Densities, Viscosities, and Refractive Indices of Some *n*-Alkane Binary Liquid Systems at 298.15 K

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In this paper the viscosities, densities, and refractive indices for 36 *n*-alkane binary liquid mixtures have been measured at 298.15 K. The experimental viscosities for all the systems studied have been correlated using the McAllister and Heric models. The results with these models agree with experimental data very well (average error less than 0.6% in all cases).

Introduction

This paper reports the viscosities, densities, and refractive indices for 36 binary *n*-alkane systems (from C_5 to C_{16}) at 298.15 K. There are scattered data in the literature for these systems under different conditions (*1–24*).

Experimental Section

Chemicals. All reagents used were purchased from Aldrich Chemical Co. A chromatographic test of reagent purity, using a Hewlett-Packard 5890 GC with a 60 m × 0.25 mm DB-1 capillary column and a flame ionization detector (FID), showed a purity of >99 mass %. The purity of the components was further ascertained by comparing their densities and refractive indices at 293.15 K as shown in Table 1, which are in close agreement with those reported in the literature (*25*).

Procedure. The densities of the pure liquids and the binary mixtures were measured at 298.15 K using an Anton Paar digital precision densimeter (model DMA 55) with a thermostated bath controlled to ±0.01 K. The overall precision of the densities measured was estimated to be better than 2×10^{-5} g·cm^{-3}. All solutions were prepared by mass using a Mettler balance with an accuracy of ±0.0001 g.

An Ubbelohde viscometer was used for determining the viscosities of pure liquids and the binary systems. The apparatus was submerged in a thermostatic bath at 25 °C with a resolution of ±0.1 °C. The viscometer was calibrated with pure components whose viscosity and density were well known, as has been described in a previous paper (*26*). Viscosity values were determined using the relation (*27*, *28*)

$$\frac{\eta}{\varrho} = At - \frac{B}{t} \qquad (1)$$

where η is the viscosity, ϱ is the liquid density, t is its flow time in the viscometer, and A and B are viscometer constants, determined for measurements with the calibration fluids. Each experimental point is the average of 10 measurements with a maximum deviation of ±0.2%.

No changes in the composition were observed on comparing the value of the refractive index before and after the viscosity measurement. The refractive indices were measured with an Abbe refractometer (type 3T) with an accuracy of ±0.0002.

Results and Discussion

The experimental viscosities and densities of 36 binary mixtures of *n*-alkanes are shown in Table 2, as well as the excess molar volumes (V^E) and the deviation in viscosities ($\Delta\eta$). These data were compared with those presented in the literature under the same conditions (*9*, *10*, *12*, *18*), and the differences were less than 1%. Experimental viscosities changed monotonically with composition for all systems.

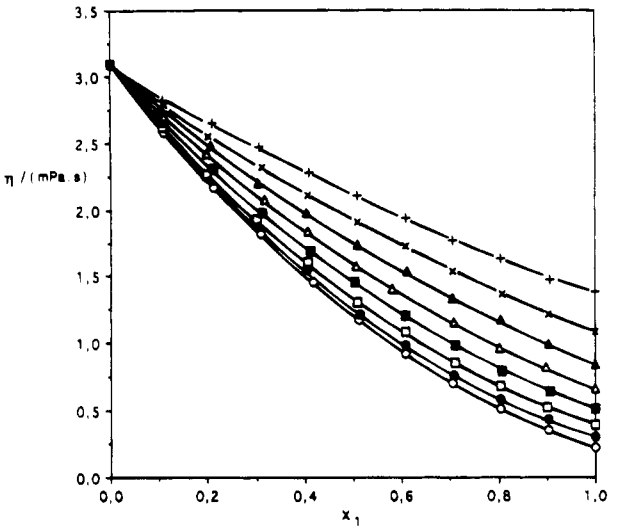

Figure 1. Viscosities of mixtures of hexadecane (2) with all other *n*-alkanes (1): (○) pentane, (●) hexane, (□) heptane, (■) octane, (△) nonane, (▲) decane, (×) undecane, (+) dodecane.

Table 1. Comparison of Data with Literature Data for Pure Components at 293.15 K

compound	ϱ/(g·cm^{-3}) exptl	ϱ/(g·cm^{-3}) lit. (*25*)	n_D exptl	n_D lit. (*25*)	GC analysis mass %
pentane	0.626 20	0.6262	1.3577	1.3575	99.2
hexane	0.659 67	0.6603	1.3756	1.3751	99.5
heptane	0.683 66	0.6837	1.3878	1.3878	99.8
octane	0.702 52	0.7025	1.3975	1.3974	99.5
nonane	0.717 68	0.7176	1.4058	1.4054	99.5
decane	0.730 16	0.7300	1.4120	1.4102	99.4
undecane	0.740 02	0.7402	1.4173	1.4198	99.8
dodecane	0.748 69	0.7487	1.4217	1.4217	99.5
hexadecane	0.773 31	0.7733	1.4345	1.4345	99.2

The excess molar volumes were calculated with the following equation:

$$V^E = V - \sum x_i V_i \qquad (2)$$

where V is the molar volume of the mixture and x_i and V_i

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Table 2. Mole Fractions, x_1, Densities, ϱ, Viscosities, η, Refractive Indices, n_D, Excess Volumes, V^E, and Viscosity Deviation, $\Delta\eta$, for Binary Mixtures

x_1	ϱ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)	x_1	ϱ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)
Pentane (1) + Hexane (2)											
0.0000	0.655 07	0.2987	1.3732	0.0000	1.0000	0.6025	0.636 23	0.2497	1.3627	−0.1001	0.9969
0.1045	0.652 08	0.2898	1.3715	−0.0338	1.0003	0.7041	0.632 66	0.2432	1.3607	−0.0972	1.0002
0.2098	0.648 94	0.2802	1.3699	−0.0581	0.9974	0.7966	0.629 28	0.2364	1.3588	−0.0854	0.9989
0.3107	0.645 82	0.2724	1.3682	−0.0746	0.9986	0.8997	0.625 32	0.2280	1.3569	−0.0540	0.9929
0.4113	0.642 61	0.2641	1.3667	−0.0869	0.9971	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.5105	0.639 35	0.2574	1.3649	−0.0961	1.0004						
Pentane (1) + Heptane (2)											
0.0000	0.679 65	0.3866	1.3852	0.0000	1.0000	0.5999	0.648 82	0.2848	1.3697	−0.1586	1.0248
0.1046	0.675 04	0.3691	1.3826	−0.0666	1.0113	0.6624	0.645 04	0.2762	1.3676	−0.1678	1.0286
0.2024	0.670 37	0.3579	1.3805	−0.0949	1.0348	0.7972	0.636 33	0.2540	1.3625	−0.1601	1.0188
0.3087	0.664 99	0.3325	1.3777	−0.1118	1.0193	0.8929	0.629 57	0.2420	1.3590	−0.1160	1.0231
0.4077	0.659 73	0.3173	1.3751	−0.1258	1.0271	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.4979	0.654 74	0.3004	1.3725	−0.1423	1.0219						
Pentane (1) + Octane (2)											
0.0000	0.698 42	0.5094	1.3951	0.0000	1.0000	0.6046	0.659 76	0.3228	1.3755	−0.3102	1.0442
0.1059	0.692 99	0.4719	1.3925	−0.1276	1.0111	0.7015	0.651 68	0.2963	1.3713	−0.3039	1.0383
0.1973	0.687 81	0.4439	1.3890	−0.1926	1.0257	0.8026	0.642 44	0.2702	1.3666	−0.2627	1.0293
0.3019	0.681 39	0.4091	1.3868	−0.2415	1.0306	0.9035	0.632 20	0.2454	1.3610	−0.1659	1.0161
0.4040	0.674 62	0.3806	1.3835	−0.2736	1.0431	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.5019	0.667 65	0.3545	1.3797	−0.2973	1.0535						
Pentane (1) + Nonane (2)											
0.0000	0.713 75	0.6600	1.4033	0.0000	1.0000	0.6016	0.670 26	0.3691	1.3811	−0.4648	1.0742
0.0925	0.708 62	0.6110	1.4008	−0.1441	1.0235	0.7020	0.660 16	0.3268	1.3758	−0.4596	1.0606
0.1995	0.701 97	0.5548	1.3975	−0.2507	1.0438	0.8033	0.648 66	0.2892	1.3696	−0.3969	1.0476
0.3080	0.694 51	0.5016	1.3940	−0.3289	1.0616	0.9040	0.635 58	0.2538	1.3626	−0.2471	1.0255
0.4030	0.687 37	0.4556	1.3901	−0.3857	1.0689	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.4861	0.680 61	0.4179	1.3859	−0.4282	1.0730						
Pentane (1) + Decane (2)											
0.0000	0.726 30	0.8459	1.4097	0.0000	1.0000	0.6029	0.679 23	0.4285	1.3822	−0.5871	1.1317
0.1031	0.720 52	0.7775	1.4068	−0.2404	1.0546	0.7058	0.667 54	0.3626	1.3791	−0.6121	1.0984
0.2082	0.713 52	0.6969	1.4034	−0.3489	1.0874	0.8040	0.654 60	0.3143	1.3727	−0.5529	1.0853
0.3062	0.706 19	0.6169	1.4000	−0.4073	1.0970	0.9008	0.639 60	0.2671	1.3650	−0.3688	1.0494
0.4080	0.697 82	0.5449	1.3956	−0.4668	1.1098	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.5061	0.688 94	0.4818	1.3911	−0.5290	1.1184						
Pentane (1) + Undecane (2)											
0.0000	0.736 30	1.0841	1.4122	0.0000	1.0000	0.5738	0.690 51	0.5061	1.3872	−0.6852	1.1567
0.0962	0.730 89	0.9653	1.4094	−0.2559	1.0367	0.6599	0.680 35	0.4333	1.3805	−0.7210	1.1348
0.1826	0.725 16	0.8798	1.4058	−0.3733	1.0832	0.7461	0.668 68	0.3731	1.3674	−0.6968	1.1198
0.2740	0.718 36	0.7841	1.4021	−0.4532	1.1155	0.8967	0.643 41	0.2805	1.4152	−0.4224	1.0683
0.3680	0.710 61	0.6944	1.3966	−0.5246	1.1462	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.4834	0.699 96	0.5825	1.3922	−0.6201	1.1540						
Pentane (1) + Dodecane (2)											
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6031	0.694 52	0.5504	1.3942	−0.7909	1.1976
0.1094	0.738 83	1.1941	1.4164	−0.3135	1.0568	0.7069	0.680 49	0.4481	1.3875	−0.7926	1.1780
0.2073	0.732 11	1.0374	1.4137	−0.4476	1.0975	0.8062	0.664 27	0.3631	1.3783	−0.6783	1.1439
0.2990	0.724 97	0.9143	1.4094	−0.5339	1.1431	0.8991	0.645 84	0.2925	1.3684	−0.4344	1.0914
0.4078	0.715 44	0.7711	1.4050	−0.6361	1.1754	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.5008	0.706 20	0.6622	1.4006	−0.7217	1.1958						
Pentane (1) + Hexadecane (2)											
0.0000	0.769 82	3.0930	1.4334	0.0000	1.0000	0.6089	0.717 55	0.9218	1.4072	−1.1113	1.4780
0.1111	0.763 65	2.5741	1.4301	−0.2936	1.1146	0.7034	0.702 79	0.7004	1.4005	−1.1581	1.4398
0.2119	0.757 29	2.1701	1.4271	−0.5855	1.2249	0.8034	0.682 93	0.5086	1.3906	−1.0706	1.3600
0.3099	0.749 91	1.8160	1.4233	−0.7859	1.3264	0.9029	0.656 57	0.3464	1.3747	−0.7160	1.2033
0.4166	0.740 24	1.4566	1.4177	−0.9205	1.4085	1.0000	0.621 24	0.2230	1.3547	0.0000	1.0000
0.5122	0.729 94	1.1722	1.4134	−1.0191	1.4574						
Hexane (1) + Heptane (2)											
0.0000	0.679 65	0.3866	1.3852	0.0000	1.0000	0.6064	0.665 50	0.3305	1.3783	−0.0164	0.9996
0.1059	0.677 25	0.3792	1.3841	0.0109	1.0080	0.7040	0.663 04	0.3227	1.3770	−0.0200	1.0009
0.2067	0.674 96	0.3658	1.3830	0.0114	0.9980	0.8008	0.660 53	0.3123	1.3758	−0.0207	0.9932
0.3020	0.672 77	0.3580	1.3819	0.0071	1.0010	0.8993	0.657 88	0.3075	1.3745	−0.0140	1.0031
0.4060	0.670 34	0.3485	1.3807	−0.0004	1.0010	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5051	0.667 98	0.3409	1.3795	−0.0095	1.0045						
Hexane (1) + Octane (2)											
0.0000	0.698 41	0.5094	1.3956	0.0000	1.0000	0.6111	0.674 73	0.3697	1.3835	−0.1101	1.0057
0.1072	0.694 83	0.4782	1.3937	−0.0546	0.9940	0.7056	0.670 40	0.3510	1.3812	−0.1108	1.0042
0.2073	0.691 22	0.4598	1.3920	−0.0776	1.0082	0.8050	0.665 58	0.3326	1.3787	−0.0991	1.0034
0.3034	0.687 57	0.4414	1.3901	−0.0904	1.0188	0.9018	0.660 57	0.3172	1.3761	−0.0677	1.0077
0.4038	0.683 57	0.4124	1.3881	−0.0978	1.0043	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5101	0.679 14	0.3920	1.3858	−0.1048	1.0104						

Table 2. (Continued)

x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)
					Hexane (1) + Nonane (2)						
0.0000	0.713 75	0.6600	1.4033	0.0000	1.0000	0.6074	0.683 49	0.4200	1.3877	−0.1992	1.0300
0.1073	0.709 26	0.6111	1.4009	−0.0630	1.0081	0.7035	0.677 37	0.3874	1.3845	−0.1853	1.0253
0.2100	0.704 66	0.5693	1.3985	−0.1129	1.0188	0.8040	0.670 44	0.3547	1.3810	−0.1496	1.0166
0.2873	0.700 98	0.5367	1.3967	−0.1423	1.0212	0.9035	0.662 97	0.3272	1.3772	−0.0881	1.0147
0.4024	0.695 14	0.5017	1.3937	−0.1766	1.0458	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5044	0.689 56	0.4527	1.3908	−0.1948	1.0231						
					Hexane (1) + Decane (2)						
0.0000	0.726 30	0.8459	1.4097	0.0000	1.0000	0.6061	0.691 27	0.4805	1.3923	−0.2651	1.0675
0.1074	0.721 32	0.7809	1.4074	−0.0904	1.0324	0.7053	0.683 54	0.4337	1.3883	−0.2530	1.0684
0.2074	0.716 24	0.7182	1.4049	−0.1493	1.0536	0.8034	0.675 09	0.3791	1.3838	−0.2127	1.0343
0.3029	0.710 98	0.6515	1.4023	−0.1909	1.0557	0.9036	0.665 46	0.3365	1.3788	−0.1294	1.0190
0.4046	0.704 93	0.5846	1.3993	−0.2288	1.0531	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5041	0.698 49	0.5315	1.3960	−0.2545	1.0619						
					Hexane (1) + Undecane (2)						
0.0000	0.736 30	1.0841	1.4150	0.0000	1.0000	0.6060	0.698 00	0.5391	1.3960	−0.3136	1.0861
0.1036	0.731 33	0.9630	1.4126	−0.1279	1.0152	0.7068	0.689 07	0.4643	1.3912	−0.3216	1.0652
0.1988	0.726 16	0.8760	1.4100	−0.1852	1.0441	0.8048	0.679 23	0.4044	1.3860	−0.2841	1.0527
0.2999	0.720 11	0.7746	1.4071	−0.2219	1.0517	0.9022	0.668 05	0.3552	1.3801	−0.1849	1.0483
0.4051	0.713 21	0.6933	1.4037	−0.2556	1.0781	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5076	0.705 82	0.6090	1.4000	−0.2873	1.0807						
					Hexane (1) + Dodecane (2)						
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6062	0.704 39	0.6105	1.3991	−0.3892	1.1190
0.1128	0.739 40	1.1959	1.4168	−0.1479	1.0305	0.7222	0.692 74	0.5009	1.3930	−0.3721	1.0964
0.2137	0.733 66	1.0470	1.4139	−0.2254	1.0527	0.8039	0.683 31	0.4331	1.3880	−0.3210	1.0742
0.3024	0.728 07	0.9328	1.4112	−0.2734	1.0742	0.9037	0.670 05	0.3631	1.3810	−0.1941	1.0491
0.4043	0.721 00	0.8164	1.4077	−0.3243	1.0988	1.0000	0.655 07	0.2987	1.3723	0.0000	1.0000
0.5067	0.713 06	0.7076	1.4037	−0.3643	1.1138						
					Hexane (1) + Hexadecane (2)						
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6072	0.725 62	0.9870	1.4107	−0.7298	1.3193
0.1046	0.764 83	2.6585	1.4306	−0.2598	1.0976	0.7062	0.713 30	0.7626	1.4045	−0.7374	1.2847
0.1966	0.759 51	2.2505	1.4278	−0.3516	1.1521	0.8048	0.698 10	0.5800	1.3966	−0.6277	1.2304
0.3000	0.752 67	1.8802	1.4242	−0.4286	1.2257	0.9026	0.679 18	0.4277	1.3864	−0.3919	1.1403
0.4037	0.744 87	1.5474	1.4203	−0.5296	1.2854	1.0000	0.655 07	0.2987	1.3732	0.0000	1.0000
0.5142	0.735 22	1.2135	1.4155	−0.6512	1.3051						
					Heptane (1) + Octane (2)						
0.0000	0.698 42	0.5094	1.3951	0.0000	1.0000	0.6081	0.687 44	0.4285	1.3900	−0.0067	0.9950
0.1073	0.696 58	0.4942	1.3945	−0.0014	0.9993	0.7052	0.685 51	0.4201	1.3891	0.0024	1.0020
0.2098	0.694 81	0.4774	1.3936	−0.0084	0.9931	0.8070	0.683 45	0.4103	1.3882	0.0106	1.0065
0.3128	0.692 99	0.4614	1.3925	−0.0145	0.9875	0.9012	0.681 53	0.3958	1.3873	0.0124	0.9965
0.4060	0.691 30	0.4539	1.3917	−0.0178	0.9967	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5089	0.689 37	0.4431	1.3907	−0.0156	1.0011						
					Heptane (1) + Nonane (2)						
0.0000	0.713 75	0.6600	1.4033	0.0000	1.0000	0.6073	0.694 82	0.4838	1.3936	−0.0468	1.0174
0.1102	0.710 70	0.6128	1.4021	−0.0263	0.9849	0.7071	0.691 16	0.4588	1.3916	−0.0327	1.0149
0.2046	0.707 97	0.5921	1.4006	−0.0446	1.0009	0.8027	0.687 50	0.4312	1.3897	−0.0168	1.0039
0.3052	0.704 92	0.5620	1.3989	−0.0564	1.0026	0.8996	0.683 65	0.4081	1.3875	−0.0032	1.0007
0.4070	0.701 69	0.5372	1.3974	−0.0630	1.0120	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5092	0.698 27	0.5104	1.3954	−0.0589	1.0156						
					Heptane (1) + Decane (2)						
0.0000	0.726 30	0.8459	1.4097	0.0000	1.0000	0.6069	0.701 53	0.5466	1.3974	−0.0861	1.0394
0.0985	0.722 84	0.8051	1.4086	−0.0247	1.0281	0.7083	0.696 39	0.4983	1.3953	−0.0728	1.0259
0.2017	0.719 03	0.7450	1.4064	−0.0523	1.0315	0.8023	0.691 31	0.4575	1.3916	−0.0539	1.0139
0.3053	0.714 97	0.6806	1.4043	−0.0742	1.0219	0.9030	0.685 50	0.4242	1.3886	−0.0267	1.0172
0.4073	0.710 71	0.6363	1.4021	−0.0871	1.0349	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5076	0.706 25	0.5891	1.3997	−0.0923	1.0364						
					Heptane (1) + Undecane (2)						
0.0000	0.736 30	1.0841	1.4152	0.0000	1.0000	0.6076	0.707 43	0.6072	1.4002	−0.1327	1.0481
0.1084	0.732 06	0.9818	1.4130	−0.0505	1.0128	0.7041	0.701 44	0.5479	1.3970	−0.1197	1.0447
0.2093	0.727 80	0.8983	1.4108	−0.0861	1.0283	0.8052	0.694 61	0.4894	1.3943	−0.0939	1.0358
0.3019	0.723 60	0.8173	1.4085	−0.1096	1.0293	0.8998	0.687 63	0.4335	1.3987	−0.0554	1.0115
0.4051	0.718 57	0.7452	1.4060	−0.1284	1.0439	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5067	0.713 21	0.6720	1.4033	−0.1369	1.0453						
					Heptane (1) + Dodecane (2)						
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6081	0.713 08	0.6772	1.4032	−0.2030	1.0643
0.1076	0.740 51	1.2194	1.4174	−0.0610	1.0139	0.7046	0.706 07	0.5964	1.3994	−0.1773	1.0597
0.2092	0.735 89	1.0858	1.4150	−0.1165	1.0274	0.8043	0.698 05	0.5157	1.3954	−0.1336	1.0402
0.3109	0.730 84	0.9598	1.4133	−0.1590	1.0336	0.9039	0.689 13	0.4454	1.3907	−0.0726	1.0198
0.4064	0.725 68	0.8662	1.4097	−0.1914	1.0533	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5062	0.719 75	0.7707	1.4067	−0.2047	1.0640						

Table 2. (Continued)

x_1	ϱ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)	x_1	ϱ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)
Heptane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6070	0.731 82	1.0801	1.4133	−0.3930	1.2341
0.1067	0.765 09	2.6179	1.4316	−0.1382	1.0567	0.7086	0.721 69	0.8554	1.4082	−0.3873	1.2073
0.1981	0.760 43	2.2676	1.4281	−0.1977	1.1069	0.8028	0.710 53	0.6800	1.4020	−0.3235	1.1675
0.3001	0.754 58	1.9219	1.4253	−0.2453	1.1599	0.9019	0.696 44	0.5217	1.3946	−0.1872	1.1007
0.4055	0.747 77	1.6034	1.4217	−0.3015	1.2048	1.0000	0.679 54	0.3865	1.3852	0.0000	1.0000
0.5077	0.740 25	1.3075	1.4186	−0.3571	1.2152						
Octane (1) + Nonane (2)											
0.0000	0.713 75	0.6600	1.4033	0.0000	1.0000	0.6076	0.704 85	0.5586	1.3991	−0.0162	0.9906
0.1092	0.712 25	0.6310	1.4027	−0.0097	0.9835	0.7044	0.703 32	0.5497	1.3983	−0.0149	0.9996
0.2071	0.710 86	0.6264	1.4021	−0.0135	1.0014	0.8047	0.701 70	0.5318	1.3974	−0.0125	0.9925
0.3038	0.709 46	0.6069	1.4012	−0.0167	0.9948	0.9025	0.700 08	0.5116	1.3963	−0.0079	0.9793
0.4058	0.707 95	0.5951	1.4005	−0.0187	1.0016	1.0000	0.698 42	0.5094	1.3951	0.0000	1.0000
0.5051	0.706 44	0.5768	1.3997	−0.0176	0.9961						
Octane (1) + Decane (2)											
0.0000	0.726 30	0.8459	1.4097	0.0000	1.0000	0.6061	0.710 81	0.6305	1.4027	−0.0463	1.0136
0.1059	0.723 85	0.8166	1.4093	−0.0156	1.0186	0.7032	0.707 97	0.6018	1.4010	−0.0460	1.0163
0.2142	0.721 23	0.7747	1.4077	−0.0258	1.0209	0.8002	0.705 01	0.5722	1.3989	−0.0414	1.0150
0.3038	0.718 98	0.7382	1.4070	−0.0323	1.0181	0.9058	0.701 61	0.5366	1.3968	−0.0242	1.0043
0.4052	0.716 34	0.6937	1.4060	−0.0377	1.0072	1.0000	0.698 42	0.5094	1.3951	0.0000	1.0000
0.5057	0.713 63	0.6694	1.4036	−0.0436	1.0227						
Octane (1) + Undecane (2)											
0.0000	0.736 30	1.0841	1.4152	0.0000	1.0000	0.6089	0.715 94	0.7019	1.4043	−0.0759	1.0255
0.1011	0.733 39	1.0124	1.4132	−0.0313	1.0080	0.7063	0.712 00	0.6450	1.4023	−0.0753	1.0143
0.2077	0.730 10	0.9375	1.4118	−0.0457	1.0116	0.8047	0.707 77	0.6014	1.4000	−0.0674	1.0187
0.3112	0.726 72	0.8621	1.4097	−0.0545	1.0059	0.9039	0.703 20	0.5503	1.3975	−0.0446	1.0047
0.4060	0.723 47	0.8112	1.4080	−0.0629	1.0168	1.0000	0.698 42	0.5094	1.3951	0.0000	1.0000
0.5073	0.719 81	0.7521	1.4056	−0.0694	1.0177						
Octane (1) + Dodecane (2)											
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6088	0.720 90	0.7703	1.4067	−0.1112	1.0242
0.1117	0.741 33	1.2325	1.4177	−0.0438	0.9989	0.7035	0.716 12	0.7100	1.4044	−0.1072	1.0374
0.2101	0.737 81	1.1383	1.4157	−0.0673	1.0175	0.8040	0.710 63	0.6353	1.4014	−0.0902	1.0260
0.3025	0.734 28	1.0381	1.4140	−0.0816	1.0174	0.9048	0.704 63	0.5647	1.3982	−0.0563	1.0083
0.4085	0.729 97	0.9477	1.4112	−0.0976	1.0322	1.0000	0.698 42	0.5094	1.3951	0.0000	1.0000
0.5069	0.725 67	0.8672	1.4094	−0.1055	1.0418						
Octane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6068	0.737 67	1.2049	1.4167	−0.2413	1.1638
0.1039	0.765 72	2.6558	1.4308	−0.0856	1.0356	0.7096	0.729 53	0.9820	1.4123	−0.2327	1.1418
0.2122	0.760 89	2.3053	1.4283	−0.1328	1.0929	0.8067	0.720 66	0.7957	1.4073	−0.1938	1.1022
0.3109	0.755 99	1.9734	1.4257	−0.1667	1.1178	0.9049	0.710 23	0.6421	1.4015	−0.1143	1.0618
0.4114	0.750 44	1.6824	1.4229	−0.1952	1.1424	1.0000	0.698 42	0.5094	1.3951	0.0000	1.0000
0.5033	0.744 81	1.4524	1.4204	−0.2229	1.1640						
Nonane (1) + Decane (2)											
0.0000	0.726 30	0.8459	1.4097	0.0000	1.0000	0.6085	0.718 93	0.7344	1.4064	−0.0016	1.0097
0.1051	0.725 04	0.8387	1.4093	0.0106	1.0177	0.7065	0.717 65	0.7185	1.4056	0.0031	1.0122
0.2082	0.723 83	0.8061	1.4088	0.0083	1.0035	0.8060	0.716 33	0.6913	1.4048	0.0073	0.9982
0.3045	0.722 69	0.7835	1.4083	0.0037	0.9989	0.8970	0.715 12	0.6734	1.4043	0.0067	0.9946
0.4048	0.721 48	0.7761	1.4077	−0.0004	1.0144	1.0000	0.713 75	0.6600	1.4033	0.0000	1.0000
0.5057	0.720 24	0.7535	1.4071	−0.0041	1.0099						
Nonane (1) + Undecane (2)											
0.0000	0.736 30	1.0841	1.4152	0.0000	1.0000	0.6037	0.723 68	0.8141	1.4086	−0.0214	1.0133
0.1034	0.734 32	1.0305	1.4136	−0.0073	1.0006	0.7055	0.721 27	0.7700	1.4073	−0.0190	1.0080
0.2088	0.732 23	0.9658	1.4130	−0.0133	0.9881	0.8002	0.718 94	0.7331	1.4060	−0.0138	1.0059
0.3024	0.730 31	0.9310	1.4123	−0.0175	0.9978	0.9038	0.716 30	0.6870	1.4045	−0.0079	0.9924
0.4073	0.728 09	0.8929	1.4108	−0.0227	1.0081	1.0000	0.713 75	0.6600	1.4033	0.0000	1.0000
0.5057	0.725 92	0.8476	1.4096	−0.0230	1.0049						
Nonane (1) + Dodecane (2)											
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6103	0.727 94	0.8955	1.4107	−0.0460	1.0181
0.0957	0.742 67	1.2731	1.4183	−0.0127	0.9906	0.7039	0.724 81	0.8282	1.4093	−0.0415	1.0088
0.1995	0.739 99	1.1868	1.4177	−0.0247	0.9969	0.8049	0.721 25	0.7721	1.4071	−0.0333	1.0132
0.3049	0.737 13	1.1109	1.4157	−0.0346	1.0085	0.9023	0.717 61	0.7118	1.4054	−0.0186	1.0036
0.4056	0.734 26	1.0224	1.4142	−0.0425	0.9996	1.0000	0.713 75	0.6600	1.4033	0.0000	1.0000
0.5088	0.731 15	0.9690	1.4126	−0.0439	1.0223						
Nonane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.5795	0.744 65	1.4037	1.4204	−0.1418	1.1108
0.1105	0.765 99	2.6980	1.4323	−0.0493	1.0346	0.7077	0.736 86	1.1517	1.4160	−0.1436	1.1110
0.2002	0.762 58	2.4156	1.4304	−0.0730	1.0640	0.8024	0.730 30	0.9655	1.4125	−0.1229	1.0781
0.3173	0.757 70	2.0717	1.4277	−0.0976	1.0935	0.8988	0.722 77	0.8177	1.4084	−0.0782	1.0596
0.4054	0.753 67	1.8324	1.4254	−0.1129	1.1081	1.0000	0.713 75	0.6600	1.4033	0.0000	1.0000
0.5056	0.748 68	1.5707	1.4227	−0.1343	1.1089						

Table 2. (Continued)

x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)	x_1	ρ/(g·cm^{-3})	η/(mPa·s)	n_D	V^E/(cm^3·mol^{-1})	$\Delta\eta$/(mPa·s)
Decane (1) + Undecane (2)											
0.0000	0.736 30	1.0841	1.4152	0.0000	1.0000	0.6080	0.730 42	0.9393	1.4125	−0.0019	1.0075
0.1074	0.735 30	1.0562	1.4148	0.0002	1.0006	0.7092	0.729 38	0.9206	1.4117	−0.0010	1.0126
0.2094	0.734 34	1.0305	1.4144	−0.0012	1.0012	0.8045	0.728 39	0.9013	1.4113	−0.0015	1.0150
0.3054	0.733 42	1.0094	1.4139	−0.0018	1.0044	0.9056	0.727 32	0.8680	1.4105	−0.0014	1.0024
0.4086	0.732 41	0.9854	1.4134	−0.0009	1.0059	1.0000	0.726 30	0.8459	1.4097	0.0000	1.0000
0.5085	0.731 42	0.9556	1.4129	−0.0012	1.0000						
Decane (1) + Dodecane (2)											
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6096	0.734 38	1.0357	1.4147	−0.0195	1.0117
0.1071	0.743 32	1.2943	1.4190	−0.0108	0.9889	0.7085	0.732 43	0.9801	1.4137	−0.0151	1.0048
0.2012	0.741 76	1.2431	1.4181	−0.0164	0.9945	0.8052	0.730 46	0.9488	1.4125	−0.0100	1.0198
0.3014	0.740 04	1.1977	1.4173	−0.0193	1.0063	0.9045	0.728 38	0.9028	1.4115	−0.0069	1.0186
0.4079	0.738 15	1.1464	1.4165	−0.0211	1.0147	1.0000	0.726 30	0.8459	1.4097	0.0000	1.0000
0.5077	0.736 32	1.0922	1.4156	−0.0220	1.0150						
Decane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6095	0.747 91	1.5301	1.4225	−0.0865	1.0902
0.1051	0.766 75	2.7492	1.4328	−0.0356	1.0186	0.7051	0.743 34	1.3364	1.4199	−0.0774	1.0779
0.2075	0.763 51	2.4810	1.4309	−0.0575	1.0497	0.8037	0.738 19	1.1702	1.4170	−0.0626	1.0725
0.3045	0.760 20	2.1999	1.4290	−0.0739	1.0555	0.9041	0.732 40	0.9885	1.4139	−0.0342	1.0320
0.4045	0.756 50	1.9760	1.4271	−0.0814	1.0794	1.0000	0.726 30	0.8459	1.4097	0.0000	1.0000
0.5081	0.752 35	1.7331	1.4243	−0.0885	1.0828						
Undecane (1) + Dodecane (2)											
0.0000	0.745 03	1.3791	1.4196	0.0000	1.0000	0.6095	0.739 87	1.1753	1.4171	−0.0017	0.9869
0.1060	0.744 18	1.3144	1.4192	−0.0048	0.9777	0.7174	0.738 89	1.1425	1.4166	0.0031	0.9846
0.2057	0.743 37	1.2972	1.4190	−0.0098	0.9884	0.8145	0.738 01	1.1265	1.4163	0.0028	0.9937
0.3093	0.742 50	1.2525	1.4188	−0.0102	0.9784	0.9084	0.737 14	1.1095	1.4156	0.0044	1.0011
0.4136	0.741 60	1.2365	1.4184	−0.0074	0.9904	1.0000	0.736 30	1.0841	1.4152	0.0000	1.0000
0.5553	0.740 35	1.1960	1.4180	−0.0022	0.9912						
Undecane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6081	0.752 24	1.7229	1.4245	−0.0429	1.0538
0.1095	0.767 14	2.7830	1.4331	−0.0228	1.0092	0.7051	0.748 71	1.5341	1.4227	−0.0364	1.0388
0.2008	0.764 76	2.5490	1.4314	−0.0340	1.0172	0.8060	0.744 77	1.3633	1.4204	−0.0273	1.0261
0.3116	0.761 68	2.3154	1.4293	−0.0428	1.0378	0.9031	0.740 69	1.2093	1.4182	−0.0157	1.0077
0.4052	0.758 90	2.1081	1.4279	−0.0464	1.0423	1.0000	0.736 30	1.0841	1.4152	0.0000	1.0000
0.5071	0.755 67	1.9046	1.4266	−0.0464	1.0479						
Dodecane (1) + Hexadecane (2)											
0.0000	0.769 81	3.0930	1.4334	0.0000	1.0000	0.6082	0.756 37	1.9359	1.4261	−0.0369	1.0229
0.1077	0.767 72	2.8209	1.4331	−0.0132	0.9949	0.7053	0.753 80	1.7671	1.4238	−0.0349	1.0099
0.2113	0.765 59	2.6426	1.4321	−0.0186	1.0134	0.8045	0.751 02	1.6361	1.4233	−0.0282	1.0131
0.3061	0.763 56	2.4667	1.4309	−0.0276	1.0212	0.9050	0.748 03	1.4756	1.4218	−0.0162	0.9909
0.4097	0.761 22	2.2808	1.4296	−0.0328	1.0267	1.0000	0.745 03	1.3791	1.4196	0.0000	1.0000
0.5073	0.758 89	2.1020	1.4279	−0.0328	1.0238						

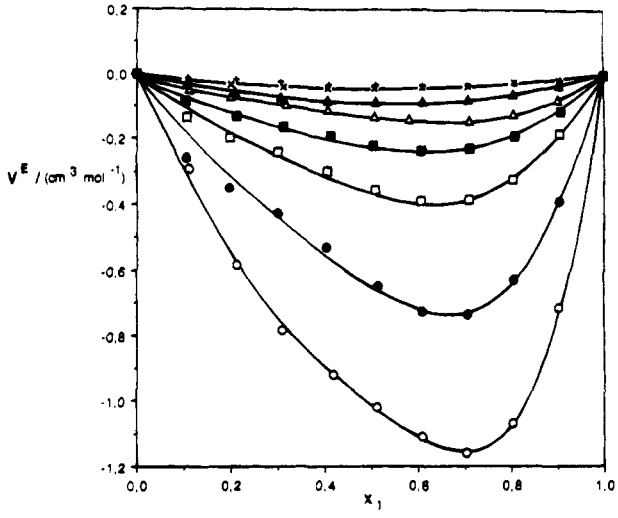

Figure 2. Excess volumes of mixtures of hexadecane (2) with all other n-alkanes (1): (○) pentane, (●) hexane, (□) heptane, (■) octane, (△) nonane, (▲) decane, (×) undecane, (+) dodecane.

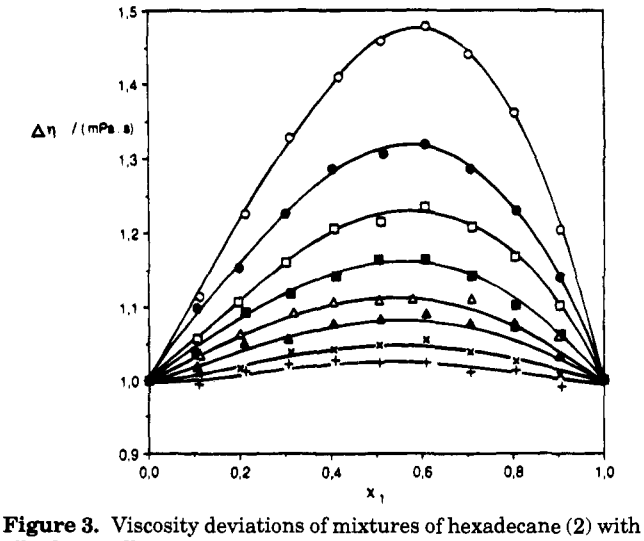

Figure 3. Viscosity deviations of mixtures of hexadecane (2) with all other n-alkanes (1): (○) pentane, (●) hexane, (□) heptane, (■) octane, (△) nonane, (▲) decane, (×) undecane, (+) dodecane.

are the mole fractions and molar volumes of the pure components, respectively.

The excess molar volumes for all the binary mixtures are negative over the whole mole fraction range at 298.15 K. They become more and more negative as the difference of the length of n-alkanes involved in the mixture increases. Only the systems whose components differ in one C atom show that V^E changes from positive to negative, but with such small values that it can be included in the experimental errors.

Table 3. Values of the McAllister Three-Body and Heric Models

	McAllister model			Heric model		
system	$\nu_{12} \times 10^6/(m^2 s^{-1})$	$\nu_{12} \times 10^6/(m^2 s^{-1})$	ϵ/%	α_{12}	α'_{12}	ϵ/%
pentane (1) + hexane (2)	0.3870	0.6478	0.14	−0.0011	−0.0012	0.14
pentane (1) + heptane (2)	0.4327	0.7974	0.41	0.0590	0.0005	0.41
pentane (1) + octane (2)	0.4807	0.9721	0.20	0.0958	0.0098	0.20
pentane (1) + nonane (2)	0.5376	1.2008	0.08	0.1586	0.0073	0.08
pentane (1) + decane (2)	0.6314	1.4727	0.52	0.2459	0.0168	0.54
pentane (1) + undecane (2)	0.7041	1.8160	0.34	0.3211	0.0357	0.34
pentane (1) + dodecane (2)	0.8426	2.1108	0.20	0.3998	0.1009	0.21
pentane (1) + hexadecane (2)	1.6179	4.2768	0.42	0.8314	0.2747	0.48
hexane (1) + heptane (2)	0.4911	0.8139	0.23	0.0046	−0.0012	0.23
hexane (1) + octane (2)	0.5318	0.9974	0.30	0.0231	−0.0122	0.33
hexane (1) + nonane (2)	0.6014	1.1995	0.32	0.0706	0.0015	0.35
hexane (1) + decane (2)	0.6636	1.5138	0.48	0.1369	−0.0122	0.48
hexane (1) + undecane (2)	0.7628	1.7673	0.48	0.1722	0.0201	0.57
hexane (1) + dodecane (2)	0.8836	2.0920	0.28	0.2562	0.0581	0.58
hexane (1) + hexadecane (2)	1.5242	4.3021	0.45	0.6089	0.1578	0.48
heptane (1) + octane (2)	0.6264	1.0070	0.28	−0.0008	0.0179	0.28
heptane (1) + nonane (2)	0.6935	1.2180	0.38	0.0345	0.0094	0.38
heptane (1) + decane (2)	0.7456	1.5489	0.45	0.0779	−0.0006	0.49
heptane (1) + undecane (2)	0.8489	1.7908	0.20	0.1045	−0.0009	0.38
heptane (1) + dodecane (2)	0.9472	2.1131	0.27	0.1474	0.0380	0.41
heptane (1) + hexadecane (2)	1.5908	4.2064	0.23	0.4498	0.1448	0.25
octane (1) + nonane (2)	0.7720	1.3183	0.50	−0.0066	−0.0205	0.50
octane (1) + decane (2)	0.8692	1.6127	0.38	0.0455	−0.0128	0.38
octane (1) + undecane (2)	0.9437	1.8808	0.26	0.0445	0.0009	0.26
octane (1) + dodecane (2)	1.0583	2.2293	0.44	0.0810	0.0235	0.44
octane (1) + hexadecane (2)	1.6620	4.3529	0.32	0.3236	0.0801	0.32
nonane (1) + decane (2)	1.0050	1.6789	0.48	0.0187	−0.0006	0.48
nonane (1) + undecane (2)	1.1043	1.9348	0.38	0.0202	−0.0006	0.46
nonane (1) + dodecane (2)	1.2126	2.2658	0.45	0.0179	0.0246	0.52
nonane (1) + hexadecane (2)	1.7978	4.5502	0.34	0.2386	0.0391	0.34
decane (1) + undecane (2)	1.2913	2.0675	0.22	0.0151	0.0166	0.22
decane (1) + dodecane (2)	1.4379	2.4088	0.47	0.0306	0.0189	0.56
decane (1) + hexadecane (2)	2.0669	4.5379	0.34	0.1609	0.0430	0.59
undecane (1) + dodecane (2)	1.5723	2.5391	0.40	−0.0189	0.0033	0.46
undecane (1) + hexadecane (2)	2.2024	4.8269	0.38	0.0989	0.0104	0.38
dodecane (1) + hexadecane (2)	2.4630	5.0585	0.44	0.0543	−0.0045	0.44

The viscosity deviations were calculated with the expression proposed by Ratcliff (*29*):

$$\ln \Delta\eta = \ln \eta - \sum x_i \ln \eta_i \quad (3)$$

where η is the viscosity of the mixture and x_i and η_i are the mole fraction and the viscosity of the pure components, respectively.

Figures 1–3 show the viscosity–composition data, the excess molar volume–composition data, and the viscosity deviation–composition data for the hexadecane (2) with all other *n*-alkanes (1) systems as an illustration.

The McAllister three-body model (*30*) and the Heric model (*31*) have been used to fit the experimental kinematic viscosity–composition data. The McAllister three-body model is given by the equation

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

and the Heric model is given by the equation

$$\log \nu_m = x_1 \log \nu_1 + x_2 \log \nu_2 + x_1 \log M_1 + x_2 \log M_2 - \log[x_1 M_1 + x_2 M_2] + \delta_{12} \quad (5)$$

where δ_{12} is a deviation function:

$$\delta_{12} = x_1 x_2[\alpha_{12} + \alpha'_{12}(x_1 - x_2)] \quad (6)$$

The values of the adjustable parameters ν_{12} and ν_{21} included in eq 4 and α_{12} and α'_{12} included in eq 6 were determined for the systems studied using the Solver method (Excel 4.0, Microsoft). These values are reported in Table 3, together with the average error , ϵ (%), defined as

$$\epsilon = 100\left|\frac{\nu_{exptl} - \nu_{calc}}{\nu_{exptl}}\right|/N \quad (N = \text{no. data points}) \quad (7)$$

The average error of the fits indicates that the models given by eqs 4 and 5 fit the experimental data very well.

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