International Journal of Thermophysics, Vol. 3, No. 3, 1982

Measurements of the Viscosity of Compressed Gaseous and Liquid Nitrogen + Methane Mixtures

D. E. Diller[1]

Received May 25, 1982

The shear viscosity coefficients of three compressed gaseous and liquid nitrogen + methane mixtures have been measured at temperatures between 100 and 300 K and at pressures to about 30 MPa (4350 psia) with a piezoelectric quartz crystal viscometer. The precision of the measurements ranges from about 0.5% at high densities to about 1% at low densities. The estimated experimental error ranges from about 2% at high densities to about 4% at densities near the critical density and at supercritical temperatures near the critical temperature. The measurements have been compared with an extended corresponding states model, previously proposed for calculating the viscosities of fluid mixtures. Differences between the measured and calculated viscosities are discussed.

KEY WORDS: composition dependence; compressed gas; compressed liquid; density dependence; methane; mixtures; nitrogen; piezoelectric crystal viscometer; shear viscosity.

1. INTRODUCTION

Accurate, wide range mathematical models for the behavior of the transport properties of fluids are needed for optimizing transport processes and equipment. As there is no satisfactory molecular theory of the transport properties of dense fluids, much use is made of extended corresponding states models. Accurate, wide range data for carefully selected fluids and their mixtures are useful for validating and improving these models.

There are few accurate viscosity data available for compressed gaseous and liquid mixtures that cover a large *PVT* range. This report presents new absolute shear viscosity coefficient measurements for three nitrogen +

---

[1] Thermophysical Properties Division, National Bureau of Standards, Boulder, Colorado 80303, U.S.A.

methane mixtures at temperatures between 100 and 300 K at pressures to about 30 MPa (4350 psia). Nitrogen + methane mixtures have been selected for this study because mixtures containing these components have considerable technological importance, and because considerable information is available for the viscosities of the pure components and for the equilibrium properties of the mixtures. The reduced density and temperature ranges covered here are substantial. Reduced densities range from about 0.1 to 2.7 and reduced temperatures range from about 0.6 to 2.

The dependences of the measured viscosities on density, temperature, and composition have been compared with an extended corresponding states model [1,2]. Differences between the measured and calculated viscosities are discussed.

2. APPARATUS AND PROCEDURES

The measurement method, apparatus, and procedures are essentially the same as we have reported for our work on argon [3], methane [4], and nitrogen [5]. Only details specific to this work are reported here. The same piezoelectric quartz crystal of approximately 5 cm in length and 0.5 cm in diameter, discussed in [3], was used for these measurements.

Viscosities were derived from measured crystal resonance-curve bandwidths using the equation [see ref. 6],

$$\eta = \frac{\pi f}{\rho}\left[\frac{M}{S}\right]^2\left[\frac{\Delta f}{f} - \frac{\Delta f_{\text{vac}}}{f_{\text{vac}}}\right]^2 \tag{1}$$

where ρ is the fluid density, M and S are the mass and surface area of the crystal, and f and Δf are the resonant frequency and resonance-curve bandwidth of the crystal. This equation has been used to derive all of the viscosities reported from this laboratory. The viscosity measurements were made on the same three mixtures previously prepared gravimetrically and used for *PVT* measurements in this laboratory [7]. The mixture compositions (mole fractions) are summarized in Table I.

Table I. Nitrogen + Methane Mixture Compositions Used for Viscosity Measurements

Mixture number	Nitrogen mole fraction	Abbreviated Nitrogen mole fraction, x_{N_2}	Methane mole fraction
1	0.50115	0.5	0.49885
2	0.28627	0.3	0.71373
3	0.68341	0.7	0.31659

The highest pressures were obtained by compressing the fluid in the cell, at a temperature well above the fluid critical temperature, with a commercially available diaphragm type compressor. Care was taken to keep the pressure well above the critical pressure of the mixture while cooling the cell below the critical temperature of the mixture.

Densities are required to obtain viscosities from Eq. (1) and to examine the dependence of the viscosity on the density. Densities were obtained from measured temperatures and pressures and a mathematical model for the *PVT* properties of nitrogen + methane mixtures. An extended corresponding states model [8] was used to calculate the densities of compressed gaseous 0.50115 nitrogen + 0.49885 methane at densities smaller than 8 $\mathrm{mol \cdot liter^{-1}}$. The error in these calculated densities is believed to be less than 2%. A 32 term modified BWR equation was used to calculate the densities of this composition at gas densities larger than 8 $\mathrm{mol \cdot liter^{-1}}$ and at liquid densities. The BWR equation was optimized [9] to the measured *PVT* properties of this composition [7] as if it were a pure fluid. The error in these calculated densities is believed to be less than 0.2%. The extended corresponding states model [8] was used to calculate all of the densities of compressed gaseous and liquid 0.28627 nitrogen + 0.71373 methane and of 0.68341 nitrogen + 0.31659 methane. The error in these calculated densities is believed to be less than 0.5%, except at densities near the critical density and at our experimental supercritical temperature nearest the critical temperature, where the error is believed to be as large as 2% [7].

3. RESULTS AND DISCUSSION

Measurements of the viscosities of compressed gaseous and liquid 0.50115 nitrogen + 0.49885 methane are presented in Table II and Fig. 1. Measurements of the viscosities of compressed gaseous and liquid 0.28627 nitrogen + 0.71373 methane are presented in Table III and Fig. 2. Measurements of the viscosity of compressed gaseous and liquid 0.68341 nitrogen + 0.31659 methane are presented in Table IV and Fig. 3. All of the measurements were made at temperatures between 100 and 300 K and at pressures to 30 MPa (4350 psia). The estimated precision of the measurements ranges from 0.5% at high densities to 1% at low densities. The experimental error is believed to be less than 2%, except at densities near the critical density and at our supercritical temperature nearest the critical temperature, where errors in the calculated densities may produce viscosity errors as large as 4%.

The dependences of the mixture viscosities on density and temperature at fixed composition, shown in Figs. 1–3, are similar to the density and temperature dependences obtained for the pure components [4, 5]. At high

Table II. Viscosity of Compressed Gaseous and Liquid 0.50115 Nitrogen + 0.49885 Methane Mixture.

P (MPa)	ρ ($\mathrm{mol \cdot liter^{-1}}$)	η ($\mu\mathrm{g \cdot cm^{-1} \cdot s^{-1}}$)	P (MPa)	ρ ($\mathrm{mol \cdot liter^{-1}}$)	η ($\mu\mathrm{g : cm^{-1} \cdot s^{-1}}$)
	$T = 300.00$ K			$T = 200.00$ K	
30.3347	11.5563	253.8	31.1740	19.0318	400.8
26.6977	10.5171	235.6	28.1632	18.4216	377.7
26.1631	10.3541	233.7	25.8977	17.8960	359.6
22.6224	9.2049	220.7	22.8686	17.0744	335.9
22.0420	9.0048	217.1	19.9076	16.0871	309.4
19.0696	7.9226	205.3	17.5834	15.1228	289.4
18.5063	7.7098	200.5	15.9774	14.3141	270.8
15.5440	6.5467	190.2	14.3944	13.3569	246.5
14.9492	6.3050	186.0	13.2721	12.5516	235.5
12.1346	5.1333	172.6	12.3980	11.8352	223.7
11.4841	4.8593	169.3	12.1069	11.5774	222.1
8.5787	3.6177	162.7	11.5597	11.0656	218.5
7.9169	3.3326	157.1	10.7837	10.2796	200.6
5.1108	2.1259	153.3	10.5578	10.0380	202.2
3.7262	1.5373	147.7	9.3825	8.7082	178.4
2.2574	0.9218	147.8	8.5600	7.7383	164.9
			8.0014	7.0837	160.4
	$T = 250.00$ K		7.5899	6.6113	152.8
32.9425	15.2289	297.8	6.5126	5.2401	144.9
30.1945	14.5363	285.0	5.8219	4.5324	138.0
27.7527	13.8469	271.9	4.0813	2.9248	123.6
24.6678	12.8543	249.2	3.1121	2.1330	116.1
21.9783	11.8544	231.8	2.0121	1.3137	114.1
19.7099	10.8963	217.6			
19.2505	10.6884	216.5		$T = 170.00$ K	
16.3457	9.2633	193.1	31.0479	21.8879	530.0
14.4183	8.2194	181.8	28.1011	21.4764	499.8
14.3553	8.1842	181.5	22.7675	20.5828	457.2
12.1689	6.9280	165.8	18.5245	19.6609	414.8
12.1328	6.9068	165.8	15.7595	18.8908	384.2
9.8638	5.4594	153.2	12.9099	17.8504	347.1
8.8640	4.8624	148.5	11.4462	17.1480	329.1
7.9752	4.3359	145.5	10.0694	16.3003	306.2
7.9691	4.3323	145.8	8.7529	15.1785	275.4
5.7978	3.0680	135.3	7.9703	14.2342	258.9
4.9761	2.6022	132.4	7.4167	13.3383	236.2
3.7162	1.9057	128.8	7.3895	13.2875	233.8
2.8565	1.4443	127.2	7.1349	12.7754	226.9
1.6607	0.8227	127.2	6.8309	12.0670	218.9

P = pressure; ρ = density; η = viscosity.

Table II. (Continued)

P (MPa)	ρ (mol · Liter^{-1})	η (μg · cm^{-1} · s^{-1})
	$T = 170.00$ K	
6.5236	11.2345	196.0
6.2972	10.5478	184.3
6.0300	9.6681	169.1
5.8241	8.9550	158.5
5.5367	7.9587	146.3
5.3123	7.2299	136.3
4.8044	5.8659	121.8
4.4859	4.9497	118.9
3.7894	3.7723	108.6
3.0886	2.8257	103.5
2.3257	1.9694	97.0
1.6957	1.3583	94.9
	$T = 155.00$ K	
31.8596	23.4123	627.3
28.2060	23.0064	597.2
23.4197	22.3907	553.3
17.8921	21.5025	498.5
14.4767	20.7986	462.9
10.8686	19.8175	423.0
8.8518	19.0700	382.8
7.3990	18.3549	361.1
6.5603	17.8167	344.0
5.8142	17.1923	324.7
5.1514	16.4000	316.4
	$T = 140.00$ K	
30.9548	24.7393	761.1
27.4193	24.4138	727.4
24.7171	24.1431	700.2
21.3083	23.7684	667.2
17.7402	23.3253	627.7
14.1914	22.8143	590.1
10.7319	22.2162	544.8
7.4535	21.4990	501.3
4.0007	20.4124	446.6

P (MPa)	ρ (mol · Liter^{-1})	η (μg · cm^{-1} · s^{-1})
	$T = 120.00$ K	
33.8660	26.7969	1055.1
30.1290	26.5492	1020.7
26.5600	26.2969	979.6
23.2849	26.0495	949.1
19.9239	25.7770	915.2
15.6289	25.3950	843.7
12.8348	25.1210	815.7
9.3648	24.7437	770.4
5.7291	24.2881	721.7
2.5177	23.8077	677.7
	$T = 110.00$ K	
30.8632	27.5119	1240.5
28.0773	27.3444	1200.4
24.6574	27.1288	1162.7
21.3706	26.9097	1106.2
17.7256	26.6507	1065.1
14.8891	26.4353	1034.9
10.8518	26.1027	977.7
7.9721	25.8421	926.2
4.5678	25.5003	877.9
1.7003	25.1737	834.8
	$T = 100.00$ K	
30.3398	28.3808	1522.4
27.4612	28.2300	1473.3
24.6142	28.0755	1421.7
21.4048	27.8942	1385.6
17.8226	27.6813	1322.5
14.3200	27.4604	1276.2
10.7847	27.2218	1218.6
7.9954	27.0197	1162.9
5.2236	26.8039	1135.3
2.3620	26.5611	1073.4

densities (larger than $2\rho_c$) the viscosity increases strongly with increasing density at fixed temperature and decreases weakly with increasing temperature at fixed density.

There are few other viscosity measurements reported for compressed gaseous and liquid nitrogen + methane mixtures in the same *PVT* range.

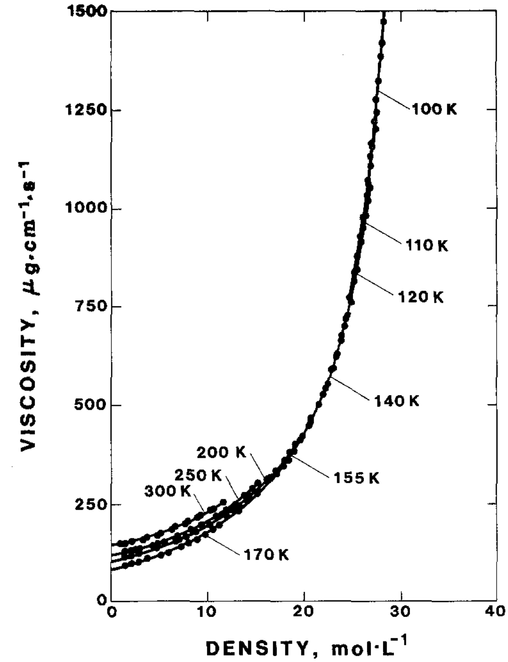

Fig. 1. Viscosity of compressed gaseous and liquid 0.50115 nitrogen + 0.49885 methane as a function of density.

Table III. Viscosity of Compressed Gaseous and Liquid 0.28627 Nitrogen + 0.71373 Methane Mixture

P (MPa)	ρ ($\mathrm{mol \cdot liter^{-1}}$)	η ($\mu\mathrm{g \cdot cm^{-1} \cdot s^{-1}}$)	P (MPa)	ρ ($\mathrm{mol \cdot liter^{-1}}$)	η ($\mu\mathrm{g \cdot cm^{-1} \cdot s^{-1}}$)
	$T = 300.00$ K			$T = 250.00$ K	
30.7863	12.2731	248.7	30.2514	15.4520	292.9
28.0996	11.5152	238.5	27.5526	14.7154	275.7
24.6274	10.4237	219.5	24.8019	13.8541	260.1
22.0291	9.5148	208.5	22.0241	12.8395	237.5
19.1767	8.4222	196.0	19.2155	11.6222	218.7
16.3318	7.2393	181.0	16.4483	10.1860	196.4
14.2296	6.3162	170.4	14.0684	8.7446	176.8
12.1500	5.3745	161.6	12.2836	7.5591	164.5
9.9904	4.3851	152.2	10.1173	6.0630	146.5
7.8531	3.4049	145.1	8.0659	4.6633	135.4
5.8242	2.4855	139.1	5.9232	3.2761	124.6
3.7992	1.5902	131.6	3.8265	2.0168	118.4
1.6924	.6922	125.1	1.7026	.8529	114.3

Pressure = P; density = ρ; viscosity = η.

Table III. (Continued)

P (MPa)	ρ (mol · liter^{-1})	η (μg · cm^{-1} · s^{-1})	P (MPa)	ρ (mol · liter^{-1})	η (μg · cm^{-1} · s^{-1})
	$T = 200.00$ K			$T = 140.00$ K	
30.8132	19.9616	427.1	6.0203	22.6717	583.5
28.0943	19.4998	408.8	3.2294	22.1680	542.6
25.5596	19.0119	388.6			
22.8598	18.4110	365.0		$T = 120.00$ K	
19.9453	17.6293	342.9	30.6724	26.8983	1145.9
17.1115	16.6659	314.7	28.2007	26.7576	1118.1
14.5695	15.5154	286.3	24.5270	26.5376	1064.0
12.3872	14.1369	255.3	21.4332	26.3413	1033.3
11.0525	12.9793	232.4	17.9183	26.1042	1003.6
10.1198	11.9453	220.3	14.1964	25.8346	954.2
8.7916	10.0387	191.1	10.7717	25.5666	920.1
7.4029	7.6204	155.7	8.1137	25.3429	873.7
5.9159	5.2771	133.0	5.2819	25.0864	847.5
4.5222	3.5867	114.3	1.8306	24.7421	794.7
3.0991	2.2204	103.4			
1.6029	1.0483	98.1		$T = 110.00$ K	
			30.1293	27.6954	1375.5
	$T = 165.00$ K		27.5805	27.5675	1336.7
31.5995	23.1538	616.3	24.7712	27.4206	1300.0
28.1512	22.7986	590.8	21.3994	27.2356	1248.1
24.7215	22.4057	556.6	17.8268	27.0283	1203.7
21.4090	21.9773	527.7	14.4708	26.8222	1149.4
17.7757	21.4314	494.1	11.5837	26.6350	1118.3
14.4679	20.8328	458.4	8.6663	26.4356	1072.6
11.9933	20.2867	434.9	5.1092	26.1765	1032.5
8.9718	19.4228	396.3	1.7905	25.9165	985.4
7.4127	18.8240	372.8			
5.8977	18.0371	346.0		$T = 100.00$ K	
			29.6496	28.4817	1732.8
	$T = 140.00$ K		27.3669	28.3822	1692.9
30.7776	25.2228	839.1	24.7275	28.2629	1635.0
28.2703	25.0374	818.4	21.5589	28.1133	1583.1
24.7465	24.7595	777.8	17.7079	27.9218	1536.8
21.3095	24.4654	740.1	14.3388	27.7450	1470.3
17.8751	24.1436	710.5	10.5610	27.5359	1397.7
14.3567	23.7773	680.3	7.9629	27.3850	1354.3
11.6627	23.4643	644.7	5.1503	27.2148	1318.2
8.8425	23.0964	613.2	2.3216	27.0360	1257.6

The capillary tube measurements of Gnezdilov and Golubev [10] on compressed gaseous 0.449 nitrogen + 0.551 methane at 298.15 K were compared with our measurements on 0.50115 nitrogen + 0.49885 methane at 300 K by comparing both sets of measurements to an extended corresponding states model [1,2]. The measurements appear to be consistent within the combined experimental errors. By contrast, the oscillating cylin-

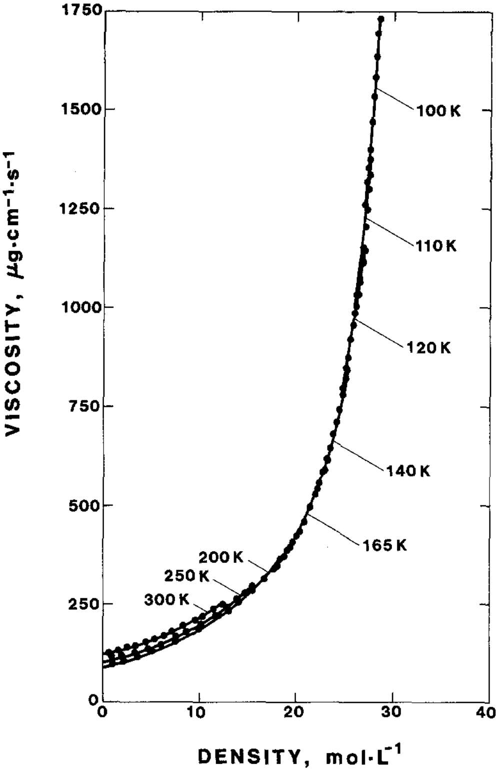

Fig. 2. Viscosity of compressed gaseous and liquid 0.28627 nitrogen + 0.71373 methane as a function of density.

der measurements of Gerf and Galkov [11] on liquid 0.494 nitrogen + 0.506 methane were compared with our measurements on liquid 0.50115 nitrogen + 0.49885 methane and were found to be about 20–30% larger.

The measurements reported in Tables II–IV have been compared with an extended corresponding states model [1,2], previously proposed for calculating the viscosities of fluid mixtures throughout a wide range of *PVTx* states. The model makes use of a methane reference state to calculate the viscosities of the other components, and is predictive in the sense that it does not make use of mixture viscosity data. Most of the differences between our measurements on compressed gaseous nitrogen + methane mixtures and the model are within our estimated experimental error and will not be discussed further here. Most of the differences between our measurements on compressed liquid nitrogen + methane mixtures are larger than our estimated experimental error and smaller than the estimated uncertainties of the model [1,2]. The differences between our

Table IV. Viscosity of Compressed Gaseous and Liquid 0.68341 Nitrogen + 0.31659 Methane Mixture

P (MPa)	ρ $(\text{mol} \cdot \text{liter}^{-1})$	η $(\mu\text{g} \cdot \text{cm}^{-1} \cdot \text{s}^{-1})$
	$T = 300.00$ K	
31.2346	11.4102	260.9
28.1067	10.5499	248.1
25.4813	9.7717	238.3
22.8188	8.9266	229.2
20.0590	7.9899	216.2
17.0725	6.9081	204.2
14.4482	5.9040	192.9
13.1287	5.3827	190.1
10.9474	4.5113	179.6
8.8114	3.6376	172.0
6.6221	2.7289	165.0
4.5659	1.8720	159.0
1.7686	0.7164	155.3
	$T = 250.00$ K	
30.3905	13.9433	284.7
27.5872	13.1081	269.0
24.7297	12.1576	253.3
21.3672	10.8872	232.6
18.2968	9.5636	212.4
15.7249	8.3310	198.3
12.8263	6.8252	180.8
10.0876	5.3288	168.6
7.3391	3.8246	154.1
4.5374	2.3080	142.7
1.6521	0.8125	138.2
	$T = 200.00$ K	
33.5588	18.8541	397.1
31.0638	18.3179	380.5
28.3282	17.6560	358.0
25.5660	16.8878	337.1
22.9169	16.0277	314.1
19.9803	14.8827	289.5
17.5355	13.7164	266.4
14.4413	11.8394	231.9
12.2766	10.1729	213.0
10.0921	8.1981	183.5
7.9643	6.1592	163.8
5.8229	4.2277	145.5
3.7634	2.5580	128.8
1.6770	1.0641	119.3

P (MPa)	ρ $(\text{mol} \cdot \text{liter}^{-1})$	η $(\mu\text{g} \cdot \text{cm}^{-1} \cdot \text{s}^{-1})$
	$T = 140.00$ K	
32.6452	24.5732	739.1
30.4744	24.3458	716.6
28.0345	24.0733	697.5
24.5507	23.6464	652.5
21.4211	23.2151	623.2
17.9195	22.6596	575.9
14.3347	21.9744	528.5
11.6594	21.3428	489.6
8.9251	20.5136	452.8
6.1444	19.2747	398.4
	$T = 120.00$ K	
31.0056	26.4252	978.4
27.9432	26.1726	948.6
24.6056	25.8766	897.3
21.3729	25.5656	861.9
17.8467	25.1927	824.7
13.6544	24.6896	766.0
11.6422	24.4178	736.2
8.8198	23.9915	698.7
5.9909	23.4908	653.8
3.1330	22.8673	609.2
	$T = 110.00$	
29.7748	27.3443	1156.6
27.4845	27.1786	1128.5
24.7182	26.9682	1086.7
22.1662	26.7629	1047.5
18.0791	26.4086	989.5
14.5707	26.0742	944.2
11.5888	25.7624	897.3
8.7905	25.4409	853.9
5.9531	25.0781	816.5
2.2632	24.5281	751.6
	$T = 100.00$ K	
30.9526	28.4244	1420.7
28.2375	28.2583	1391.1
24.6603	28.0270	1335.2
21.5045	27.8100	1279.0
17.9260	27.5476	1225.8
14.5691	27.2833	1173.4
10.8072	26.9629	1110.4
8.1101	26.7144	1072.4
5.1829	26.4232	1018.7
2.4493	26.1265	968.3

Pressure = P; density = ρ; viscosity = η.

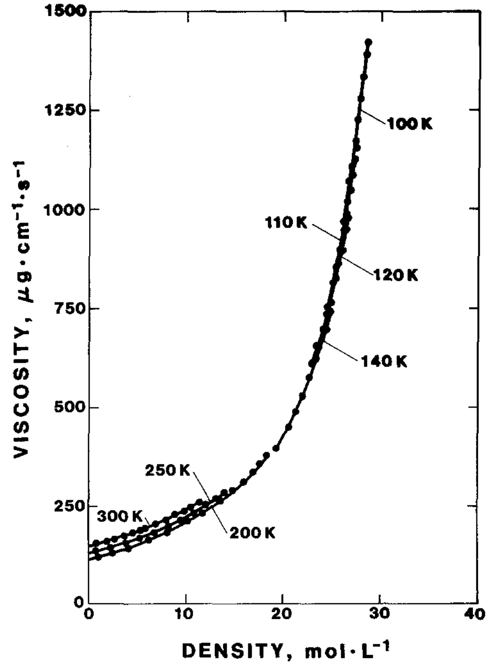

Fig. 3. Viscosity of compressed gaseous and liquid 0.68341 nitrogen + 0.31659 methane as a function of density.

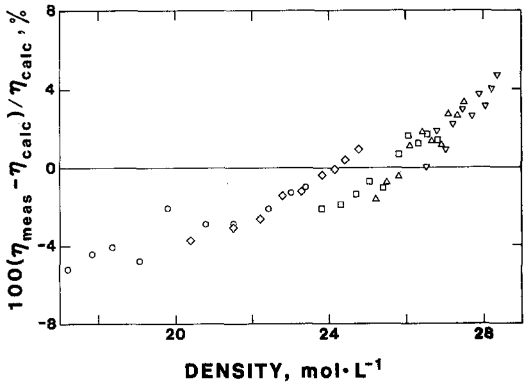

Fig. 4. Comparison of measured viscosities of compressed liquid 0.50115 nitrogen + 0.49885 methane with the extended corresponding states model [1, 2]. The temperatures are 155 K, ○; 140 K, ◇; 120 K, □; 110 K, △; and 100 K, ▽.

measurements on compressed liquid 0.50115 nitrogen + 0.49885 methane and the model are shown in Fig. 4. The largest differences are about 5%, and there are noticeable dependences on density and temperature. The dependence of the measured viscosities on density at fixed temperature is a little stronger than that given by the model. The differences are weakly dependent on temperature at fixed density. The differences between the measured and calculated viscosities, and the dependences of the differences on density and temperature, are similar for the other mixture compositions. The largest differences, up to 8%, were obtained for 0.68341 nitrogen + 0.31659 methane at the highest density.

Measurements of the viscosities of the three compressed liquid nitrogen + methane mixtures, and of the pure components [4, 5], all at high densities (25.0–28.6 mol · liter^{-1}) and the same temperature (100 K), are shown in Fig. 5. The viscosity clearly decreases with increasing nitrogen concentration at fixed molar density and at fixed temperature. The dependence of the measured viscosities on composition at fixed molar density (28.0 mol · liter^{-1}) and at fixed temperature (100 K) is shown in Fig. 6. The measured viscosity is smaller than the mole fraction average of the pure

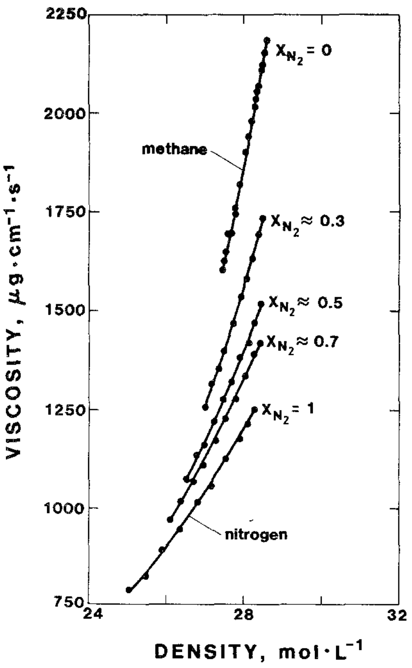

Fig. 5. Viscosity of compressed liquid nitrogen + methane mixtures and their pure components as a function of molar density at fixed temperature (100 K).

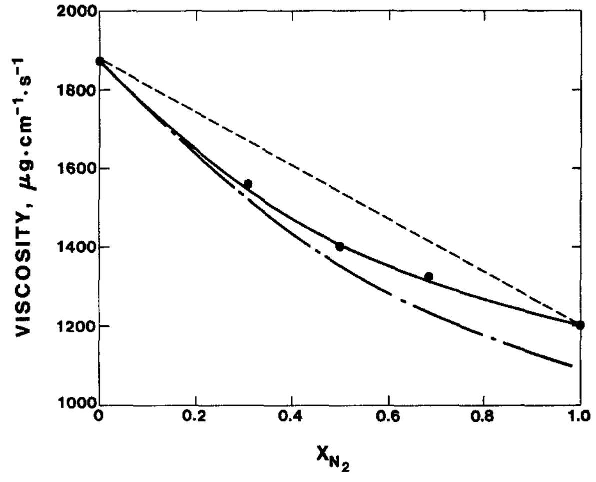

Fig. 6. Viscosity of compressed liquid nitrogen + methane mixtures and their pure components as a function of composition at fixed molar density (28.0 mol · liter^{-1}) and at fixed temperature (100 K). The present measurements, ●; mole fraction average of the pure component viscosities, ---; extended corresponding states model [1, 2], — - —.

components, and the largest difference between them is about 10%. Calculated viscosities, obtained from the extended corresponding states model [1,2], at the same compositions, density, and temperature, are shown in Fig. 6 for comparison. As the measured viscosity of pure liquid methane at 28.0 mol · liter^{-1} and 100 K [4] is about 9% larger than that given by the methane reference state, and the viscosity of pure liquid nitrogen at 28.0 mol · liter^{-1} and 100 K [5] is about 15% larger than that given by the model, all of the calculated viscosities have been multiplied by the ratio of the measured to calculated viscosities of pure methane at 28.0 mol · liter^{-1} and 100 K to focus on the composition dependence. The calculated viscosity of pure liquid nitrogen is still about 9% smaller than the measured value. This difference is believed due mainly to poor correspondence between the viscosities of liquid nitrogen and liquid methane at high reduced densities [5]. The calculated composition dependence is quite similar to the measured composition dependence at fixed density and temperature.

4. SUMMARY

New absolute viscosity measurements have been reported for three compressed gaseous and liquid nitrogen + methane mixtures throughout a wide range of *PVT* states. The dependences of the viscosities on density and temperature at fixed composition, and on composition at fixed molar density and temperature, have been examined. The dependences on density and temperature are similar to those obtained for the pure components. The measurements have been compared with an extended corresponding states model, previously proposed for calculating the viscosities of mixtures of nonpolar fluids throughout a wide range of *PVT* states. The model gives a good account of the dependences on density, temperature, and composition. The largest differences between measured and calculated mixture viscosities are less than 8%. Much of the difference is believed to be due to the poor correspondence between the viscosities of pure liquid nitrogen and pure liquid methane at high reduced densities.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy, Division of Geothermal Energy. Howard J. M. Hanley encouraged this work and made helpful comments. James F. Ely provided computer programs for processing the data. Scott Starsky assisted with data processing.

REFERENCES

1. J. F. Ely and H. J. M. Hanley, *I and EC Fundamentals* **20**:323 (1981).
2. J. F. Ely and H. J. M. Hanley, Natl. Bur. Stand. (U.S.), Technical Note 1039 (April 1981).
3. W. M. Haynes, *Physica* **67**:440 (1973).
4. D. E. Diller, *Physica* **104A**:417 (1980).
5. D. E. Diller, unpublished data.
6. R. H. W. Webeler, Ph.D. thesis, University of Cincinnati, 1961 (University Microfilms No. 61-5234, Ann Arbor, Mich.).
7. G. C. Straty and D. E. Diller, *J. Chem. Thermodyn.* **12**:937 (1980).
8. R. D. McCarty, Natl. Bur. Stand. (U.S.), Technical Note 1030 (December 1980).
9. R. D. McCarty, unpublished data.
10. N. E. Gnezdilov and I. F. Golubev, *Gazov. Prom.* **13**:46 (1968).
11. S. F. Gerf and G. I. Galkov, *J. Tech. Phys.* (USSR) **11**:801 (1941).