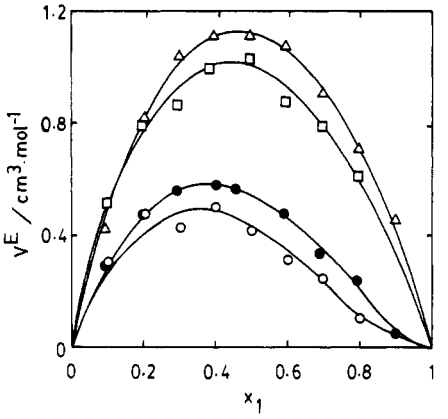

Figure 1. Comparison of changes in molar volumes for mixtures of diglyme with alkanes at 298.15 K: (○) hexane, (□) heptane, (△) octane, and (●) 2,2,4-trimethylpentane.

earlier (*1–6*). The speed of sound data are accurate to ±2 m·s^{-1}.

In all the property measurements, an INSREF, model 016 AP, thermostat was used within the temperature control of ±0.01 K at the desired temperature as checked by means of a calibrated 1/10 °C thermometer. The results of binary mixtures compiled in Table 2 are the averages of at least three independent measurements for each composition.

Results and Discussion

Mixing Quantities. The experimental values of densities, shear viscosities, and speeds of sound for the binary mixtures are used to calculate the mixing quantities by using (*8*)

$$\Delta Y = Y_m - Y_1x_1 - Y_2x_2 \quad (1)$$

where Y_m refers to the property of the mixture under consideration, viz., ρ, η, n_D, and u, Y_i refers to the property of the pure component of the mixture, and x_i represents the mole fraction of the ith component. The quantity ΔY represents the mixing property under consideration, viz., changes in volume V^E and deviations in shear viscosity $\Delta\eta$ and speed of sound Δu of the binary mixtures as a function of mixture composition. Each of these quantities, $\Delta Y = (V^E, \Delta\eta$, and $\Delta u)$, has been fitted to the Redlich–Kister (*9*) relation

$$\Delta Y = x_1x_2\sum_{i=0}^{4} A_i(x_2 - x_1)^i \quad (2)$$

The binary interaction coefficients, A_i, have been estimated by using a nonlinar least-squares procedure (Marquardt algorithm). The stanard errors, σ, between the calculated and the experimental values have been estimated by using

$$\sigma = [\sum_{i=1}^{m}\{\Delta Y_{expt} - \Delta Y_{calc}\}^2/(m-p)]^{1/2} \quad (3)$$

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.

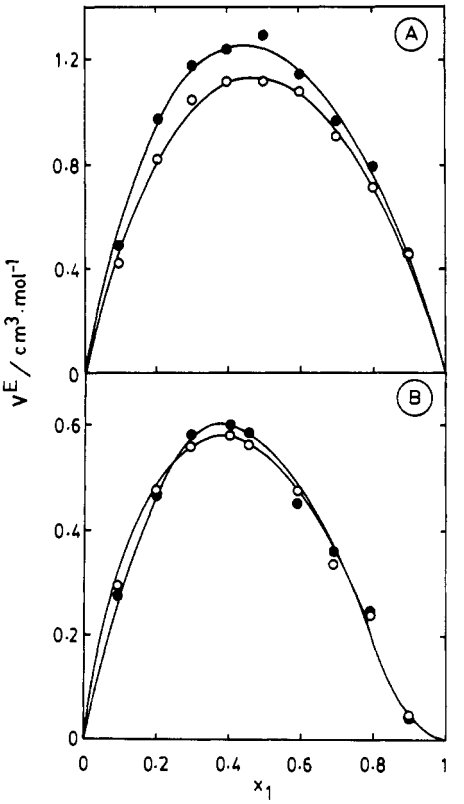

Figure 2. Effect of temperature on changes in molar volume for mixtures of diglyme with (A) octane and (B) 2,2,4-trimethylpentane: (○) 298.15 K and (●) 318.15 K.

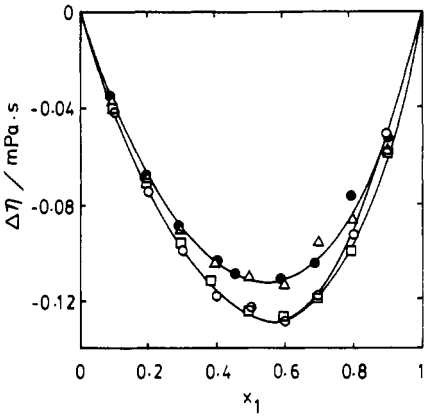

Figure 3. Comparison of the deviation in shear viscosity for mixtures of diglyme with alkanes at 298.15 K. Symbols are the same as in Figure 1 (common curve for octane and 2,2,4-trimethylpentane).

Figure 1 displays the dependence of V^E on x_1 for all the mixtures at 298.15 K. It is observed that, for all the mixtures, these values are positive, suggesting the weak dispersive-type intermolecular interactions. The values of V^E vary according to the sequence hexane < 2,2,4-trimethylpentane < heptane

Table 2. Experimental Densities (ρ), Viscosities (η), Refractive Indices (n_D), and Speeds of Sound (u) of Binary Mixtures at Different Temperatures

x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	u/(m·s^{-1})	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	u/(m·s^{-1})
				Diglyme (1) + Hexane (2)					
				298.15 K					
0.0000	0.6612	0.298	1.3755	1074	0.5986	0.8322	0.584	1.3938	1179
0.1017	0.6903	0.326	1.3782	1082	0.6954	0.8588	0.662	1.3968	1203
0.2006	0.7187	0.362	1.3810	1098	0.8011	0.8878	0.761	1.4013	1236
0.3006	0.7480	0.407	1.3838	1115	0.8957	0.9137	0.868	1.4036	1261
0.3974	0.7752	0.455	1.3869	1138	1.0000	0.9399	0.991	1.4058	1284
0.4984	0.8040	0.520	1.3909	1153					
				303.15 K					
0.0000	0.6567	0.285	1.3731	1051	0.5986	0.8273	0.548	1.3911	1159
0.1017	0.6857	0.310	1.3753	1066	0.6954	0.8539	0.620	1.3944	1182
0.2006	0.7139	0.344	1.3786	1082	0.8011	0.8829	0.710	1.3978	1214
0.3006	0.7432	0.385	1.3814	1098	0.8957	0.9088	0.806	1.4012	1239
0.3974	0.7704	0.430	1.3848	1117	1.0000	0.9356	0.914	1.4040	1266
0.4984	0.7989	0.490	1.3886	1135					
				308.15 K					
0.0000	0.6518	0.269	1.3707	1025	0.5986	0.8223	0.512	1.3889	1136
0.1017	0.6808	0.294	1.3728	1040	0.6954	0.8490	0.576	1.3920	1166
0.2006	0.7091	0.324	1.3759	1054	0.8011	0.8778	0.657	1.3960	1193
0.3006	0.7383	0.362	1.3790	1075	0.8957	0.9039	0.750	1.3993	1218
0.3974	0.7654	0.404	1.3832	1096	1.0000	0.9301	0.842	1.4017	1250
0.4983	0.7942	0.461	1.3863	1114					
				313.15 K					
0.0000	0.6473	0.257	1.3672	1001	0.5986	0.8176	0.482	1.3864	1116
0.1017	0.6761	0.280	1.3698	1018	0.6954	0.8442	0.541	1.3904	1144
0.2006	0.7045	0.308	1.3730	1035	0.8011	0.8730	0.616	1.3936	1172
0.3006	0.7336	0.345	1.3766	1053	0.8957	0.8891	0.699	1.3971	1199
0.3974	0.7603	0.383	1.3802	1073	1.0000	0.9257	0.786	1.3992	1229
0.4983	0.7895	0.434	1.3838	1092					
				318.15 K					
0.0000	0.6424	0.247	1.3642	980	0.5986	0.8127	0.457	1.3846	1095
0.1017	0.6714	0.268	1.3676	990	0.6954	0.8392	0.511	1.3874	1122
0.2006	0.6998	0.285	1.3711	1010	0.8011	0.8680	0.579	1.3913	1150
0.3006	0.7286	0.326	1.3739	1032	0.8957	0.8940	0.657	1.3945	1175
0.3974	0.7552	0.363	1.3775	1050	1.0000	0.9201	0.725	1.3972	1203
0.4983	0.7846	0.410	1.3812	1073					
				Diglyme (1) + Heptane (2)					
				298.15 K					
0.0000	0.6793	0.388	1.3857	1137	0.5940	0.8271	0.619	1.3957	1170
0.0978	0.7016	0.407	1.3861	1136	0.6956	0.8541	0.689	1.3978	1206
0.1970	0.7254	0.436	1.3870	1146	0.7955	0.8815	0.768	1.4003	1213
0.2958	0.7502	0.471	1.3896	1141	0.8992	0.9085	0.871	1.4031	1238
0.3834	0.7720	0.508	1.3908	1145	1.0000	0.9399	0.991	1.4058	1284
0.4946	0.8004	0.562	1.3929	1167					
				303.15 K					
0.0000	0.6750	0.368	1.3828	1117	0.5940	0.8223	0.580	1.3933	1164
0.0978	0.6972	0.386	1.3838	1101	0.6956	0.8491	0.643	1.3956	1177
0.1970	0.7210	0.412	1.3847	1122	0.7955	0.8767	0.714	1.3979	1205
0.2958	0.7455	0.444	1.3870	1114	0.8992	0.9054	0.807	1.4009	1220
0.3834	0.7673	0.478	1.3889	1121	1.0000	0.9356	0.914	1.4040	1266
0.4946	0.7954	0.527	1.3906	1145					
				308.15 K					
0.0000	0.6706	0.350	1.3805	1090	0.5940	0.8174	0.545	1.3910	1144
0.0978	0.6927	0.367	1.3813	1073	0.6956	0.8443	0.602	1.3940	1166
0.1970	0.7166	0.390	1.3827	1103	0.7955	0.8717	0.668	1.3956	1171
0.2958	0.7409	0.421	1.3847	1101	0.8992	0.9007	0.751	1.3993	1205
0.3834	0.7626	0.451	1.3873	1107	1.0000	0.9301	0.842	1.4017	1250
0.4946	0.7911	0.500	1.3884	1116					
				313.15 K					
0.0000	0.6663	0.333	1.3782	1073	0.5940	0.8125	0.513	1.3892	1115
0.0978	0.6883	0.351	1.3792	1072	0.6956	0.8395	0.566	1.3927	1146
0.1970	0.7121	0.371	1.3805	1082	0.7955	0.8667	0.627	1.3942	1163
0.2958	0.7363	0.398	1.3821	1081	0.8992	0.8955	0.700	1.3981	1194
0.3834	0.7580	0.426	1.3847	1089	1.0000	0.9257	0.786	1.3992	1229
0.4946	0.7863	0.468	1.3862	1100					
				318.15 K					
0.0000	0.6618	0.317	1.3761	1059	0.5940	0.8078	0.484	1.3877	1101
0.0978	0.6841	0.333	1.3777	1051	0.6956	0.8345	0.532	1.3898	1120
0.1970	0.7076	0.354	1.3781	1066	0.7955	0.8619	0.587	1.3926	1145
0.2958	0.7317	0.378	1.3795	1064	0.8992	0.8906	0.656	1.3957	1174
0.3834	0.7534	0.404	1.3820	1078	1.0000	0.9201	0.725	1.3972	1203
0.4946	0.7817	0.443	1.3841	1076					

Table 2 (Continued)

x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	u/(m·s^{-1})	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	u/(m·s^{-1})
				Diglyme (1) + Octane (2)					
				298.15 K					
0.0000	0.6984	0.506	1.3956	1172	0.5945	0.8281	0.681	1.3980	1199
0.0946	0.7167	0.515	1.3944	1170	0.6970	0.8544	0.748	1.3999	1219
0.2030	0.7385	0.535	1.3945	1175	0.7972	0.8812	0.807	1.4013	1232
0.2985	0.7588	0.561	1.3955	1174	0.8977	0.9092	0.884	1.4033	1256
0.3956	0.7806	0.594	1.3957	1184	1.0000	0.9399	0.991	1.4058	1284
0.4955	0.8040	0.636	1.3965	1192					
				303.15 K					
0.0000	0.6943	0.477	1.3929	1156	0.5945	0.8236	0.636	1.3957	1181
0.0946	0.7125	0.485	1.3924	1148	0.6970	0.8497	0.686	1.3972	1195
0.2030	0.7341	0.503	1.3922	1152	0.7972	0.8762	0.746	1.3988	1218
0.2985	0.7543	0.536	1.3930	1155	0.8977	0.9043	0.820	1.4010	1237
0.3956	0.7762	0.557	1.3934	1163	1.0000	0.9356	0.914	1.4040	1266
0.4955	0.7994	0.593	1.3953	1168					
				308.15 K					
0.0000	0.6902	0.450	1.3906	1137	0.5945	0.8189	0.596	1.3933	1162
0.0946	0.7082	0.458	1.3897	1133	0.6970	0.8449	0.641	1.3954	1178
0.2030	0.7298	0.475	1.3898	1133	0.7972	0.8712	0.695	1.3965	1197
0.2985	0.7499	0.501	1.3905	1136	0.8977	0.8994	0.762	1.3987	1219
0.3956	0.7715	0.523	1.3908	1146	1.0000	0.9301	0.842	1.4017	1250
0.4955	0.7944	0.556	1.3929	1150					
				313.15 K					
0.0000	0.6862	0.425	1.3880	1116	0.5945	0.8144	0.559	1.3906	1143
0.0946	0.7041	0.432	1.3877	1111	0.6970	0.8401	0.604	1.3931	1145
0.2030	0.7254	0.448	1.3878	1112	0.7972	0.8665	0.650	1.3947	1159
0.2985	0.7456	0.473	1.3883	1111	0.8977	0.8947	0.712	1.3967	1197
0.3956	0.7671	0.493	1.3887	1116	1.0000	0.9257	0.786	1.3992	1229
0.4955	0.7899	0.524	1.3905	1133					
				318.15 K					
0.0000	0.6820	0.403	1.3855	1096	0.5945	0.8095	0.523	1.3882	1121
0.0946	0.6998	0.410	1.3846	1086	0.6970	0.8355	0.575	1.3905	1141
0.2030	0.7209	0.425	1.3854	1070	0.7972	0.8618	0.610	1.3923	1142
0.2985	0.7410	0.446	1.3855	1087	0.8977	0.8898	0.667	1.3942	1172
0.3956	0.7625	0.466	1.3862	1094	1.0000	0.9201	0.725	1.3972	1203
0.4955	0.7853	0.493	1.3881	1100					
				Diglyme (1) + 2,2,4-Trimethylpentane (2)					
				298.15 K					
0.0000	0.6877	0.478	1.3892	1084	0.5881	0.8241	0.668	1.3980	1174
0.0931	0.7069	0.490	1.3896	1097	0.6870	0.8507	0.726	1.3993	1198
0.1978	0.7297	0.511	1.3912	1106	0.7926	0.8796	0.808	1.4016	1226
0.2916	0.7510	0.538	1.3924	1119	0.8997	0.9107	0.887	1.4040	1254
0.4016	0.7771	0.580	1.3939	1135	1.0000	0.9399	0.991	1.4058	1284
0.4538	0.7899	0.602	1.3952	1140					
				303.15 K					
0.0000	0.6836	0.451	1.3867	1059	0.5881	0.8194	0.624	1.3951	1155
0.0931	0.7026	0.460	1.3874	1074	0.6870	0.8460	0.677	1.3970	1178
0.1978	0.7252	0.481	1.3888	1083	0.7926	0.8749	0.741	1.3990	1206
0.2916	0.7466	0.507	1.3903	1098	0.8997	0.9058	0.821	1.4016	1234
0.4016	0.7726	0.545	1.3915	1114	1.0000	0.9356	0.914	1.4040	1266
0.4538	0.7854	0.564	1.3929	1117					
				308.15 K					
0.0000	0.6792	0.426	1.3843	1043	0.5881	0.8147	0.584	1.3935	1132
0.0931	0.6983	0.435	1.3852	1051	0.6870	0.8412	0.632	1.3948	1158
0.1978	0.7208	0.455	1.3865	1060	0.7926	0.8699	0.690	1.3968	1183
0.2916	0.7421	0.478	1.3873	1075	0.8997	0.9006	0.762	1.3993	1215
0.4016	0.7680	0.512	1.3892	1091	1.0000	0.9301	0.842	1.4017	1250
0.4538	0.7807	0.529	1.3903	1101					
				313.15 K					
0.0000	0.6751	0.404	1.3818	1023	0.5881	0.8101	0.548	1.3911	1113
0.0931	0.6941	0.413	1.3826	1040	0.6870	0.8365	0.592	1.3926	1136
0.1978	0.7166	0.430	1.3839	1044	0.7926	0.8652	0.647	1.3946	1165
0.2916	0.7376	0.451	1.3852	1056	0.8997	0.8959	0.712	1.3970	1193
0.4016	0.7635	0.482	1.3867	1077	1.0000	0.9257	0.786	1.3992	1229
0.4538	0.7762	0.500	1.3879	1083					
				318.15 K					
0.0000	0.6708	0.381	1.3790	1002	0.5881	0.8056	0.512	1.3878	1099
0.0931	0.6898	0.389	1.3799	1013	0.6870	0.8316	0.553	1.3900	1116
0.1978	0.7122	0.405	1.3813	1022	0.7926	0.8603	0.601	1.3922	1147
0.2916	0.7331	0.425	1.3825	1038	0.8997	0.8911	0.602	1.3949	1170
0.4016	0.7589	0.453	1.3850	1058	1.0000	0.9201	0.725	1.3972	1203
0.4538	0.7716	0.468	1.3860	1067					

Table 3. Estimated Parameters of Excess Functions for Mixtures

function	temp/K	A_0	A_1	A_2	A_3	A_4	σ
			Diglyme (1) + Hexane (2)				
V^E/(cm^3·mol^{-1})	298.15	1.618	1.049	0.976	2.463	−2.452	0.043
	303.15	1.954	1.054	0.252	1.985	−0.410	0.049
	308.15	1.652	1.146	0.861	2.407	−2.254	0.054
	313.15	1.800	1.253	0.639	1.616	−1.416	0.069
	318.15	1.572	1.645	0.449	1.337	−2.278	0.079
$\Delta\eta$/(mPa·s)	298.15	−0.502	0.125	−0.145	−0.104	0.234	0.002
	303.15	−0.442	0.097	−0.117	−0.109	0.205	0.002
	308.15	−0.386	0.103	−0.212	−0.168	0.416	0.003
	313.15	−0.354	0.090	−0.155	−0.133	0.290	0.002
	318.15	−0.298	0.039	−0.275	−0.172	0.531	0.002
Δu/(m·s^{-1})	298.15	−93.32	−9.67	50.93	−123.83	−39.68	2.152
	303.15	−91.61	14.79	62.89	−61.03	−27.39	1.361
	308.15	−89.08	−2.34	59.47	−23.90	−99.79	2.595
	313.15	−89.16	0.03	82.16	−1.76	−87.91	1.112
	318.15	−75.65	2.20	71.23	−80.35	−163.18	0.839
			Diglyme (1) + Heptane (2)				
V^E/(cm^3·mol^{-1})	298.15	4.056	1.570	−2.840	−3.476	10.798	0.060
	303.15	4.385	0.774	−1.354	−0.607	5.770	0.052
	308.15	4.106	0.630	−0.223	0.615	3.089	0.026
	313.15	4.399	0.552	−0.439	−0.383	4.210	0.017
	318.15	4.110	0.683	0.507	−0.240	1.390	0.025
$\Delta\eta$/(mPa·s)	298.15	−0.498	0.135	−0.096	−0.013	0.013	0.001
	303.15	−0.443	0.111	−0.079	0.001	0.007	0.001
	308.15	−0.379	0.087	−0.108	−0.021	0.106	0.001
	313.15	−0.357	0.065	−0.033	0.031	0.008	0.001
	318.15	−0.305	0.056	−0.027	−0.049	0.067	0.001
Δu/(m·s^{-1})	298.15	−199.90	−25.10	164.46	239.74	−404.31	7.459
	303.15	−201.12	−54.86	156.04	148.38	−518.44	7.846
	308.15	−198.67	24.59	312.84	58.74	−829.37	9.150
	313.15	−203.66	15.79	189.76	33.13	−286.21	3.577
	318.15	−197.33	51.74	235.41	−132.07	−385.46	5.431
			Diglyme (1) + Octane (2)				
V^E/(cm^3·mol^{-1})	298.15	4.491	0.945	0.801	−1.325	−0.172	0.019
	303.15	4.716	0.978	1.886	−2.300	−1.036	0.019
	308.15	4.830	1.097	0.620	−1.702	0.545	0.033
	313.15	5.021	0.930	1.690	−1.516	−0.767	0.034
	318.15	4.966	1.386	1.199	−1.309	−0.798	0.034
$\Delta\eta$/(mPa·s)	298.15	−0.448	0.031	0.016	0.144	−0.248	0.003
	303.15	−0.401	0.113	−0.017	−0.032	−0.146	0.003
	308.15	−0.351	0.083	−0.029	−0.042	−0.063	0.002
	313.15	−0.321	0.072	−0.014	−0.021	−0.087	0.002
	318.15	−0.277	0.016	0.068	−0.004	−0.133	0.004
Δu/m·s^{-1})	298.15	−147.38	27.55	−4.45	7.12	−17.53	2.782
	303.15	−167.87	32.32	51.05	−71.49	−145.97	1.930
	308.15	−164.88	30.97	−29.41	−28.41	−9.42	1.927
	313.15	−161.35	55.74	−376.68	18.71	497.84	5.293
	318.15	−168.63	−82.59	−199.80	113.76	95.74	7.466
			Diglyme (1) + 2,2,4-Trimethylpentane (2)				
V^E/(cm^3·mol^{-1})	298.15	2.148	1.168	0.180	0.833	−0.609	0.020
	303.15	2.395	1.019	0.118	0.567	0.444	0.021
	308.15	2.246	1.292	−0.058	0.213	0.376	0.025
	313.15	2.434	1.290	0.016	−0.340	0.454	0.023
	318.15	2.171	1.341	0.592	0.295	−1.696	0.023
$\Delta\eta$/(mPa·s)	298.15	−0.448	0.049	0.012	0.039	−0.125	0.004
	303.15	−0.394	0.062	−0.080	0.017	−0.030	0.001
	308.15	−0.347	0.052	−0.048	−0.010	−0.022	0.001
	313.15	−0.318	0.051	−0.058	−0.010	0.005	0.001
	318.15	−0.283	0.043	−0.041	−0.026	0.011	0.001
Δu/(m·s^{-1})	298.15	−126.06	−31.60	96.65	88.35	−72.01	2.007
	303.15	−125.48	−31.60	109.99	118.06	−93.88	3.389
	308.15	−138.52	−31.40	3.87	72.41	−22.81	1.703
	313.15	−127.61	−16.97	−47.99	127.00	131.98	2.519
	318.15	−101.59	−33.93	−23.52	70.04	−10.51	2.913

< octane. The behavior of octane and its equivalent molecule 2,2,4-trimethylpentane is quite different though they possess the same number of carbon atoms. The magnitude of V^E for octane is about twice that for 2,2,4-trimethylpentane. However, there is no systematic variation of V^E on the molecular size of the straight-chain alkanes, and the nature of V^E vs x_1 curves for all the mixtures in the investigated temperature interval is almost identical, but the V^E values show an increase with temperature. This dependence is shown typically in Figure 2 for mixtures of diglyme + octane and diglyme + 2,2,4-trimethylpentane for the extreme temperature, viz., 298.15 and 318.15 K.

The dependence of $\Delta\eta$ on the mole fraction of the diglyme at 298.15 K is displayed in Figure 3. wherein we observe that $\Delta\eta$ values are negative for all the mixtures, further supporting the presence of weak intermolecular interactions. The deviations in shear viscosities of mixtures of diglyme with octane and 2,2,4-trimethylpentane are identical. Similarly, in the case of mixtures of diglyme with hexane and heptane, the $\Delta\eta$ values and their variations with x_1 follow almost the

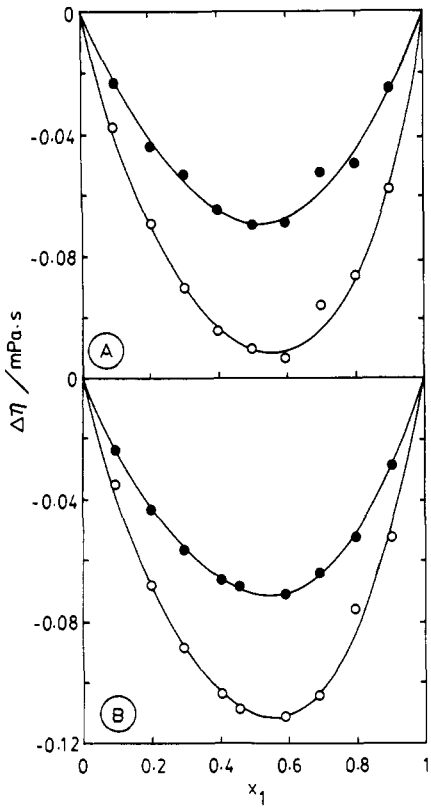

Figure 4. Effect of temperature on the deviation in shear viscosity for mixtures of diglyme with (A) octane and (B) 2,2,4-trimethylpentane at the same temperatures as given in Figure 2.

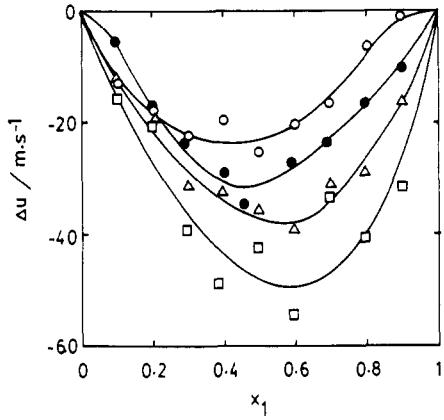

Figure 5. Comparison of the deviation in speed of sound at 298.15 K for mixtures of diglyme with alkanes as given in Figure 1.

same pattern. However, at equimolar compositions of the mixtures, we find that the $\Delta\eta$ values of the mixtures follow the sequence heptane < hexane < octane < 2,2,4-trimethylpentane in the investigated temperature range. With an increase in temperature, the values of $\Delta\eta$ become more negative for all the mixtures; such dependencies at 298.15 and 318.15 K are presented in Figure 4 for mixtures of octane or 2,2,4-trimethylpentane with diglyme.

The results of Δu at 298.15 K for all the binaries are presented in Figure 5. The values of Δu are also negative for all the mixtures over the entire composition. These values vary according to the sequence heptane < octane < 2,2,4-trimethylpentane < hexane. This pattern is very much different from that observed for the dependence of $\Delta\eta$ on x_1. However, the effect of temperature on Δu is not systematic in that for mixtures of diglyme with heptane, octane, and

Table 4. Comparison of Refractive Index Mixing Rules at 298.15 K

	Δn_D % for mixtures of diglyme with			
mixing rule	hexane	heptane	octane	2,2,4-TMP
Arago–Biot	−0.0417	−0.1846	−0.2765	−0.0712
Gladstone–Dale	−0.0417	−0.1846	−0.2765	−0.0712
Lorentz–Lorenz	−0.0359	−0.1820	−0.2758	−0.0695
Eykman	−0.0398	−0.1837	−0.2763	−0.0707
Weiner	−0.0819	−0.2033	−0.2815	−0.0848
Heller	−0.0366	−0.1822	−0.2759	−0.0695
Newton	−0.0478	−0.1872	−0.2772	−0.0731
Oster	−0.0449	−0.1860	−0.2769	−0.0722
Eyring–John	−0.0387	−0.1832	−0.2762	−0.0703

2,2,4-trimethylpentane the negative values of Δu increase with temperature, while for the diglyme + hexane mixture, the negative values of Δu decrease. However, the changes in the Δu values with temperature are not significant to display their dependencies graphically.

***Refractive Index Mixing* Rules.** Realizing the importance of refractive index mixing rules to test the accuracy of the refractive index data of the mixtures (*10*), we have analyzed the binary refractive index data using the refractive index mixing rules. In this pursuit, the equations of Arago–Biot (*11*), Gladstone–Dale (*12*), Lorentz–Lorenz (*13, 14*), Eykman (*15*), Weiner (*16*), Heller (*17*), Newton (*18*), Oster (*19*), and Eyring–John (*20*) are employed. The calculated refractive indices from all these mixing rules are used to calculate the average refractive index difference, Δn_D, as (*6*)

$$\Delta n_D = \frac{(n_{D,expt} - n_{D,calc})}{n_{D,expt}} \times 100 \qquad (4)$$

The values of Δn_D for all the equations and all the mixtures at 298.15 K are compiled in Table 4.

It is found that, with the majority of mixtures, the Δn_D values calculated from the Lorentz–Lorenz relation are smaller than the values calculated from the other mixing rules. However, as can be seen from the Δn_D values given in Table 4, it may not be possible to unequivocally decide about the accuracy of the mixing rules. All the relations might be useful, and it is left to the researcher to select any of the mixing rules for such a calculational purpose.

Literature Cited

(1) Aralaguppi, M. I.; Aminabhavi, T. M.; Balundgi, R. H.; Joshi, S. S. *J. Phys. Chem.* **1991**, *95*, 5299.
(2) Aminabhavi, T. M.; Aralaguppi, M. I.; Harogoppad, S. B.; Balundgi, R. H. *Fluid Phase Equilib.* **1992**, *72*, 211.
(3) Aralaguppi, M. I.; Aminabhavi, T. M.; Balundgi, R. H. *Fluid Phase Equilib.* **1992**, *71*, 99.
(4) Aralaguppi, M. I.; Aminabhavi, T. M.; Harogoppad, S. B.; Balundgi, R. H. *J. Chem. Eng. Data* **1992**, *37*, 298.
(5) Aminabhavi, T. M.; Aralaguppi, M. I.; Harogoppad, S. B.; Balundgi, R. H. *J. Chem. Eng. Data* **1993**, *38*, 31.
(6) Aminabhavi, T. M.; Phayde, H. T. S.; Khinnavar, R. S.; Bindu, G.; Hansen, K. C. *J. Chem. Eng. Data*, in press.
(7) Thompson, C. M. The Use of Polyalkylene Glycol in Sonar Transducers. Naval Research Laboratory Report No. 8283; Washington, DC, Feb 1979.
(8) Aminabhavi, T. M.; Phayde, H. T. S.; Aralaguppi, M. I.; Khinnavar, R. S. *J. Chem. Eng. Data* **1993**, *38*, 540.
(9) Redlich, O.; Kister, A. T. *Ind. Eng. Chem.* **1948**, *40*, 345.
(10) Aminabhavi, T. M. *J. Chem. Eng. Data* **1984**, *29*, 54.
(11) Arago, D. F. J.; Biot, J. B. *Mem. Acad. Fr.* **1806**, 7.
(12) Gladstone, J. H.; Dale, T. P. *Philos. Trans.* **1863**, *153*, 317.
(13) Lorentz, H. A. *Weid. Ann.* **1880**, *9*, 641.
(14) Lorentz, L. *Weid. Ann.* **1880**, *11*, 70.
(15) Eykman, J. F. *Recl. Trav. Chim Pays-Bas* **1895**, *14*, 185.
(16) Weiner, O. *Leipz. Ber.* **1910**, *62*, 256.
(17) Heller, W. *Phys. Rev.* **1945**, *68*, 5.
(18) Kurtz, S. S. Jr.; Ward, A. L. *J. Franklin Inst.* **1936**, *222*, 563.
(19) Oster, G. *Chem. Rev.* **1948**, *43*, 319.
(20) Eyring, H.; John, M. S. *Significant liquid structures*; Wiley: New York, 1969; p 110.

(21) Treszczanowicz, A. J.; Halpin, C. J.; Benson, G. C. *J. Chem. Eng. Data* **1982**, *27*, 321.
(22) Daubert, T. E.; Danner, R. P. *Physical and Thermodynamic Properties of Pure Chemicals, Data Compilation*; Hemisphere Publishing Corp.: Washington, DC, 1992; Part I.
(23) Eduljee, G. H.; Boyes, A. P. *J. Chem. Eng. Data* **1980**, *25*, 249.
(24) Chevalier, J. L. E.; Petrino, P. J.; Gaston-Bonhomme, Y. H. *J. Chem. Eng. Data* **1990**, *35*, 206.
(25) Junguera, S.; Tardajos, G.; Aicart, E. *J. Chem. Thermodyn.* **1988**, *20*, 1461.
(26) Garcia, I.; Cobos, J. C.; Gonzalez, J. A.; Casanova, C.; Cocero, M. J. *J. Chem. Eng. Data* **1988**, *33*, 423.
(27) Kouris, S.; Panayiotou, C. *J. Chem. Eng. Data* **1989**, *34*, 200.
(28) Ortega, J.; Matos, J. S. *Mater. Chem. Phys.* **1986**, *15*, 415.
(29) Rai, R. D.; Shukla, R. K.; Shukla, A. K.; Pandey, J. D. *J. Chem. Thermodyn.* **1989**, *21*, 125.
(30) Awwad, A. M.; Al-Azzawi, S. F.; Salman, M. A. *Fluid Phase Equilib.* **1986**, *31*, 171.

Received for review November 15, 1993. Accepted April 11, 1994.[⊕]

[⊕] Abstract published in *Advance ACS Abstracts,* May 15, 1994.