Viscosity of Methane–*n*-Decane Mixtures

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Data are presented for methane–*n*-decane mixtures containing, nominally, 30, 50, and 70 mole % methane. The methods for correlation are discussed and tables of recommended viscosity values for temperatures from 100° to 340° F. and pressures from bubble point pressure to 10,000 p.s.i.a. are presented.

THIS investigation is one of several recent efforts by the authors to provide viscosity data for pure hydrocarbons and mixtures. The results for methane (*8*), ethane (*5*), propane (*14*), *n*-butane (*4*), *n*-pentane (*10*), and *n*-decane (*11*) have been presented. Detailed studies of the viscosity behavior in the critical region for ethane, propane, and *n*-butane have also been reported (*15*).

Few investigations of the viscosity behavior of binary hydrocarbon mixtures for an extensive pressure-temperature range have been found in the literature. Bicher and Katz (*1*) and Giddings (*7*) reported viscosity values for the pure components and mixtures of the methane-propane system. Dolan and coworkers (*3*) reported viscosity values for methane–*n*-butane mixtures. No data were found on methane–*n*-decane mixtures.

APPARATUS AND MATERIALS

The viscometer used for this investigation has been described (*3, 6*). A sample-circulating pump (*6*) and Teflon spaghetti were installed to permit automatic operation and thorough mixing of multicomponent samples. The Teflon spaghetti is mounted on a Teflon O-ring, which in turn floats on the mercury. The sample is circulated through the spaghetti, into the bottom of the vessel, bubbles through the bulk of the mixture, and leaves the vessel at the top. A schematic diagram is presented in Figure 1.

An analysis of the methane used (Southern California Gas Co.) yielded 99.6% methane and 0.1% nitrogen; the remainder was ethane, propane, *n*-butane, and carbon dioxide. The *n*-decane used was Phillips Petroleum Co. pure grade, certified 99 mole % minimum purity.

EXPERIMENTAL DATA

Data were obtained on three binary mixtures of methane–*n*-decane, which have compositions (mole fraction): $0.3C_1$-$0.7nC_{10}$, $0.5C_1$-$0.5nC_{10}$, and $0.7C_1$-$0.3nC_{10}$. The temperature range was from 100° to 340° F. and the pressure range was from bubble point pressure to 7000 p.s.i.a. Experimental data are presented in parentheses in Tables I to V.

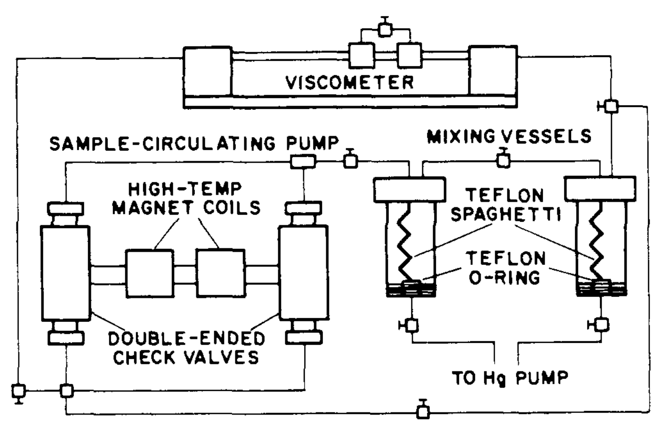

Figure 1. Schematic diagram of viscometer, sample-circulating pump, and mixing vessels

This system was chosen because of the availability of density data (*13*) and the possibility of extensive study of the effect of a heavier hydrocarbon on the viscosity behavior in a mixture. Mixtures of desired composition were prepared by the volumetric displacement technique (*3*). Duplicate mixtures of $0.5C_1$-$0.5nC_{10}$ were measured and the sample analysis showed a deviation in composition of $\pm 1\%$.

Plots of viscosity *vs.* pressure for these three mixtures are presented in Figures 2 and 3; viscosity *vs.* mole fraction of methane at 100° F. is presented in Figure 4 to illustrate the general behavior of this system. Experimental data of the mixtures as well as of *n*-decane (*11*) and methane (*8*) are indicated by open symbols.

DATA TREATMENT

The residual viscosity concept, discussed elsewhere (*2, 3*), was used in this work. Residual viscosity is defined as the difference between the viscosity at a given pressure and temperature, and μ_o, the viscosity at the dilute gas phase, which is usually at 1-atm. pressure and the same temperature. The residual viscosity is then plotted against density on linear coordinates; usually a smooth continuous curve may be drawn through all the data points. If the density values for a system are known for various temperatures and pressures, the viscosity values at those conditions may be interpolated from this plot.

Because of the high critical temperatures and the critical pressures of the methane–*n*-decane system (*12*), the gas phase of this system is below 1-atm. pressure for the conditions studied in this paper; no experimental data were taken. The gas phase viscosity values are estimated by the method of Lee and Eakin (*9*), and the residual viscosity-density plot is presented in Figure 5. As can be seen, the residual viscosity shows temperature dependence for these mixtures, especially at lower temperatures. This behavior could be due to the lack of accurate data on μ_o, the gas phase viscosities.

Since experimental data for methane, *n*-decane, and three methane–*n*-decane mixtures are available, plots of viscosity *vs.* mole fraction of methane were constructed for temperatures of 100°, 160°, 220°, 280°, and 340° F. From the plots of

Table I. Viscosity of

Methane,

	0.1		0.2		0.3			0.4		0.5
P,[a] P.S.I.A.	D,[a] g./cc.	V,[a] μpoises	D, g./cc.	V, μpoises	D, g./cc.	V, μpoises		D, g./cc.	V, μpoises	G./cc.
					100° F.					
400	0.7100	...	...	...	...	...	...	...	...	...
600	0.7108	6445	...	...	...	...	...	...	...	...
800	0.7125	6590	0.6982	5835	...	...	...	...	...	...
1,000	0.7137	6800	0.6998	5950	...	...	...	...	...	...
1,250	0.7157	6910	0.7019	6075	...	...	...	...	...	...
1,500	0.7176	7075	0.7037	6215	0.6838	5330	(5444.9)[b]	...	...	...
1,750	0.7191	7240	0.7055	6350	0.6857	5440	...	0.6614	4625	...
2,000	0.7206	7420	0.7074	6450	0.6874	5550	(5607.1)	0.6617	4720	...
2,250	0.7216	7550	0.7090	6600	0.6891	5650	...	0.6647	4810	...
2,500	0.7241	7700	0.7109	6715	0.6911	5750	(5789.1)	0.6668	4900	0.6375
2,750	0.7262	7850	0.7125	6840	0.6926	5860	...	0.6689	4980	0.6391
3,000	0.7267	8000	0.7141	6950	0.6943	5960	(5892.8)	0.6704	5050	0.6414
3,500	0.7285	8310	0.7163	7200	0.6975	6150	(6110.1)	0.6760	5240	0.6453
4,000	0.7308	8610	0.7185	7450	0.7001	6360	(6315.5)	0.6794	5400	0.6483
4,500	0.7331	8875	0.7210	7665	0.7031	6550	(6597.2)	0.6829	5565	0.6520
5,000	0.7365	9125	0.7238	7890	0.7052	6750	(6730.1)	0.6854	5735	0.6560
6,000	0.7396	9700	0.7275	8320	0.7091	7125	...	0.6899	5050	0.6616
7,000	0.7431	10235	0.7303	8720	0.7133	7500	...	0.6948	6370	0.6664
8,000	0.7463	10745	0.7343	9140	0.7170	7830	...	0.6988	6680	0.6717
9,000	0.7492	11250	0.7377	9525	0.7207	8165	...	0.7031	6980	0.6767
10,000	0.7525	11740	0.7404	9910	0.7235	8500	...	0.7065	7300	0.6811
					160° F.					
400	0.6809	...	...	...	...	...	...	...	...	...
600	0.6832	4350	...	...	...	...	...	...	...	...
800	0.6877	4470	0.6690	3925	...	...	...	...	...	...
1,000	0.6877	4600	0.6722	4000	...	...	...	...	...	...
1,250	0.6923	4700	0.6748	4100	...	...	...	...	...	...
1,500	0.6927	4825	0.6773	4220	0.6556	3625	(3694.4)	...	...	...
1,750	0.6944	4950	0.6795	4320	0.6584	3715	(3743.2)	...	...	...
2,000	0.6967	5060	0.6822	4400	0.6616	3800	(3800.7)	0.6373	3225	...
2,250	0.6990	5175	0.6849	4510	0.6642	3890	...	0.6403	3315	...
2,500	0.7014	5280	0.6874	4620	0.6671	3970	(4018.8)	0.6431	3395	...
2,750	0.7038	5400	0.6899	4710	0.6693	4050	...	0.6454	3475	0.6125
3,000	0.7062	5500	0.6925	4820	0.6719	4130	(4182.3)	0.6480	3550	0.6152
3,500	0.7086	5715	0.6956	5000	0.6752	4300	...	0.6520	3700	0.6188
4,000	0.7115	5910	0.6985	5175	0.6788	4460	(4464.8)	0.6561	3850	0.6240
4,500	0.7142	6110	0.7016	5350	0.6818	4625	...	0.6596	4000	0.6296
5,000	0.7169	6310	0.7045	5550	0.6855	4800	(4798.0)	0.6644	4150	0.6353
6,000	0.7206	6700	0.7082	5870	0.6897	5100	...	0.6692	4440	0.6420
7,000	0.7244	7000	0.7128	6190	0.6952	5400	...	0.6763	4730	0.6499
8,000	0.7280	7350	0.7163	6450	0.6998	5650	...	0.6816	5000	0.6564
9,000	0.7315	7650	0.7205	6750	0.7049	5920	...	0.6873	5300	0.6618
10,000	0.7352	7960	0.7241	6950	0.7091	6175	...	0.6922	5575	0.6678

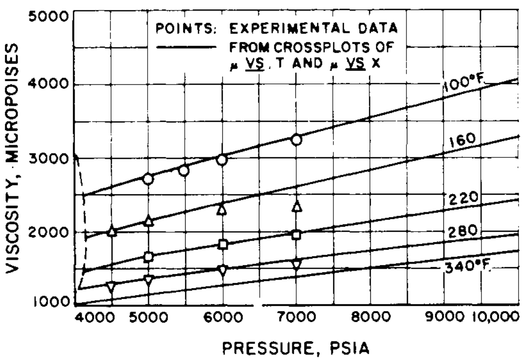

Figure 2. Viscosity *vs.* pressure
70 mole % methane–30 mole % *n*-decane

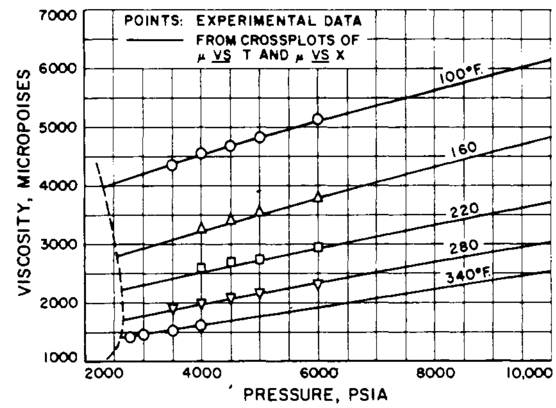

Figure 3. Viscosity *vs.* pressure
50 mole % methane–50 mole % *n*-decane

Methane–*n*-Decane Mixtures

Mole Fraction

0.5		0.6		0.7			0.8		0.9	
V, μpoises		D, g./cc.	V, μpoises	D, g./cc.	V, μpoises		D, g./cc.	V, μpoises	D, g./cc.	V, μpoises
					100° F.					
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
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...	...	...	...	...	...	...	...	...	...	...
4050	...	...	...	...	...	...	...	...	...	...
4120	...	...	...	...	...	...	...	...	...	...
4200	...	...	...	...	...	...	...	...	...	...
4350	(4351.7)[b]	0.6080	3410	...	...	...	...	...	...	...
4510	(4530.2)	0.6122	3530	...	...	...	...	...	...	...
4665	(4701.7)	0.6161	3675	0.5656	2600	...	...	...	...	...
4825	(4830.4)	0.6200	3810	0.5712	2750	(2683.4)[b]	0.4980	1625	...	...
5125	(5134.7)	0.6277	4095	0.5808	3030	(2793.3)	0.5109	1965	0.4010	885
5350	...	0.6340	4320	0.5887	3260	(3235.9)	0.5220	2250	0.4182	1119
5630	...	0.6401	4595	0.5948	3550	...	0.5312	2500	0.4312	1310
5900	...	0.6452	4850	0.6018	3820	...	0.5381	2720	0.4402	1485
6150	...	0.6503	5100	0.6069	4065	...	0.5466	2925	0.4484	1650
					160° F.					
...	...	...	...	...	...	...	...	...	...	...
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...	...	...	...	...	...	...	...	...	...	...
										...
...	...	...	...	...	...	...	...	...	...	...
2840	...	...	...	...	...	...	...	...	...	...
2925	...	...	...	...	...	...	...	...	...	...
3080	...	0.5805	2475	...	...	...	...	...	...	...
3245	(3307.5)	0.5853	2600	...	...	...	...	...	...	...
3380	(3426.0)	0.5928	2725	0.5384	2000	(1977.5)	...	...	...	...
3525	(3568.6)	0.5991	2850	0.5459	2120	(2132.5)	0.4648	1365	...	...
3800	(3788.3)	0.6090	3090	0.5575	2340	(2275.4)	0.4800	1575	0.3679	760
4070	...	0.6171	3325	0.5674	2550	(2318.8)	0.4939	1750	0.3852	920
4335	...	0.6244	3560	0.5757	2750	...	0.5037	1900	0.4000	1060
4590	...	0.6314	3780	0.5831	2940	...	0.5136	2060	0.4140	1180
4850	...	0.6371	4000	0.5907	3130	...	0.5224	2280	0.4236	1290

Table I. Viscosity of

Methane,

P,[a] P.S.I.A.	0.1 D,[a] g./cc.	0.1 V,[a] μpoises	0.2 D, g./cc.	0.2 V, μpoises	0.3 D, g./cc.	0.3 V, μpoises		0.4 D, g./cc.	0.4 V, μpoises	0.5 G./cc.
					220° F.					
400	0.6531	...	...	...	...	...	...	...	...	...
600	0.6572	...	...	...	...	...	...	...	...	...
800	0.6593	3320	...	...	...	...	...	...	...	...
1,000	0.6614	3400	0.6435	3000	...	...	...	...	...	...
1,250	0.6635	3490	0.6469	3080	...	...	...	...	...	...
1,500	0.6657	3580	0.6489	3160	0.6258	2580	(2819.7)	...	...	...
1,750	0.6678	3670	0.6505	3204	0.6289	2670	(2861.4)	...	...	...
2,000	0.6700	3760	0.6532	3320	0.6313	2750	(2908.9)	0.6050	2440	...
2,250	0.6721	3840	0.6548	3400	0.6339	2840	(2959.5)	0.6083	2500	...
2,500	0.6743	3930	0.6568	3470	0.6368	2930	(3042.5)	0.6116	2560	...
2,750	0.6743	4020	0.6592	3550	0.6388	3000	(3090.1)	0.6152	2620	0.5778
3,000	0.6787	4110	0.6617	3620	0.6420	3080	(3162.6)	0.6180	2680	0.5832
3,500	0.6809	4280	0.6657	3770	0.6459	3250	(3265.6)	0.6235	2800	0.5905
4,000	0.6854	4450	0.6693	3920	0.6492	3410	(3388.9)	0.6275	2920	0.5952
4,500	0.6877	4620	0.6734	4080	0.6535	3550	(3501.8)	0.6321	3050	0.6000
5,000	0.6923	4790	0.6773	4220	0.6579	3690	(3651.4)	0.6365	3170	0.6055
6,000	0.6978	5100	0.6842	4510	0.6653	3970	...	0.6443	3420	0.6137
7,000	0.7033	5400	0.6902	4800	0.6722	4240	...	0.6508	3650	0.6206
8,000	0.7083	5700	0.6956	5090	0.6777	4520	...	0.6572	3900	0.6277
9,000	0.7132	6000	0.7005	5390	0.6832	4780	...	0.6635	4150	0.6349
10,000	0.7176	6280	0.7050	5680	0.6883	5050	...	0.6695	4400	0.6414
					280° F.					
400	...	...	...	...	...	...	...	...	...	...
600	0.6293	...	...	...	...	...	...	...	...	...
800	0.6313	2550	...	...	...	...	...	...	...	...
1,000	0.6332	2610	0.6146	2350	...	...	...	...	...	...
1,250	0.6371	2680	0.6167	2420	...	...	...	...	...	...
1,500	0.6390	2760	0.6207	2480	0.5963	2120	(2148.4)	...	...	...
1,750	0.6430	2840	0.6249	2540	0.6008	2180	(2218.2)	...	...	...
2,000	0.6450	2900	0.6274	2600	0.6048	2240	(2265.0)	0.5743	1920	...
2,250	0.6470	2970	0.6301	2660	0.6074	2310	(2314.1)	0.5791	1980	...
2,500	0.6490	3030	0.6325	2720	0.6098	2370	(2386.9)	0.5827	2030	...
2,750	0.6511	3100	0.6348	2780	0.6123	2430	(2417.5)	0.5867	2080	0.5476
3,000	0.6531	3170	0.6372	2830	0.6150	2490	(2473.3)	0.5902	2120	0.5531
3,500	0.6572	3300	0.6420	2960	0.6200	2600	(2567.7)	0.5962	2220	0.5614
4,000	0.6614	3430	0.6460	3080	0.6251	2720	(2676.9)	0.6021	2320	0.5682
4,500	0.6657	3570	0.6509	3200	0.6303	2830	...	0.6078	2420	0.5744
5,000	0.6700	3700	0.6557	3320	0.6356	2950	...	0.6131	2520	0.5802
6,000	0.6765	3970	0.6624	3560	0.6430	3160	...	0.6211	2720	0.5894
7,000	0.6832	4230	0.6690	3800	0.6500	3370	...	0.6291	2920	0.5980
8,000	0.6900	4500	0.6751	4050	0.6564	3570	...	0.6359	3120	0.6058
9,000	0.6946	4770	0.6805	4300	0.6623	3760	...	0.6429	3320	0.6134
10,000	0.7000	5040	0.6862	4550	0.6679	3950	...	0.6485	3520	0.6200
					340° F.					
400	...	...	...	...	...	...		...	...	...
600	0.5985	...	...	...	...	...		...	...	...
800	0.6020	2000	...	...	...	...		...	...	...
1,000	0.6055	2080	0.5822	1880	...	...		...	...	...
1,250	0.6090	2140	0.5877	1930	...	...		...	...	...
1,500	0.6126	2200	0.5914	1990	0.5631	1730		...	...	...
1,750	0.6163	2260	0.5951	2040	0.5675	1790		...	...	...
2,000	0.6200	2320	0.5989	2090	0.5737	1840		0.5401	1600	...
2,250	0.6218	2380	0.6008	2140	0.5781	1890		0.5470	1640	...
2,500	0.6256	2430	0.6047	2190	0.5817	1940		0.5521	1680	...
2,750	0.6245	2500	0.6087	2240	0.5838	2000		0.5552	1720	0.5119
3,000	0.6293	2560	0.6106	2290	0.5877	2050		0.5605	1770	0.5193
3,500	0.6351	2680	0.6167	2400	0.5934	2140		0.5694	1830	0.5346
4,000	0.6390	2790	0.6207	2500	0.5987	2240		0.5754	1920	0.5426
4,500	0.6430	2910	0.6261	2600	0.6048	2330		0.5813	2000	0.5476
5,000	0.6490	3025	0.6318	2700	0.6105	2420		0.5874	2090	0.5553
6,000	0.6572	3280	0.6416	2900	0.6219	2600		0.5991	2240	0.5662
7,000	0.6635	3510	0.6496	3110	0.6300	2770		0.6078	2400	0.5763
8,000	0.6700	3750	0.6550	3320	0.6351	2940		0.6139	2550	0.5840
9,000	0.6765	4000	0.6599	3520	0.6402	3090		0.6190	2720	0.5897
10,000	0.6809	4230	0.6662	3730	0.6462	3240		0.6248	2850	0.5958

[a] Experimental data. [b] P, pressure. D, density. V, viscosity.

Methane–*n*-Decane Mixtures (*Continued*)

Mole Fraction

0.5		0.6		0.7			0.8		0.9	
V, μpoises		D, g./cc.	V, μpoises	D, g./cc.	V, μpoises		D, g./cc.	V, μpoises	D, g./cc.	V, μpoises
					220° F.					
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
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...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
2185	...	...	...	...	...	...	...	...	...	...
2250	...	...	...	...	...	...	...	...	...	...
2365	...	0.5441	1860	...	...	...	...	...	...	...
2475	(2603.8)	0.5519	1975	...	...	...	...	...	...	...
2585	(2700.0)	0.5592	2070	0.5009	1590	...	...	...	...	...
2700	(2743.3)	0.5657	2170	0.5092	1670	(1684.8)	0.4270	1090	0.3103	...
2910	(2959.1)	0.5755	2360	0.5231	1825	(1829.4)	0.4484	1260	0.3366	675
3120	...	0.5843	2545	0.5351	1975	(1971.2)	0.4641	1405	0.3568	805
3315	...	0.5931	2730	0.5445	2125	...	0.4755	1540	0.3706	915
3510	...	0.6015	2920	0.5539	2275	...	0.4867	1670	0.3878	1010
3685	...	0.6083	3110	0.5611	2425	...	0.4969	1780	0.3996	1100
					280° F.					
...	...	...	...	...	...	...	...	...	...	...
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1720	...	...	...	...	...	...	...	...	...	...
1775	...	...	...	...	...	...	...	...	...	...
1870	(1951.3)	0.5127	1500	...	...	...	...	...	...	...
1965	(2042.9)	0.5219	1575	...	...	...	...	...	...	...
2050	(2106.9)	0.5305	1655	0.4691	1290	(1295.6)	0.3801	850	0.2624	...
2145	(2181.1)	0.5386	1735	0.4790	1370	(1375.4)	0.3941	930	0.2802	...
2325	(2317.9)	0.5502	1900	0.4960	1500	(1495.6)	0.4186	1060	0.3080	600
2500	...	0.5609	2070	0.5098	1625	(1554.3)	0.4368	1180	0.3301	705
2670	...	0.5699	2220	0.5206	1750	...	0.4511	1300	0.3487	805
2840	...	0.5786	2380	0.5301	1875	...	0.4628	1420	0.3636	890
3010	...	0.5863	2540	0.5397	2000	...	0.4745	1525	0.3770	970
					340° F.					
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1420	(1411.6)	...	...	...	...		...	...	...	...
1460	(1449.5)	...	...	...	...		...	...	...	...
1530	(1526.4)	0.4811	1250	...	...		...	...	...	...
1610	(1597.0)	0.4941	1315	0.4215	1020		...	...	0.2199	...
1680	...	0.5020	1385	0.4355	1075		0.3466	...	0.2385	...
1760	...	0.5104	1455	0.4482	1140		0.3636	825	0.2552	...
1910	...	0.5253	1585	0.4686	1260		0.3909	940	0.2836	555
2060	...	0.5375	1725	0.4841	1375		0.4111	1040	0.3065	645
2210	...	0.5477	1860	0.4972	1500		0.4273	1150	0.3259	730
2360	...	0.5554	1980	0.5077	1620		0.4415	1250	0.3419	810
2510	...	0.5624	2110	0.5177	1730		0.4539	1360	0.3554	890

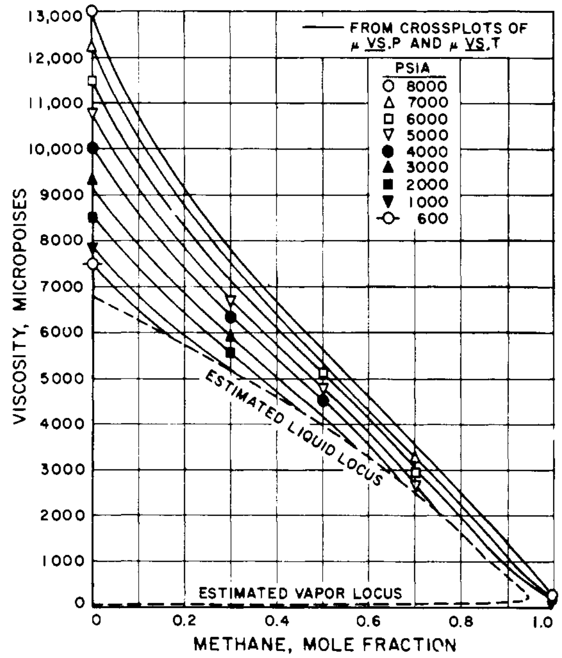

Figure 4. Viscosity of methane–*n*-decane mixtures *vs.* mole fraction of methane at 100° F.

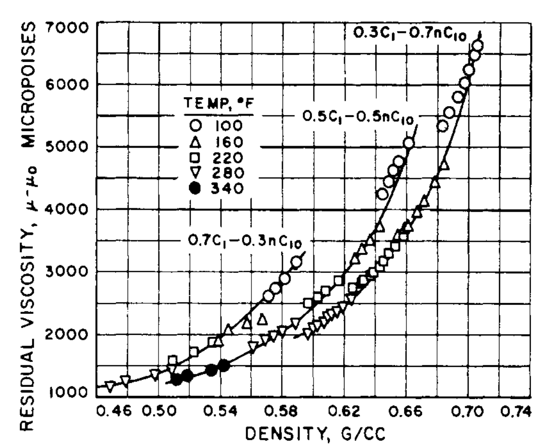

Figure 5. Residual viscosity of methane–*n*-decane mixtures *vs.* density

viscosity *vs.* pressure and viscosity *vs.* temperature, a set of viscosity values was interpolated (Figures 2 and 3, solid lines).

Experimental data were further analyzed graphically. As shown in Figure 6, $\mu/(\mathrm{MW})^{0.25}$ is plotted against Pr/Tr, where

μ = viscosity, micropoises
$MW = [\sum_i X_i (MW_i)^{1/2}]^2$ = molecular weight
$Pr = P/Pc$ = reduced pressure
$Pc = \sum_i X_i P_{ci}$ = critical pressure
$Tr = T/Tc$ = reduced temperature
$Tc = \sum_i X_i T_{ci}$ = critical temperature

These plots correlate the data in straight lines with temperature as parameters for all three methane–*n*-decane mixtures and *n*-decane, but not for methane. The slope and intercept of the lines were plotted against molecular weight with temperature as parameter (Figure 7 and 8). From these plots, viscosity of methane–*n*-decane mixtures from 0% methane to 70% methane can be interpolated. Vis.osity values obtained from this correlation agree with experimental data with a largest deviation of ±3%.

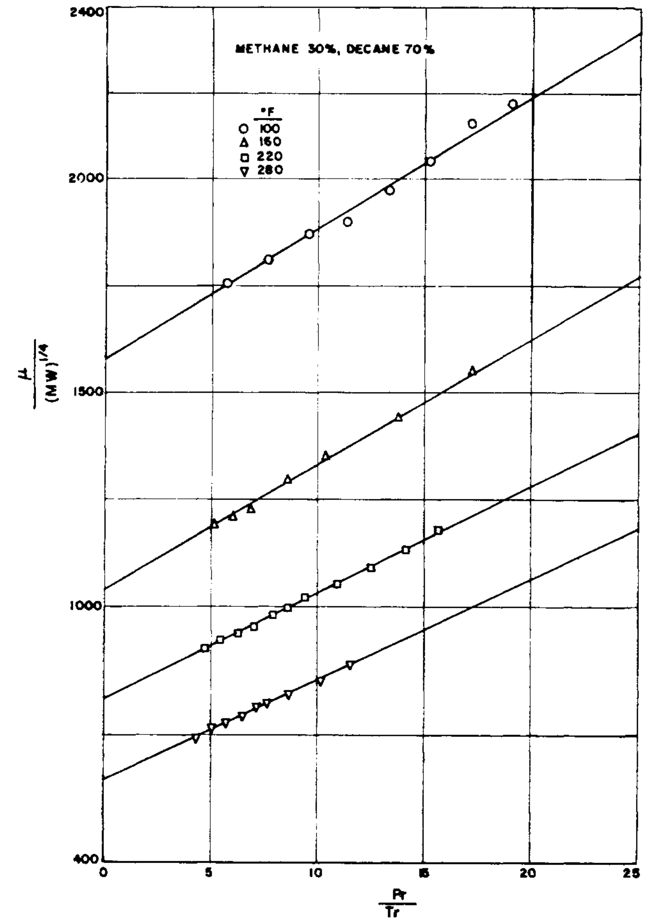

Figure 6. Graphical viscosity correlation of methane–*n*-decane mixtures

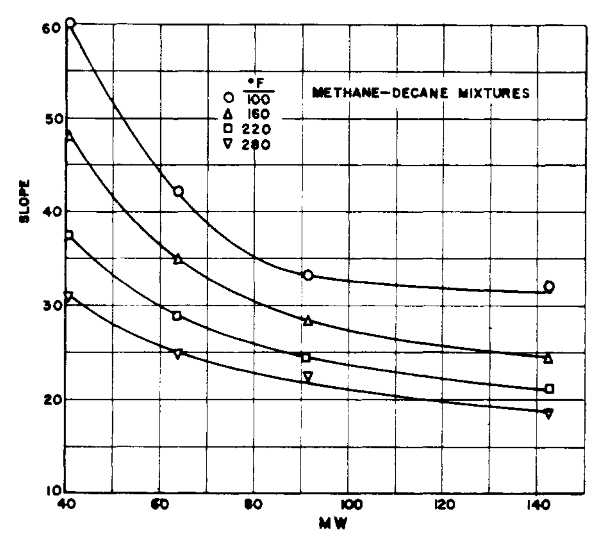

Figure 7. Graphical viscosity correlation of methane–*n*-decane mixtures

For mixtures with a methane mole fraction from 70 to 100% the data were correlated using the formula (*8*)

$$\frac{1}{\mu} = \frac{1}{A} - \frac{\rho B}{A} \qquad (1)$$

where

μ = viscosity, μp.
A, B = temperature-dependent parameters
ρ = density of fluid, g./cc.

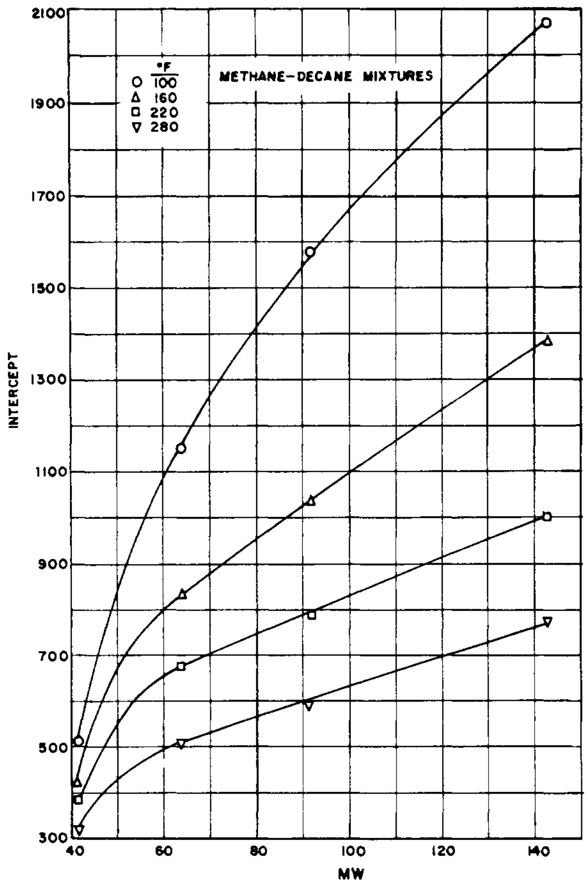

Figure 8. Graphical viscosity correlation of methane-*n*-decane mixtures

Constants *A* and *B* were determined from experimental data of methane and methane-*n*-decane mixtures by the method of least squares. From a plot of *A* and *B vs.* molecular weight, values of these two constants for mixtures were substituted into Equation 1. The viscosity values calculated from Equation 1 deviate from those obtained from cross plots of μ *vs.* P, μ *vs.* T, and μ *vs.* X by less than $\pm 4\%$.

RECOMMENDED VALUES

Recommended values for viscosity of nine methane-*n*-decane mixtures for temperatures from 100° to 340° F. and pressures from bubble point pressure to 10,000 p.s.i.a. are presented in Table I (experimental data in parentheses). The density values used were those of Sage and Lacey (*13*). Recommended values were based on the combination of values given by smoothed large-scale viscosity-pressure, viscosity-temperature, and viscosity-composition plots, residual viscosity correlation where it agrees well with the experimental data, and the two correlations described above. The values presented in Tables I to V are believed accurate within $\pm 5\%$ of the true viscosity of the mixtures. Detailed tables of the experimental data are available from ADI.

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