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Thermal Conductivity of Methane

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This paper reports thermal conductivity data for methane measured in the temperature range 120–400 K and pressure range 25–700 bar with a maximum uncertainty of ± 1%. A simple correlation of these data accurate to within about 3% is obtained and used to prepare a table of recommended values.

KEY WORDS: methane; thermal conductivity; transport properties.

1. INTRODUCTION

Many measurements of the thermal conductivity of methane have been reported (Table I) [1–12]. A survey of the literature shows that few experiments have covered wide ranges of temperature and pressure. In this paper, measurements are reported in the range 120–400 K and 25–700 bar with a maximum uncertainty of 1%. It provides new measurements at low temperatures ($T < 300$ K) and high pressures ($P > 500$ bar) in addition to accurate second measurements in other regions.

A simple equation for the thermal conductivity of methane is proposed. The new correlation is used to prepare a table of recommended value that are accurate to within ± 3%.

2. EXPERIMENTAL

The measurements reported here are obtained with a transient hot-wire instrument described elsewhere [13]. The thermal conductivity cell con-

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Table I. Survey of Experimental Work on the Thermal Conductivity of Methane

Ref.	Author(s)	Year	T (K)	P(bar)	Method
1	Borovik *et al.*	1940	103–173	Near saturated liquid	Concentric cylinders
2	Johnston and Grilly	1946	96–385	Atmospheric	Concentric cylinders
3	Keyes	1954	120–273	1.1–9.0	Concentric cylinders
4	Geier and Schafer	1961	273–973	Atmospheric	Concentric cylinders
5	Ikenberry and Rice	1963	99–235	1.6–500	Concentric cylinders
6	Golubev	1963	196–508	1.0–608	Concentric cylinders
7	Carmichael *et al.*	1966	278–411	1.0–345	Concentric spheres
8	Misic and Thodos	1966	275–348	1.0–585	Concentric cylinders
9	Rosenbaum and Thodos	1967	336–435	3.8–697	Concentric cylinders
10	Le Neindre *et al.*	1969	298–725	1.0–1247	Concentric cylinders
11	Sikolova and Golubev	1967	109–239	1.0–500	Regular regime
12	Gonzales *et al.*	1968	122–173	5.0–100	Axial flow cylinder

sisted of a platinum wire 25 μm in diameter. Potential leads were welded onto the main wire to provide a test section of about 8.7 cm.

The platinum wire was stretched vertically in the test fluid and electrically heated with a step current from zero time. To a first approximation, the wire simulated an infinite line source with constant heat dissipation and the conductivity was calculated [14] from the temperature rise ΔT_w of the wire between times t_1 and t_2 according to the following equation[4]:

$$\Delta T_w(t_1, t_2) = (Q_l/4\pi\lambda)\ln(t_2/t_1) \tag{1}$$

The transient response of the wire was recorded by a computerized data acquisition system. Apparent thermal conductivities at increasing times were computed and a true conductivity estimated by extrapolation to zero time with the condition [15]

$$\left.\frac{d\lambda}{dt}\right|_{t=0} = 0 \tag{2}$$

Corrections for the finite heat capacity of the wire and nonconstant heat dissipation were applied during data processing.

3. RESULTS

The thermal conductivity of methane was measured along 15 nominal isotherms from 120 to 400 K at 20 K intervals. In all, 180 measurements are reported (Appendix, Table IV). Density ρ ($g \cdot cm^{-3}$) at the stated tempera-

[4] For an explanation of symbols, see nomenclature at the end of the paper.

ture T (K) and pressure P (bar) are obtained [16] and tabulated in addition to the thermal conductivity values λ ($mW \cdot m^{-1} \cdot K^{-1}$).

The accuracy and reproducibility of the apparatus were estimated to be within 1 and 0.5%, respectively.

The methane sample used in the experiment was supplied by Air Products and Chemicals Inc., Pennsylvania, and was of CP grade with a certified purity of better than 99%. The purity of this sample was tested in a mass spectrometer.

4. CORRELATION AND DISCUSSION

4.1. General Correlation

The thermal conductivity model (Fig. 1) suggested by Sengers *et al.* [17] and employed by us in a previous correlation of the data for ethane [18] was used with

$$\lambda(\rho, T) = \lambda_{bg}(\rho, T) + \Delta\lambda_{cr}(\rho, T) \tag{3}$$

$$\lambda_{bg}(\rho, T) = \lambda_1(T) + \Delta\lambda_e(\rho, T) \tag{4}$$

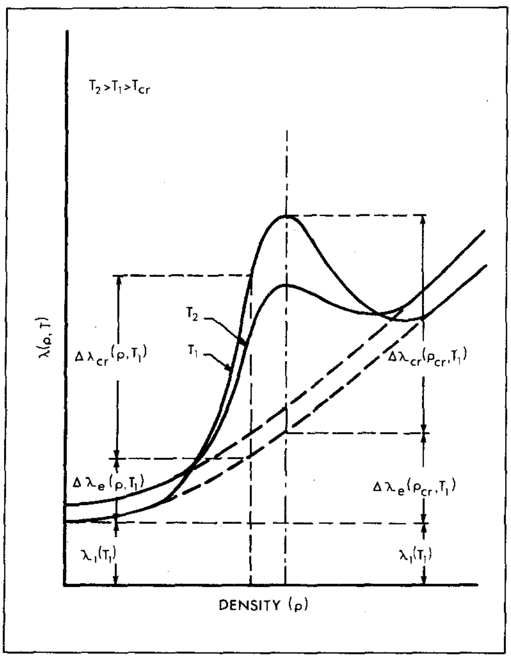

Fig. 1. The thermal conductivity model.

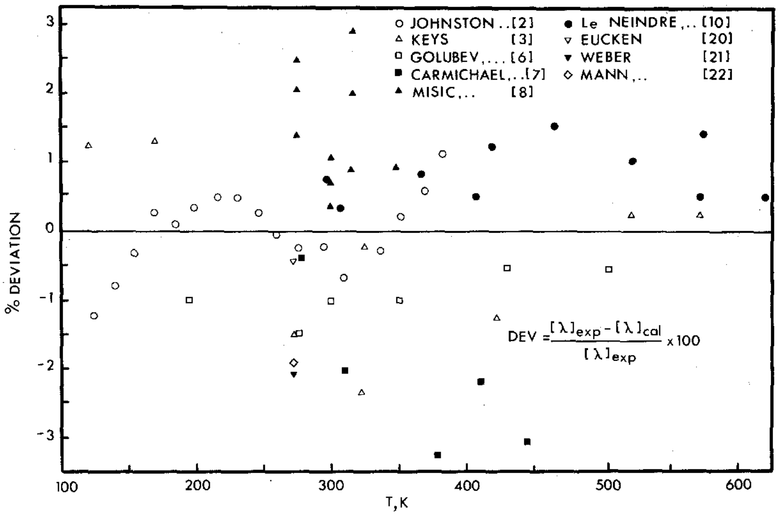

Fig. 2. Deviation plot: correlation of the thermal conductivity of methane at 1 bar.

4.2. Thermal Conductivity at 1 Bar

The hot wire utilized in this experiment closely approximated an ideal line source in the dense region. In the low-density region, however, the minimum-length criterion [19] was not satisfied and resulted in a high slope of the apparent thermal conductivity as a function of time. Extrapolation to zero time was not utilized in these cases due to high uncertainty in the extrapolated values. Consequently, measurements in the low-density region were not obtained with this cell.

Data in the low-density region ($P < 1.5$ bar, $120 < T < 622$ K) re-

Table II. Parameters of the Equations for the Thermal Conductivity of Methane

(A) Correlation for $\lambda_1(T)$ in the range of 120–622 K with Eq. (5):		
	$n = 3$	$a_0 = -0.47313668 \times 10^{-2}$
		$a_1 = 9.35882659 \times 10^{-2}$
		$a_2 = -5.37104001 \times 10^{-2}$
		$a_3 = 1.32157337 \times 10^{-2}$
(B) Correlation for $\Delta\lambda_e$ as a function of density with Eq. (6):		
	$k = 1, 2, 5$	$b_1 = 15.94004983$
		$b_2 = 10.20614596$
		$b_5 = 0.47065428$

ported by other investigators [2, 3, 6–8, 10, 20–22] were correlated with [17]

$$\lambda_1(T) = \sqrt{T_r} \Big/ \sum_{k=0}^{n} (a_k / T_r^k) \tag{5}$$

This model is consistent with the theory [23] as well as with experimental evidence [17, 24] that the thermal conductivity of fluids in the low-density region depends only on temperature and not on density.

A correlation within 3% (Fig. 2) was obtained with Eq. (5) with $n = 3$ using the critical parameters from Ref. 16. Least square estimates of the parameters a_k are listed in part A of Table II.

4.3. The Excess Thermal Conductivity $\Delta\lambda_e$

The measurements in the high-density region indicated an increase in excess thermal conductivity $\Delta\lambda_e$ with increase in density along any isotherm. A thermal conductivity anomaly was observed in the critical region in a few measurements along the 200–300 K isotherms. These measurements were obtained in regions far from the critical point ($T_{cr} = 190.55$ K, $P_{cr} = 48.988$ bar, $\rho_{cr} = 0.16043\ \mathrm{g \cdot cm^{-3}}$) [16] and consequently only a weak anomalous effect is noticed.

On the basis of a preliminary analysis, eight measurements showing critical region enhancement and some in the low-density region were excluded from the data set for general correlation. In addition, it was necessary to include other available experimental data [3, 5–10] at low and moderate pressures in the region $\rho < 0.66\ \mathrm{g \cdot cm^{-3}}$.

The excess thermal conductivity $\Delta\lambda_e$ was first correlated with density alone with

$$\Delta\lambda_e(\rho) = \sum_k b_k \rho_r^k, \qquad b_0 = 0 \tag{6}$$

A stepwise regression analysis of the data was performed. The best three-parameter model with $k = 1, 2, 5$ was selected and least square estimates of b_k were obtained (part B of Table II). A correlation of the present data to within 2–3% and a correlation of the other data within 4% was obtained with Eqs. (5) and (6). Figure 3 shows the deviation plot. This figure shows a dependence of $\Delta\lambda_e$ on temperature. Therefore, a correlation in terms of density and temperature was attempted with

$$\Delta\lambda_e(\rho, T) = \sum_{i=0}^{m} \sum_{j=0}^{n} b_{ij} T_r^i \rho_r^j, \qquad b_{00} = 0 \tag{7}$$

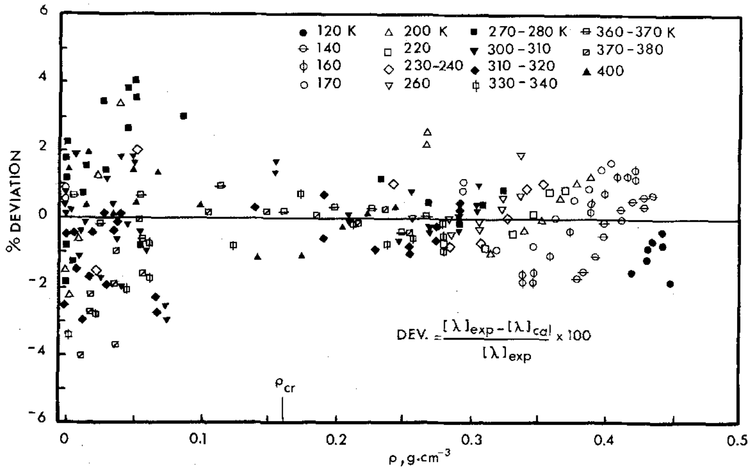

Fig. 3. Deviation plot: correlation of the thermal conductivity of methane.

Although this model matched the experimental data accurately, it did not properly estimate the background thermal conductivity values along various isotherms. Equation (6) was thus preferred over Eq. (7) for the general correlation of $\Delta\lambda_e$.

4.4. The Anomalous Thermal Conductivity $\Delta\lambda_{cr}$

A weak critical anomaly was observed in eight measurements. Table III shows these data and the magnitude of the critical region enhancement. A survey of the available experimental data indicated only a few data in the anomalous region. It was therefore not possible to establish an equation for $\Delta\lambda_{cr}$ in terms of density and temperature similar to that in Ref. 18.

5. DISCUSSION AND COMPARISON

The thermal conductivity calculated from the present correlation [Eqs. (5) and (6)] was compared with other experimental data [3, 4–10]. The data of Le Neindre *et al.* [10] show agreement within ±2% along all the isotherms in the range 300–650 K up to 700 bar (Fig. 4). Deviations of 4% are observed only along the 300 K isotherm in the near-critical density region. Along the 725 K isotherm and at pressures above 700 bar, the deviations are about 5%. The measurements of Keyes [3] agree to within 2% (Fig. 5). Deviations of other experimental data are also shown in Fig. 5. The deviations are generally within ±2–3% in the low-density region but increase somewhat in the dense-fluid region. Large systematic deviations of

Table III. Anomalous Thermal Conductivity of Methane

ID#	T (K)	P (bar)	ρ ($g \cdot cm^{-3}$)	λ_{exp} ($mW \cdot m^{-1} \cdot K^{-1}$)	λ_{bg} ($mW \cdot m^{-1} \cdot K^{-1}$)	$\Delta\lambda_{cr}$ ($mW \cdot m^{-1} \cdot K^{-1}$)	$100\Delta\lambda_{cr}/\lambda_{bg}$ (%)
CH4-069	199.99	50.86	0.0925	40.15	34.36	5.79	14.42
CH4-077	220.03	100.84	0.1890	66.15	58.09	8.06	12.19
CH4-164	260.71	200.96	0.2062	71.73	68.13	3.60	5.02
CH4-165	260.90	150.90	0.1618	60.45	56.10	4.35	7.19
CH4-166	261.15	200.96	0.2055	70.62	67.97	2.65	3.75
CH4-167	261.17	100.84	0.1011	46.18	43.35	2.83	6.13
CH4-175	278.28	200.89	0.1804	65.16	63.13	2.03	3.12
CH4-176	278.52	150.90	0.1382	55.87	53.01	2.86	5.11

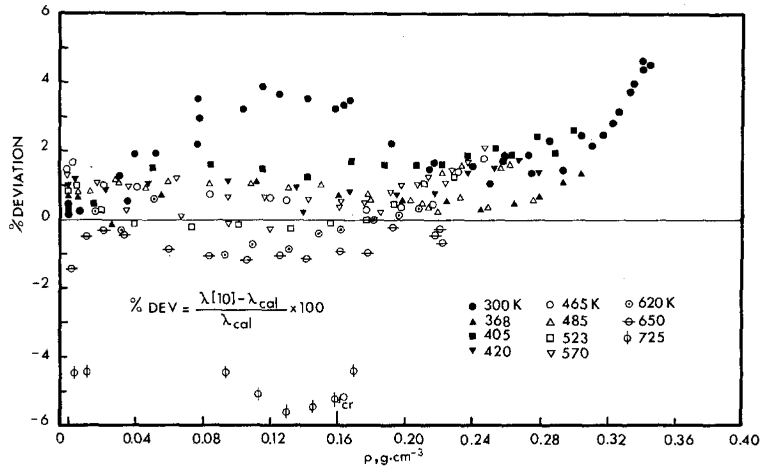

Fig. 4. Deviation plot of the thermal conductivity of methane: experimental data of LeNeindre *et al.* [10] and present correlation.

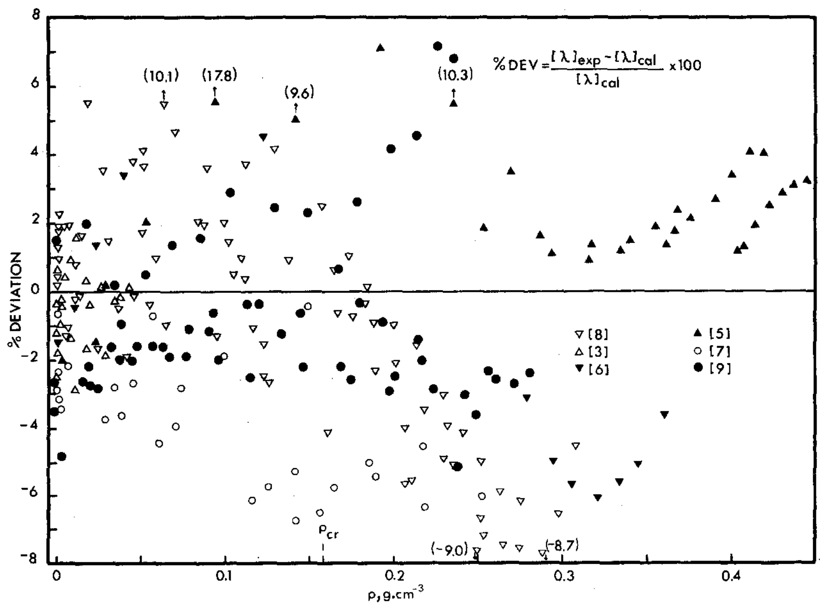

Fig. 5. Deviation plot of the thermal conductivity of methane: experimental data of Keyes [3]; Ikenberry and Rice [5]; Golubev [6]; Carmichael *et al.* [7]; Misic and Thodos [8]; Rosenbaum and Thodos [9]; and the present correlation.

6–8% are observed for the data of Rosenbaum and Thodos [9] and of Misic and Thodos [8]. Some measurements of Ikenberry and Rice [5] indicate the anomalous effect of 7–18%, but in general these data agree within 3–4%. The measurements reported by Carmichael *et al.* [7] are consistently lower than the present correlation.

It is seen that the available thermal conductivity data in the low-density region are accurate. In the dense region, however, systematic errors are observed in some data. The present correlation has been developed on the basis of experimental data obtained in the dense region with a transient hot-wire apparatus. The accuracy of these measurements has been established by an error analysis [15].

In the absence of any equation for $\Delta\lambda_{cr}$, this correlation determines only the background thermal conductivity λ_{bg} in the anomalous region and total conductivity value outside the extended critical region defined by [25]

$$|\Delta T^*| \leqq 1/3 \quad \text{and} \quad |\Delta\rho^*| \leqq 2/3 \tag{8}$$

6. CONCLUSION

The thermal conductivity of methane has been measured in the range 120–400 K at pressures to 700 bar and correlated to within $\pm 3\%$ in the experimental range except in the anomalous critical region. Accurate measurements are needed in this region in order to develop a model for reliably estimating the anomalous conductivity $\Delta\lambda_{cr}$.

A thermal conductivity table has been prepared in terms of temperature (K) and pressure (bar) and can be obtained from the authors. This table does not include the anomalous contribution, but the grid points falling within the anomalous region are identified.

APPENDIX

The experimental data on the thermal conductivity of methane are collected in Table IV.

ACKNOWLEDGMENTS

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Table IV. Thermal Conductivity of Methane. The Experimental Data

Serial #	Test ID#	T (K)	P (bar)	ρ ($g \cdot cm^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
1	CH4-001	139.92	600.85	0.4357	204.88
2	CH4-002	140.07	600.85	0.4356	204.70
3	CH4-003	139.95	500.88	0.4289	196.45
4	CH4-004	139.97	500.88	0.4289	195.83
5	CH4-005	140.00	400.91	0.4214	187.30
6	CH4-006	140.01	400.87	0.4214	187.37
7	CH4-007	140.09	300.93	0.4129	176.87
8	CH4-008	140.00	300.93	0.4130	177.60
9	CH4-009	120.08	100.91	0.4199	179.56
10	CH4-010	120.01	100.91	0.4200	179.65
11	CH4-011	120.08	100.91	0.4199	179.74
12	CH4-012	119.90	200.89	0.4287	190.16
13	CH4-013	119.89	200.89	0.4287	190.80
14	CH4-014	120.04	300.86	0.4360	199.96
15	CH4-015	119.91	300.86	0.4361	200.32
16	CH4-016	119.94	400.91	0.4428	208.37
17	CH4-017	119.86	400.91	0.4429	209.33
18	CH4-018	121.01	500.88	0.4480	212.99
19	CH4-019	139.90	200.89	0.4034	166.96
20	CH4-020	139.93	200.89	0.4034	166.32
21	CH4-021	139.89	100.91	0.3917	154.05
22	CH4-022	139.89	100.91	0.3917	154.20
23	CH4-023	139.89	100.91	0.3917	153.85
24	CH4-024	139.92	50.86	0.3846	147.09
25	CH4-025	139.90	50.86	0.3846	147.19
26	CH4-026	139.95	25.83	0.3806	143.24
27	CH4-027	139.95	25.83	0.3806	143.39
28	CH4-028	159.93	25.83	0.3402	115.33
29	CH4-029	159.94	25.83	0.3401	115.08
30	CH4-030	159.90	200.89	0.3763	143.77
31	CH4-031	159.89	200.89	0.3763	143.74
32	CH4-032	159.96	300.86	0.3890	156.17
33	CH4-033	159.98	300.86	0.3890	155.82
34	CH4-034	159.98	100.91	0.3591	129.31
35	CH4-035	159.98	100.91	0.3591	129.16
36	CH4-036	159.98	50.86	0.3475	120.29
37	CH4-037	160.01	50.86	0.3474	119.94
38	CH4-038	160.04	25.83	0.3399	115.18
39	CH4-039	160.00	25.83	0.3400	114.93
40	CH4-040	160.00	400.91	0.3995	166.74
41	CH4-041	160.00	400.91	0.3995	166.64
42	CH4-042	160.00	500.81	0.4086	176.81
43	CH4-043	159.95	500.81	0.4087	176.98
44	CH4-044	159.98	600.85	0.4167	185.53
45	CH4-045	159.97	600.85	0.4167	185.80
46	CH4-046	160.05	700.83	0.4238	193.60

Table IV. (Continued) Thermal Conductivity of Methane. The Experimental Data

Serial #	Test ID#	T (K)	P (bar)	ρ $(g \cdot cm^{-3})$	λ $(mW \cdot m^{-1} \cdot K^{-1})$
47	CH4-047	159.94	700.83	0.4239	194.17
48	CH4-048	179.96	700.83	0.4060	176.98
49	CH4-049	180.00	700.83	0.4060	177.06
50	CH4-050	179.91	600.85	0.3977	168.28
51	CH4-051	179.96	500.88	0.3882	158.37
52	CH4-052	179.92	400.91	0.3773	148.17
53	CH4-053	179.95	300.86	0.3640	136.53
54	CH4-054	180.00	200.89	0.3467	122.91
55	CH4-055	179.98	200.89	0.3467	122.79
56	CH4-056	179.98	100.84	0.3201	106.00
57	CH4-057	179.98	100.84	0.3201	105.83
58	CH4-058	179.98	50.86	0.2948	93.92
59	CH4-059	179.99	50.86	0.2948	94.16
60	CH4-060	199.99	700.83	0.3882	161.18
61	CH4-061	200.01	600.85	0.3787	152.39
62	CH4-062	200.01	600.85	0.3787	152.44
63	CH4-063	200.01	500.88	0.3677	142.54
64	CH4-064	200.00	400.91	0.3545	131.59
65	CH4-065	199.99	300.75	0.3380	119.76
66	CH4-066	199.99	200.89	0.3145	104.91
67	CH4-067	200.00	100.91	0.2674	84.95
68	CH4-068	199.99	100.91	0.2674	84.65
69	CH4-069	199.99	50.86	0.0925	40.15
70	CH4-070	220.02	700.83	0.3708	147.79
71	CH4-071	220.00	700.83	0.3709	147.89
72	CH4-072	220.05	600.85	0.3600	139.11
73	CH4-073	220.01	500.88	0.3474	128.97
74	CH4-074	220.05	400.91	0.3318	118.07
75	CH4-075	220.11	300.86	0.3111	105.42
76	CH4-076	220.00	200.89	0.2793	89.67
77	CH4-077	220.03	100.84	0.1890	66.15
78	CH4-078	240.02	700.83	0.3539	137.42
79	CH4-079	240.06	600.85	0.3418	128.56
80	CH4-080	240.00	500.88	0.3274	118.30
81	CH4-081	240.00	400.91	0.3093	106.96
82	CH4-082	240.00	300.86	0.2843	94.38
83	CH4-083	240.06	200.89	0.2423	78.35
84	CH4-084	260.03	700.83	0.3375	128.14
85	CH4-085	260.00	600.85	0.3242	119.20
86	CH4-086	260.00	500.88	0.3081	109.25
87	CH4-087	260.03	400.91	0.2873	98.59
88	CH4-088	260.05	300.93	0.2579	86.20
89	CH4-089	300.18	700.83	0.3068	114.95
90	CH4-090	299.33	700.83	0.3075	115.72
91	CH4-091	300.06	700.83	0.3069	114.75
92	CH4-092	300.08	700.83	0.3069	114.55

Table IV. (Continued) Thermal Conductivity of Methane. The Experimental Data

Serial #	Test ID#	T (K)	P (bar)	ρ ($g \cdot cm^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
93	CH4-093	300.00	600.85	0.2913	106.00
94	CH4-094	300.01	600.85	0.2913	106.39
95	CH4-095	300.00	500.81	0.2720	97.09
96	CH4-096	300.03	500.81	0.2720	97.22
97	CH4-097	300.03	400.91	0.2468	86.59
98	CH4-098	300.05	400.91	0.2468	86.64
99	CH4-099	299.97	300.86	0.2112	74.99
100	CH4-100	299.97	300.86	0.2112	75.09
101	CH4-101	299.96	200.89	0.1560	60.81
102	CH4-102	300.04	200.89	0.1559	61.01
103	CH4-103	300.00	100.84	0.0759	43.04
104	CH4-104	299.93	100.84	0.0759	43.14
105	CH4-105	300.24	50.86	0.0356	35.13
106	CH4-106	299.66	50.86	0.0357	35.33
107	CH4-107	299.87	50.86	0.0357	35.73
108	CH4-108	300.00	50.86	0.0356	35.81
109	CH4-109	320.02	700.83	0.2929	110.32
110	CH4-110	320.07	700.83	0.2928	110.47
111	CH4-111	320.00	600.85	0.2762	101.51
112	CH4-112	319.95	600.85	0.2763	101.96
113	CH4-113	319.95	500.88	0.2558	92.80
114	CH4-114	319.94	500.88	0.2558	92.60
115	CH4-115	319.98	400.91	0.2291	83.05
116	CH4-116	319.98	400.91	0.2291	82.90
117	CH4-117	319.96	300.86	0.1922	72.75
118	CH4-118	319.98	300.86	0.1921	71.86
119	CH4-119	320.06	200.89	0.1389	59.19
120	CH4-120	320.04	200.89	0.1389	59.19
121	CH4-121	319.98	100.91	0.0683	44.92
122	CH4-122	320.00	100.91	0.0683	44.79
123	CH4-123	339.80	700.83	0.2798	106.60
124	CH4-124	339.96	100.91	0.0623	47.18
125	CH4-125	339.98	100.91	0.0623	47.67
126	CH4-126	340.00	100.91	0.0623	47.67
127	CH4-127	340.05	700.83	0.2796	106.05
128	CH4-128	340.02	700.83	0.2796	105.66
129	CH4-129	340.00	600.85	0.2622	98.53
130	CH4-130	340.02	600.85	0.2622	98.39
131	CH4-131	339.98	500.88	0.2407	90.13
132	CH4-132	339.96	400.91	0.2132	81.33
133	CH4-133	339.95	300.86	0.1762	71.26
134	CH4-134	340.23	200.89	0.1255	58.67
135	CH4-135	400.15	700.83	0.2449	102.24
136	CH4-136	400.07	600.85	0.2261	95.35

Table IV. (Continued) Thermal Conductivity of Methane. The Experimental Data

Serial #	Test ID#	T (K)	P (bar)	ρ ($g \cdot cm^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
137	CH4-137	399.99	500.88	0.2036	87.89
138	CH4-138	399.95	400.91	0.1759	79.47
139	CH4-139	399.92	300.86	0.1416	71.29
140	CH4-140	399.88	200.89	0.0991	63.87
141	CH4-141	399.89	100.91	0.0502	54.03
142	CH4-142	379.92	700.83	0.2557	102.25
143	CH4-143	379.97	600.85	0.2372	95.98
144	CH4-144	379.98	500.88	0.2147	88.08
145	CH4-145	380.03	400.91	0.1867	79.98
146	CH4-146	379.97	400.91	0.1868	79.93
147	CH4-147	379.99	300.93	0.1514	71.16
148	CH4-148	380.09	200.89	0.1063	61.76
149	CH4-149	379.91	100.91	0.0536	52.97
150	CH4-150	359.90	700.83	0.2673	104.39
151	CH4-151	357.90	700.83	0.2685	104.54
152	CH4-152	359.89	600.85	0.2492	96.62
153	CH4-153	359.89	500.88	0.2272	89.34
154	CH4-154	359.90	400.91	0.1992	80.52
155	CH4-155	359.89	300.93	0.1628	70.68
156	CH4-156	359.91	200.89	0.1150	60.69
157	CH4-157	359.94	200.89	0.1150	60.69
158	CH4-158	359.94	100.98	0.0576	50.07
159	CH4-159	260.58	700.83	0.3371	129.47
160	CH4-160	260.51	600.85	0.3238	119.32
161	CH4-161	260.48	500.88	0.3076	109.35
162	CH4-162	260.53	400.91	0.2868	98.79
163	CH4-163	260.57	300.86	0.2572	86.61
164	CH4-164	260.71	200.96	0.2062	71.73
165	CH4-165	260.90	150.90	0.1618	60.45
166	CH4-166	261.15	200.96	0.2055	70.62
167	CH4-167	261.17	100.84	0.1011	46.18
168	CH4-168	261.69	50.86	0.0437	32.65
169	CH4-169	261.93	50.86	0.0436	32.45
170	CH4-170	277.15	700.83	0.3241	122.16
171	CH4-171	277.31	600.85	0.3096	113.22
172	CH4-172	277.43	500.81	0.2919	103.41
173	CH4-173	277.72	400.91	0.2687	93.36
174	CH4-174	277.98	300.86	0.2356	81.06
175	CH4-175	278.28	200.89	0.1804	65.16
176	CH4-176	278.52	150.90	0.1382	55.87
177	CH4-177	279.19	100.84	0.0869	44.47
178	CH4-178	279.51	50.93	0.0395	35.72
179	CH4-179	279.63	51.00	0.0395	35.72
180	CH4-180	279.99	100.84	0.0864	44.61

NOMENCLATURE

a_k, b_{ij}, b_k	Parameters of the regression model, $k = 0$ to n; $i = 0$ to m; $j = 0$ to n
P	Pressure (MPa or bar)
Q_l	Heat flux per unit length ($mW \cdot m^{-1}$)
t	time (s)
T	Temperature (K)
T_{cr}	Critical temperature (K)
T_r	reduced temperature ($= T/T_{cr}$)
ΔT_w	Temperature rise of wire between times t_1 and t_2 (deg K)
ΔT^*	Reduced temperature difference $(T - T_{cr})/T_{cr}$
λ	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
λ_1	Thermal conductivity at 1 bar ($mW \cdot m^{-1} \cdot K^{-1}$)
λ_{bg}	Background thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
$\Delta\lambda_{cr}$	Anomalous thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
$\Delta\lambda_e$	Excess thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
ρ	Density ($g \cdot cm^{-3}$)
ρ_{cr}	Critical density ($g \cdot cm^{-3}$)
ρ_r	Reduced density ($= \rho/\rho_{cr}$)
$\Delta\rho^*$	Reduced density difference $(\rho - \rho_{cr})/\rho_{cr}$

REFERENCES

1. E. S. Borovik, A. Manveev, and Y. E. Pania, *Z. Tekh. Fiz.* **10**:988 (1940).
2. H. L. Johnston and E. R. J. Grilly, *J. Chem. Phys.* **14**:233 (1946).
3. F. G. Keyes, *Trans. ASME* **76**:809 (1954).
4. V. H. Geier and K. Schafer, *Allg. Warmetechnik.* **10**:70 (1961).
5. L. Ikenberry and S. A. Rice, *J. Chem. Phys.* **39**:1561 (1963).
6. I. F. Golubev, *Teploenergetika* **12**:78 (1963).
7. L. T. Carmichael, H. H. Reamer, and B. H. Sage, *J. Chem. Eng. Data* **11**:52 (1966).
8. D. Misic and G. Thodos, *Physica* **32**:885 (1966).
9. B. H. Rosenbaum and G. Thodos, *Physica* **37**:442 (1967).
10. B. Le Neindre, R. Tufeu, P. Bury, P. Johannin, and B. Vodar, Laboratoire des Hautes Pressions-CNRS-1, Place-A, Briand-Bellevue, France (1969).
11. V. P. Sikolova and I. F. Golubev, *Teploenergetica* **14**:91 (1967).
12. M. H. Gonzales, T. K. Subramaniam, R. L. Rao, and A. L. Lee, Inst. Gas Tech., Session No. 5, paper 21, Chicago (1968).
13. R. C. Prasad and J. E. S. Venart, to be published.
14. E. R. M. Van der Held and F. G. Van Drunen, *Physica* **15**:865 (1949).
15. N. Mani, Precise Determination of the Thermal Conductivity of Fluids Using Absolute Transient Hot-Wire Technique, Ph.D. Dissertation, University of Calgary, Canada (1971).
16. R. D. Goodwin, Nat. Bur. Stand. (U.S.) Tech. Note 653 (1954).
17. J. V. Sengers, R. S. Basu, and J. M. H. L. Sengers, NASA Contractor Report 3424 (1981).
18. R. C. Prasad and J. E. S. Venart, to be published.
19. W. T. Kierkus, N. Mani, and J. E. S. Venart, *Can. J. Phys.* **51**:1182 (1973).

20. A. Eucken, *Z. Physik*, **14**:342 (1913), as cited in Ref. 22.
21. S. Weber, *Ann. Physik* **54**:437 (1917).
22. W. B. Mann and B. G. Dickins, *Proc. Roy. Soc. London A* **134**:77 (1931).
23. N. V. Tsederberg, *Thermal Conductivity of Gases and Liquids* (MIT Press, Cambridge, Massachusetts, 1965).
24. B. Le Neindre, R. Tufeu, P. Bury, and J. V. Sengers, *Ber. Bunsen ges. Phys. Chem.* **77**:262 (1973).
25. H. J. M. Hanley, J. V. Sengers, and J. F. Ely, in *Thermal Conductivity 14*, P. G. Klemens and T. K. Chu, eds. (New York, 1976), p. 383.