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Note

Measurements of the Thermal Conductivity of Nitrogen with a Parallel-Plate Instrument

R. Mostert,[1] H. R. van den Berg,[1] and P. S. van der Gulik[1]

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A parallel-plate apparatus is suited for accurate measurements of the thermal conductivity coefficient of fluids over a wide range of densities. This is illustrated by measurements of the thermal conductivity coefficient of nitrogen at a temperature of 308.15 K and at pressures up to 20.1 MPa with an accuracy of 0.5%. The agreement with a recent correlation based on accurate measurements by other authors is satisfactory.

KEY WORDS: measurement techniques; nitrogen; parallel-plate apparatus; thermal conductivity.

1. INTRODUCTION

For measurements of the thermal conductivity, the guarded parallel-plate method, in which a horizontal layer of fluid enclosed between two parallel plates is heated from above [1–3], offers advantages over other methods. In the first place, a horizontal layer heated from above is the most favorable geometrical configuration for avoiding convection. Consequently, a guarded parallel-plate device is particularly suitable in the critical region. Furthermore, none of the fluid properties need to be known in order to calculate the thermal conductivity at the prevalent temperature and pressure from the experimentally determined quantities. The principal drawback of the guarded parallel-plate cell is its difficult mechanical construction. This explains why only a few accurate instruments of this kind have been built and, consequently, why, for the development of some

[1] Van der Waals Laboratory, University of Amsterdam, Valckenierstraat 67, 1018 XE Amsterdam, The Netherlands.

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recent correlations of the thermal conductivity of pure fluids [4, 5] as a function of temperature and pressure, data obtained with parallel-plate apparatuses were left out completely in the normal fluid region.

The purpose of this article is to establish that the present guarded parallel-plate device can provide accurate thermal conductivity measurements over a wide range of densities. This is demonstrated by the results of measurements of the thermal conductivity of nitrogen at a temperature of 308.15 K and at pressures up to 20.1 MPa.

2. METHOD AND RESULTS

For the measurements we employed the apparatus described previously [1], in which a horizontal fluid layer is heated from above. Temperature differences of, on average, 65 mK were applied across the measuring gap, which has a width of 155 μm.

The nitrogen used was supplied by Matheson and has a stated purity of 99.9997%. The measurements were performed at a temperature of 308.15 K and at pressures up to 20.1 MPa. The density was calculated from the measured pressure and temperature using the IUPAC equation of state

Table I. The Thermal Conductivity of Nitrogen Near 308.15 K

P (MPa)	T (K)	ρ ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
1.115	308.116	12.209	27.12
2.008	308.103	21.995	27.75
2.999	308.144	32.849	28.11
3.995	308.134	43.744	28.56
4.990	308.134	54.598	29.26
6.021	308.144	65.801	29.72
6.950	308.132	75.841	30.25
8.022	308.137	87.344	30.82
8.999	308.130	97.750	31.33
10.030	308.130	108.62	32.06
11.012	308.130	118.87	32.40
11.991	308.133	128.96	33.06
13.000	308.124	139.23	33.65
13.994	308.111	149.21	34.09
15.072	308.114	159.84	34.68
16.044	308.110	169.28	35.50
17.023	308.112	178.62	36.06
18.005	308.120	187.81	36.65
19.079	308.116	197.68	37.54
20.060	308.119	206.51	38.03

for nitrogen [6]. The thermal conductivity coefficients were computed by means of an accurate working equation [1]. The accuracy of the measured temperature and pressure is estimated to be 2 mK and 0.01% respectively. The accuracy of the measured thermal conductivity is 0.5%.

The results are given in Table I. They were fitted with a standard deviation of 0.31% to a quadratic polynomial in the density ρ

$$\lambda = \sum_{i=0}^{2} \lambda_i \rho^i$$

with

$$\lambda_0 = 26.73\ \mathrm{mW \cdot m^{-1} \cdot K^{-1}}$$

$$\lambda_1 = 40.4\ \mu\mathrm{W \cdot m^2 \cdot K^{-1} \cdot kg^{-1}}$$

$$\lambda_2 = 67.1\ \mathrm{nW \cdot m^5 \cdot K^{-1} \cdot kg^{-2}}$$

It may be noted that the zero density limit λ_0 obtained from the data of Haran *et al.* [7] is 26.63 $\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$, which is very close to our value.

3. DISCUSSION

In Fig. 1 the percentage deviations of our data from the correlation developed by Stephan *et al.* [4] are given together with the deviations of some selected experimental data obtained by other authors at or near 308.15 K [7–11]. This correlation, which has an accuracy of about 1%, is used as a convenient reference line and for the calculation of the small temperature corrections for the data obtained at temperatures slightly different from 308.15 K [8, 9, 11].

Our data show small positive differences from the correlation which are within the combined accuracy. Our data agree also with those obtained with the static concentric cylinder method of Zheng *et al.* at 298.68 K [8] and those obtained with the dynamic transient hot wire method of Clifford *et al.* at 345 K [9] and Haran *et al.* at 308.15 K [7]. The differences with the transient hot wire data of Assael and Wakeham at 308.15 K [10] are slightly larger than the combined experimental accuracy, although the density dependence is the same. The older data of Michels and Botzen at 298.15 K [11], obtained with an earlier, less sophisticated guarded parallel-plate device, are inconsistent with the present results and with the results obtained by the other authors. They show a systematic increase in the deviations from the correlation, amounting to 10% at the highest density reached here. In view of the present results, obtained with the newly developed apparatus [1], this behavior can no longer be explained with a general argument concerning the technique of guarded parallel-plate

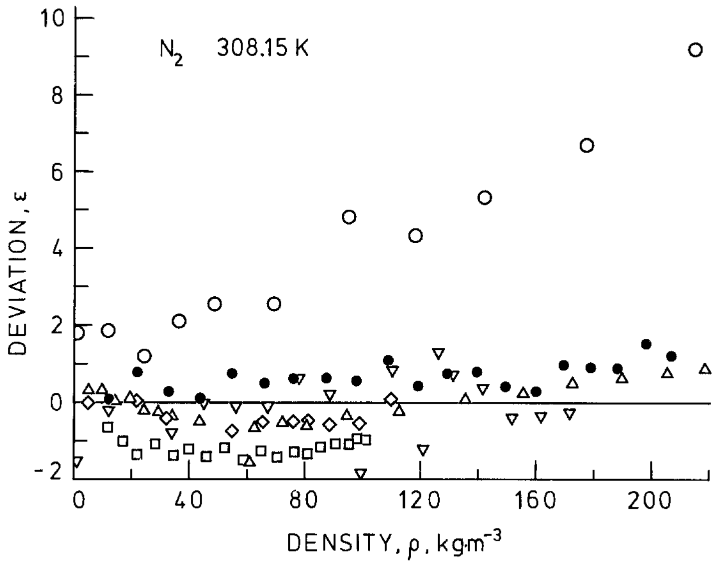

Fig. 1. The percentage deviation. $\varepsilon = 100\ (\lambda - \lambda_{calc})/\lambda_{calc}$ of the measured thermal conductivity coefficient λ from λ_{calc} calculated from the correlation of Stephan *et al.* [4]. (●) This work; (◇) Haran *et al.* [7]; (▽) Zheng *et al.* [8]; (△) Clifford *et al.* [9]; (□) Assael *et al.* [10]; (○) Michels *et al.* [11].

devices. The deviations of the older results of Michels and Botzen [11] are due to the occurrence of heat transport by convection in the thermal conductivity cell, because the initial construction allowed parasitic fluid flow and imperfect temperature balancing of guardring and top plate. This explanation has also been given by Michels *et al.* [12] in their paper on the thermal conductivity of argon measured with the second, improved version of that apparatus.

It may, thus, be concluded that no fundamental design objections or problems with working equations exist for a guarded parallel-plate device. The present results on the thermal conductivity of nitrogen as well as those mentioned on argon [12] are consistent with those obtained with the transient hot wire and concentric cylinder devices and show, therefore, that accurate measurements can be performed with a guarded parallel-plate apparatus over a wide range of densities.

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