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THERMAL CONDUCTIVITY OF NITROGEN AT HIGH PRESSURES AND ATMOSPHERIC PRESSURE: REFINEMENT OF GENERALIZED DATA

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The paper analyzes possible causes of discrepancies in the generalized literature data on thermal conductivity of nitrogen for $P = 0.1$ MPa and $T \geq 300$ K. The data are refined with the aid of a temperature power dependence in the region of 300–2500 K.

Introduction. To date, a great number of measurements have been performed for thermal conductivity of gaseous molecular nitrogen at pressures not higher than atmospheric and temperatures ranging from the normal boiling point to 6000 K. While being amassed, experimental data were repeatedly generalized, generalization procedures were improved, and generalized data reported in the scientific and information literature were revised and refined.

In the past twenty years some generalizations [1-7] of extensive experimental data on thermophysical properties of nitrogen have been made, and as a result, recommended [2, 6], reference [1, 5, 8], and standard reference data [3, 4]* and [7] (Table 1) have been obtained for thermal conductivity in the region of state parameters $T = 65$–2500 K and $P = 0.1$ MPa. Their error at temperatures above room temperature was not greater than 3% (Table 1). In that case, processing did not include experimental data [9-11] on thermal conductivity of nondissociated nitrogen which were obtained using an unsteady shock-tube method at temperatures of 1000–6000 K because of their significant deviation (from 6 to 19%) from more numerous results of measurements by steady-state methods in the overlapping temperature region of 1000–2500 K.

Since the error of thermal conductivities of gases obtained by the shock-tube method, is estimated as 10–20%, their deviation from the data of steady-state methods is within the limits of a resultant error of the compared values. Notwithstanding, the systematic understatement of the results of the shock-tube method relative to the data on thermal conductivity of gases obtained by steady-state methods induced researchers to search for causes of this regularity [10-16].

We adhere to the viewpoint [14, 15] that the most likely cause of this discrepancy lies in the contradiction inherent in the mathematical model of the shock-tube method, in which for the temperature dependence of thermal conductivity of the considered gases [9, 14] (or the contribution of translational or rotational degrees of freedom to thermal conductivity of multiatomic gases [10, 11]) the following power function is specified a priori:

$$\frac{\lambda(T)}{\lambda_0} = \left(\frac{T}{T_0}\right)^n, \quad n = \text{const}, \tag{1}$$

where the exponent n depends on the kind of gas, and $\lambda_0 \equiv \lambda(T_0)$ is a so-called reference point (a known value of thermal conductivity of gas at the datum temperature T_0). The value of n was determined by the shock-tube method on the basis of experimental data obtained in the temperature range of gas heated by a shock wave from $T_{\text{exp.min}} \cong 1000$ K to $T_{\text{exp.max}} \cong 6000$ K. However, because researchers used the reference point λ_0 at room temperature

* Study [3] presents a detailed draft of the tables of standard reference data [4].

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TABLE 1. Generalized Data (λ_{gen}) on Thermal Conductivity of Nitrogen at $P = 0.1$ MPa and Recommended Data (λ_{recom}) of the Present Study Characterized by Relative Error $\delta\lambda$, %.

T, K	[1]		[2]		[3, 4]		[5]		[6]		[7, 8]		Present study	
	λgen	δλ	λgen	δλ	λgen	δλ	λgen	δλ	λgen	δλ	λgen	δλ	λrecom	δλ
65					6.292	7.0					6.3	7.0		
70					6.772						6.8			
80	7.82	2.5	7.44	2–3	7.734						7.7			
90	8.63	2.5	8.40	2–3	8.701						8.7			
100	9.58	2.5	9.36	2–3	9.665	5.0					9.7	5.0		
200	18.3	2.5	18.19	1	18.61	2.5–3.0					18.6	2.7		
300	25.7	1.5–2.5	25.68	1	26.09	0.8			25.92	3	26.1	0.8	25.91	0.8
320	27.1	1.5	27.06	1	27.46				27.31	3	27.4		27.25	
340	28.5	1.5	28.39	1	28.78				28.65	3	28.8		28.58	
360	29.8	1.5	29.71	1	30.09				29.97	3	30.1		29.88	
380	31.1	1.5	31.01	1	31.39				31.26	3	31.4		31.17	
400	32.4	1.5	32.29	1	32.65	1.3			32.52	3	32.7	1.3	32.44	1.3
450	35.6	1.5	35.43	1	35.76				35.60	3	35.8		35.57	
500	38.7	1.5	38.51	1	38.82		38.5	2	38.57	3	38.9		38.62	
600	44.6	1.5	44.60	2–3	44.78	2.0	44.3	2			44.8	2.0	44.53	2.0
700	50.1	1.5	50.65	2–3	50.65		50.2	2			50.7		50.23	
800	55.4	1.5–2.0	56.63	2–3	56.45	2.3	56.0	2			56.4	2.3	55.75	2.3
900	60.5	2.0	62.51	2–3	62.17		61.8	2			62.1		61.12	
1000	65.4	2.0	68.21	2–3	67.72	2.4	67.4	2			67.6	2.4	66.36	2.4
1100	70.2	2.0	73.71	2–3	73.07		73.0	2			73.0		71.49	
1200	75.0	2.0	79.10	2–3	78.21		78.3	2			78.3		76.52	
1300	79.7	2.0	84.27	2–3	83.25		83.5	2			83.4		81.45	
1400	84.4	2.0	89.28	2–3	88.18		88.6	2			88.3		86.31	
1500	89.1	2.0–2.5	94.13	2–3	93.02	2.5	93.4	2			93.1	2.5	91.08	2.5
1600	93.8	2.5	98.83	2–3	97.77						97.8		95.79	
1700	98.6	2.5	103.4	2–3	102.26						102.3		100.44	
1800	103	2.5	107.9	2–3	106.65						106.7		105.02	
1900	108	2.5	112.1	2–3	110.95						110.9		109.55	
2000	113	2.5	116.3	2–3	115.27	2.7	116.3	2			115.1	2.7	114.03	2.7
2100	118	2.5	120.4	2–3	119.42						119.2		118.46	
2200	122	2.5	124.4	2–3	123.51						123.3		122.84	
2300	127	2.5	128.4	2–3	127.51						127.3		127.18	
2400	131	2.5	132.2	2–3	131.46						131.4		131.48	
2500	135	2.5	135.9	2–3	135.32	3.0	136.7	2			135.5	3.0	135.74	3.0

$T_0 \cong 300$ K, a systematic error was introduced in the values of expression (1), which led to their understatement relative to the results of measurements by steady-state methods. This methodological nonconformity was surmounted for thermal conductivity of monatomic gases in study [14] via restricting the range of applicability of expression (1) to the experimentally studied temperature range with the aid of the reference point $\lambda_0^* \equiv \lambda(T_0^*)$ at the temperature $T_0^* = T_{exp.min}$.

In order to correct the data of the shock-tube method for nitrogen [9-11] in a similar fashion, it is necessary to use, as new reference points λ_0^* at temperatures $T_0^* = T_{exp.min} = 1000-1100$ K, reliable values of thermal conductivity from the available reference information [1-8]. However, as is seen from Fig. 1a, which shows deviations of the recommended values of thermal conductivity of nitrogen [1, 2, 5, 6] from standard values [4, 7], the spread in the data [1-5] at temperatures of 1000–1100 K is 4–5%. Particularly noteworthy is the region ($800 < T < 2000$ K) of a significant systematic understatement of the results [1] relative to the data of [2-5]. At a temperature of 1400 K, discrepancy of the values [1-5] attains a maximum of 5.5%, which is larger than their resultant error (Table 1).

Therefore, the current study aims at 1) analyzing the causes of deviation of the reference data [1-8] on thermal conductivity of nitrogen at a pressure not higher than 0.1 MPa and temperatures of 300–2500 K and 2) determining generalized values adequately reflecting, within the framework of errors inherent in them, the character of experimental data in this region of state parameters.

Review of the Methods of Generalizing Experimental Data on Thermal Conductivity of Nitrogen in the Rarefied-Gas State. As work steps, all generalizations include the accumulation of experimental data, their analysis, and the formation of working collections.

The reference book [1] is based on an experiment as a truth criterion. For reliable experimental data on thermal conductivity of nitrogen with assigned weights obtained by 1976, we carried out a graphical averaging of the results of individual authors in limited temperature intervals, and afterward we performed their smoothing in the range of 80–2500 K within the framework of absolute errors of the averaged data. Possible allowances for the recommended tabular values [1] are also estimated by a graphical smoothing of absolute errors of the averaged data.

As an ideological foundation of works [2-5] concurrently generalizing experimental data on diverse properties of gases, historically one may regard the proposal of J. Kestin et al. [17] to rely, in determining thermal conductivity of monatomic gases, on the relation of molecular-kinetic theory $\lambda(T) = 15k\eta(T)f_\lambda^{(3)}/(4mf_\eta^{(3)})$, which links thermal conductivity to coefficient of viscosity and specific heat, which are measured more accurately.

Using the procedure worked out in study [18] for inert gases, the authors of study [2] conducted a joint processing of the collections of experimental data on viscosity and thermal conductivity of nitrogen obtained by 1976. With the aid of the Chapman–Enskog design equations for thermal conductivity and viscosity [19] and the relation

$$\lambda(T) = \eta(T)\, c_v(T)\, f_E(T) \tag{2}$$

the unified temperature dependence $Y(T) \equiv \sigma^2\Omega^{(2.2)^*}(kT/\varepsilon) = 5\cdot 10^{21}\sqrt{mkT/\pi}/(16\eta_{exp}(T)) = 5\cdot 10^{21}c_v(T)f_E(T) \times \times \sqrt{mkT/\pi}/(16\lambda_{exp}(T))$ was ascertained. Based on the generalized curve obtained by graphically smoothing the $Y(T)$ data for which the Eucken factor was calculated from the Mason–Monchik relations [20], the recommended tabular values of transfer coefficients of nitrogen were calculated in the region of 77.35–2500 K.

The procedure [3, 4] for generalizing reliable experimental data on diverse properties of nitrogen for $P \le 0.1$ MPa published by 1981 was also based on the design equations [19, 20] for transfer coefficients of a diatomic gas (thermal conductivity, viscosity, self-diffusion, thermodiffusion factor, and Eucken factor), the second virial coefficient, and its first derivative. Parameters of the potential (m–6–8) were identified as optimal for nitrogen using a nonlinear method of least squares with weights that minimize the sum of the squares of deviations of the calculated values for the complex of its properties from relevant experimental data at temperatures of 77–2473 K. An important feature of [3, 4] is careful evaluation of the error of calculated tabular data for the above-stated nitrogen properties in the range of 65–2500 K.

The generalizing procedure of study [5] determined the parameters of the potential (12-6) by joint processing of the data on equilibrium and nonequilibrium properties of rarefied and moderately compressed diatomic and multiatomic gases using the method of least squares with weights. An analytical reapproximation of theoretically substantiated (calculated from the relations [19, 20]) and reliable empirical relations for compressibility factor and coefficients of viscosity and thermal conductivity obtained by 1978 was performed for nitrogen. Based on a careful evaluation of errors of the obtained optimal parameters of the potential (12-6), the following maximum possible errors were ascertained for the calculated tabular values of transfer coefficients at T = 500–2500 K: $\delta\eta = 1\%$ and $\delta\eta = 2\%$ for rarefied gas.

Study [6] determined the temperature dependence of thermal conductivity of nitrogen $\lambda = \sqrt{T}(1.647 + 5.255\cdot 10^{-4}T - 92.39/T)$ in the range of 300–2200 K by analytically matching the results of direct generalization of the reliable experimental data in the literature on thermal conductivity at T = 300–1000 K published in 1962-1984 and the results of measurement by the shock-tube method conducted in study [6] in the region of 590–2224 K. Table 1 includes the data [6] for T = 300–500 K as generalized values based on precision measurements in the region of moderate temperatures and free from the influence of less accurate data of the shock-tube method.

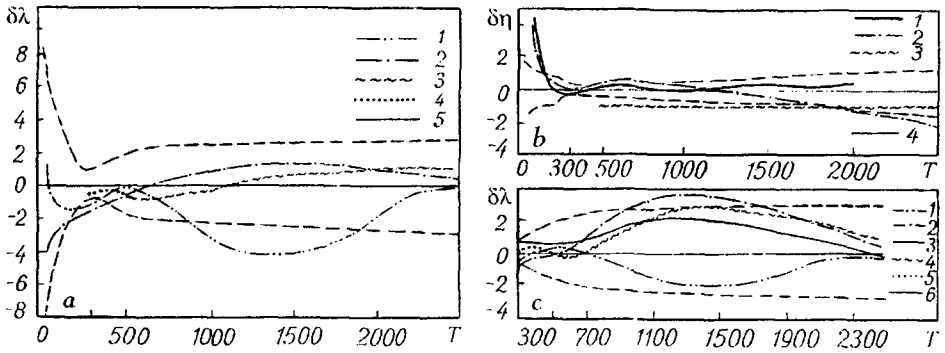

Fig. 1. Deviations for nitrogen of generalized data: a) on thermal conductivity (λ_{gen} from standard reference data (λ_{st}) [4]: 1) [1], 2) [2], 3) [5], 4) [6], 5) [4, 7, 8]; $\delta\lambda = (\lambda_{gen} - \lambda_{st})/\lambda_{st}$, %; b) on coefficient of viscosity (η_{gen}) from standard reference data (η_{st}) [4]: 1) [21], 2) [2], 3) [5], 4) [4]; $\delta\eta = (\eta_{gen} - \eta_{st})/\eta_{st}$, %; c) on thermal conductivity (λ_{gen}) from refined values recommended in the present study (λ_{recom}): 1) [1], 2) [2], 3) [3, 4, 7, 8], 4) [5], 5) [6], 6) the present study; $\delta\lambda = (\lambda_{gen} - \lambda_{refin})/\lambda_{refin}$, %. Dashed lines represent the corridors of errors of standard data [4].

Reference book [8] contains the standard data [7] on thermal conductivity of nitrogen at $P = 0.1$ MPa, which are an approximation of the tabular values [4]. Therefore, here we regard the data [7, 8] not as the outcome of independent generalization but as an analog of the data [4].

Thus, according to the generalization method, studies [1-6] are divided into two groups, namely, 1) results of direct averaging (graphically [1] and analytically [6]) of the experimental data on thermal conductivity of nitrogen and 2) theoretically substantiated values [2-5] calculated using the relations of molecular-kinetic theory [19, 20] with the aid parameters of the interaction potential for nitrogen that was employed in the joint processing of diverse experimental data on nitrogen properties.

Analysis of Causes of Discrepancy of Generalized Data on Thermal Conductivity of Nitrogen for $P = 1$ MPa and $T \geq 300$ K. As is seen from Fig. 1a, there is the following regularity of mismatch of the reference data depending on the method of their determination: at temperatures above 400 K, theoretically substantiated values [2-5] agree well with one anothher (within the limits of 1–2%), and results [1] in the region of 800–2200 K lie systematically below them. However, at a temperature of 300 K, in the vicinity of which most of the experimental studies were conducted, the data [2] approach the values [1] and deviate from the standard values [4] by 1.5% (which is about twice as large as the error inherent in the latter at this point), and the results [6] lie between the data [1, 2] and [4]. In the temperature ranges of 500–700 and 2200–2500 K, all generalized values [1-6] agree well with one another (within the limits of 1.2%).

First of all, it should be noted that studies [1-5] used practically the same experimental data on thermal conductivity of nitrogen for $T > 600$ K; therefore, the discrepancy of the data [1-5] in the range of 800–2200 K observed in Fig. 1a cannot stem from differences in the initial collection of experimental data on thermal conductivity.

At first glance, it seems that the cause of understatement of the results [1] relative to highly consistent data [2-5] (Fig. 1a) is a defect in the method for processing the collection of experimental data in study [1] (graphical smoothing) and (or) for evaluating the error of data [1]. However, while paying homage to the professionalism of the authors of [1], who themselves experimentally studied and repeatedly generalized the data on thermal conductivity of nitrogen, it would be premature to decide in favor of this viewpoint.

In order to assess the degree of certainly of the generalized values [2-4, 6] for $T = 300$ K and data [2-5] for $T > 600$ K let us consider the deviation patterns of the processed experimental collections from the generalized results presented in [2-4, 6]. It is clear from Fig. 3a on p. 25 of work [4] that, in the vicinity of room temperature, the spread in the experimental data on thermal conductivity varies from +2 to −5%. At $T = 300$ K, most of them lie below the value $\lambda_{st}(300\ K) = 26.09$ mW/(m·K). At temperatures above 700 K, most of the experimental values

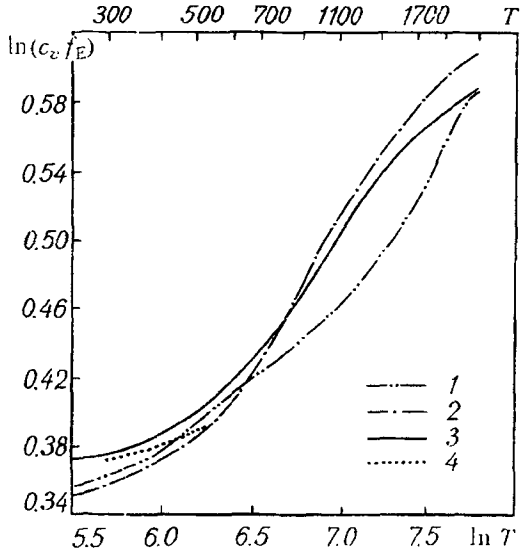

Fig. 2. Temperature dependence of $\lambda/\eta = c_v f_E$ for nitrogen according to generalized data: 1) [1, 21], 2) [2, 5], 3) [4], 4) [6, 21].

also experience negative deviations from the standard values [4], and in the region of 1400–1600 K *all experimental values* lie below the standard values, and the maximum deviation from the latter attains 7–8%. This fact was also noted by the authors of [3] on p. 180: "When $T > 1300$ K, all experimental data on thermal conductivity (except for results of the work of Faubert and Springer) lie below the calculated curve on the average by 3%. This difference exceeds evaluated errors of the reference data." Figure 1 on p. 69 of study [2] also shows that, in the temperature region of 700–2000 K, most of the $Y(T)$ values calculated on the basis of experimental data (apart from erroneous results of Trautz and related data on nitrogen viscosity) lie above the generalizing curve. Such an asymmetric position of deviations of the working experimental collections from the generalized results makes it possible to assert with confidence that there is a certain overstatement of the λ_{st} value [4] at $T = 300$ K, and also of the data [2, 4] for $T > 600$ K and of values close to them [5] for $T > 800$ K.

The initial experimental data used in [6] lie absolutely symmetrically relative to the generalized results in the region of 300–500 K (Fig. 11 at p. 661 [6]). This allows a high appraisal of the adequacy of the data [6] at moderate temperatures, although the authors modestly characterize them by an error of 3%.

Taking as a case in point the coefficient of viscosity, which is a physical property defined more exactly than thermal conductivity both theoretically and experimentally, we check the possibility in principle of good agreement of generalized data obtained by various methods over a wide temperature range. It follows from Fig. 1b that the results [2-4] in the temperature range of 150–2500 K agree practically within the limits of the corridor of errors of the data [4] (or [2]). The values [5] in the entire temperature range lie below the standard values [4] by 1%, i.e., within the framework of the inherent error. The generalized data [21]*, which for the nitrogen viscosity are an ideological analog of the data [1] on thermal conductivity, are in excellent agreement with the standard data at temperatures above 150 K** (Fig. 1b).

Since for nitrogen the generalized results for the coefficient of viscosity [2, 4, 21] for $T \geq 300$ K tally with one another well, and the data on specific heat are also fairly accurate. According to relation (2), the overstatement of the generalized values [2-5] of thermal conductivity relative to the experimental values can, most probably, be

* The results [21] are obtained by direct processing of a large collection of experimental data on coefficients of viscosity of nitrogen measured by 1987 for $T \leq 2000$ K with an error, on the average, of 0.2–0.3% (in the worst case not higher than 1%) using a method of least squares with allowance for weights and with a careful evaluation of the error.

** When $T < 150$ K, discrepancy of the data [2, 21] and [4] on the coefficient of viscosity of nitrogen is due to nonideality effects (density corrections) that take place in the low-temperature region even at atmospheric pressure and are a subject of independent inquiry.

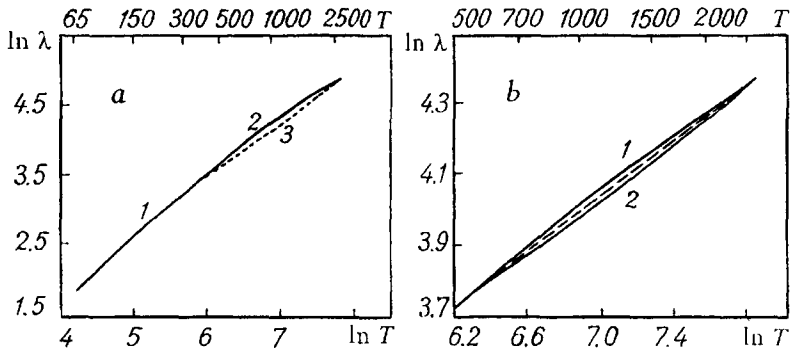

Fig. 3. Temperature dependence of thermal conductivity of nitrogen according to generalized data (a: 1) [1-6] in the range of 65–500 K, 2) [2-5], and 3) [1] in the range of 500–2500 K; b: 1) [2-5] and 2) [1] in the range of 500–2500 K. The dashed curve represents refined generalized values recommended in the present study.

attributed to improper calculation of the Eucken factor in studies [2-5]. As follows from Table 1 on p. 4 of work [4], the error of this quantity is significant ($\delta f_E = 0.7\%$ for $T = 300$ K and 2% $T \geq 400$ K), and it is a primary cause of the error of data [4] on thermal conductivity of nitrogen. Figure 2 plots temperature dependences for the relation $\lambda/\eta = c_v f_E$ based on the data [1-6, 21]. Cleary, the behavior of these dependences for $T \geq 300$ K duplicates the pattern of discrepancy of the generalized values for thermal conductivity of nitrogen in Fig. 1a and in Fig. 3.

Thus, it can be concluded that deviations of the data [1-5] are most likely due to an error inherent in the empirical results [1], because the graphical method for processing the collection of experimental data is imperfect, and the errors introduced in the theoretically substantiated results [2-5] because the Eucken factor was calculated by the Mason–Monchik method [20] insufficiently accurately.

Refinement of Generalized Data [1-5] on Thermal Conductivity of Nitrogen at Temperatures of 300–2500 K. Proceeding from the foregoing, a rigorous correction of the generalized data [2-5] should be based on a more perfect method of determining the factor f_E. Since it is not possible to more accurately calculate this factor for nitrogen in the present work, we will attempt to refine the data [1-5] on thermal conductivity of nitrogen in a first approximation relying on their temperature dependences in logarithmic coordinates (Fig.3a).

As is seen from Fig. 3b, for 500 K < T < 2200 K the data [2-5] on one side and [1] on the other manifest nearly symmetric deviations from a straight line (depicted by a dashed line) drawn through points λ (500 K) and λ (2500 K), at each of which the values of thermal conductivity [1-6] are very close (see Fig. 1a and Table 1). Therefore, it appears to be logical to average and thus refine the results [1-5] on thermal conductivity of rarefied nitrogen, interpreting them in the range of 500–2500 K by the power dependence (1) in the form

$$\lambda_{\text{refin}[1-5]}(T) = \lambda\,(500\ K)\left(\frac{T}{500}\right)^n, \quad n = \text{const}. \tag{3}$$

Although the error of generalized data for $T = 500$ K, evaluated by the authors of [1-6], varies from 1 to 3% (Table 1), they agree with a very high accuracy (the spread is not greater than ±0.4%). Therefore, the value of the reference point λ (500 K) can be determined as an arithmetic mean of practically coinciding data [1-6]: $\lambda_{m[1-6]}$ (500 K) = 38.62 mW/(m·K). With the aid of the value of thermal conductivity $\lambda_{m[1-5]}$ (2500 K) = 135.73 mW/(m·K) obtained in the same fashion from the data [1-5], checking within the limits of ±0.6%, we determine the exponent of relation (3) $n = 0.781$.

Calculating thermal conductivity of nitrogen by relation (3) with the above-stated parameters indicated (Table 1 and Fig. 1c) that the power dependence excellently averages the generalized data [1-5] not only in the expected range of 500–2500 K but also in the region of lower temperatures 300–500 K.

Thus, the refined values of generalized data [1-5] on thermal conductivity of nitrogen recommended in the present study are described by the relation

TABLE 2. Values of Thermal Conductivity of Nitrogen in the Rarefied Gas State for Temperature $T = 300$ K [22]

Author	Year	Reference in [22]	λ
H. Gregory, S. Marshall	1928	[72]	25.67
B. G. Dickins	1934	[22]	26.09
F. G. Keyes	1954	[54]	25.96
B. Le Neindre, R. Tufeu, et al.	1969–1971	[25–27]	25.80
T. F. Buthers, T. S. Storvic	1973	[86]	25.97
J. W. Haarman	1973	[36]	26.03
A. A. Clifford, J. Kestin, et al.	1979	[37]	26.03
M. J. Assael, W. A. Wakeham	1981	[42]	25.70
E. N. Haran, G. C. Mainthland, et al.	1983	[45]	25.59
N. Imashi, J. Kestin, et al.	1984	[47]	25.90
A. I. Johns, et al.	1986	[49]	26.10
J. Millat, M. Mustafa, et al.	1988	[52]	26.00

$$\lambda_{\text{recom}}(T) \equiv \lambda_{\text{refin}[1-5]}(T) \approx 38.62 \left(\frac{T}{500}\right)^{0.781} \text{ mW/(m·K)}, \quad 300 \text{ K} \le T \le 2500 \text{ K}. \tag{4}$$

Generally speaking, the reference point of relation (4) can be any value of thermal conductivity from the temperature region in which this relation is valid. Usually, design equations are written as the power function (1) using the λ_0 value at a minimal temperature. Therefore, formally the relation

$$\lambda_{\text{recom}}(T) \equiv \lambda_{\text{refin}[1-5]}(T) = 25.91 \left(\frac{T}{300}\right)^{0.781} \text{ mW/(m·K)}, \quad 300 \text{ K} \le T \le 2500 \text{ K} \tag{5}$$

is practically identical to relation (4) except a difference that the employed value of the reference point $\lambda(300\text{ K}) = 25.91$ mW was calculated from relation (4) and does not coincide with a mean value for the generalized data [1-4, 6] $\lambda_{m[1-4,6]}(300\text{ K}) = 25.85$ mW/(m·K). For the recommended power dependence (4), relying on the generalized data [1-6], the reference point $\lambda_0 = \lambda_{m[1-6]}(500\text{ K})$ is more justified physically, since in the range of 300–2500 K the data [1-6] agree best exactly at a temperature of 500 K (Fig. 1a and c).

Table 1 and Fig. 1c, which present deviations of the data [1-6] from the recommended refined generalized values, show that relation (4) corrects the data [1] and [2-5], increasing and decreasing them in the range of 700-2200 K, specifically, by 2.3% and by 2–3.4% at the point of maximum discrepancy at $T = 1400$ K. Thus, it follows that the results [2-5] in this temperature range are brought into good agreement with the experimental data on thermal conductivity of nitrogen used in the generalization.

At temperatures of 300–500 K, the refined values correlate with high accuracy (within ±0.3%) with the data [6] obtained by generalizing more numerous and reliable (in comparison with those used in studies [1, 2, 4]) experimental results in the region of moderate temperatures. Deviations of the data [1, 2], on the one hand, and the data [4], on the other, from the refined values of relation (4) are practically symmetric (Fig. 1c). The value of $\lambda_{\text{recom}}(300\text{ K}) = 25.9148$ mW/(m·K), calculated from relation (4), ideally fits the value of $\lambda_{[6]}(300\text{ K}) = 25.9233$ mW/(m·K) determined from the above-stated design equation [6], and the data [1, 2] deviate from them by, respectively, −0.8 and +0.7% (Table 1 and Fig. 1c).

Table 2 presents experimental values of thermal conductivity of nitrogen for a temperature of 300 K borrowed from the review [22] (Table 8 on pp. 90-92). Data of the 80s were obtained by an unsteady heated-filament method and are characterized by a high accuracy. The arithmetic mean of these values $\lambda_m(300\text{ K}) = 25.9033$ mW/(m·K) is also in good aggrement with the results of [6] and of the present paper (see Table 1).

No less noteworthy is the fact that the refined values of relation (4) correlate with the generalized data [1-6] practically within the framework of the author's errors estimated for them (Table 1). It is seen from Fig. 1c

that deviations of the results [1-6] from the values recommended in this paper fit well into the corridor of errors characterizing the standard data [4, 7], namely, an excess within the limits of 0.8% takes place only for the data [2] in the region of 1000–1800 K. Since the estimation of errors of the generalized results for diverse properties of nitrogen carried out in [3, 4] inspires high confidence, we characterize the recommended values of thermal conductivity of the present study by the same relative errors $\delta\lambda$ as those in [3, 4] in the range of 300–2500 K* (Table 1).

CONCLUSIONS

In the present work we succeeded in fitting the generalized data [1-5] on thermal conductivity of nitrogen in the state of a rarefied gas in the range of 300–2500 K by averaging them with the aid of a simple temperature power dependence (4). It can be stated that relations (4) and (5) reflect the collections of experimental data on thermal conductivity of nitrogen used in generalizations [1-5] with a higher assurance than do the data [4-5]. It can be assumed that the values of $\lambda_{[6]}(300\ \text{K}) = 25.92$ mW/(m·K) and $\lambda_{\text{recom}}(300\ \text{K}) = 25.91$ mW/(m·K) obtained independently in [6] and in the present paper are characterized by high reliability.

The results of relations (4) and (5) are an empirical reapproximation of the generalized literature data. However, since, unlike for monatomic gases [15], it has not been proved theoretically that the thermal conductivity of a diatomic gas above a certain temperature T_0 can be described with good accuracy by the power dependence (1) (as, for example, coefficients of viscosity and diffusion of monatomic and multiatomic gases), a proof of this fact, obtained empirically, is of importance for both the practice and the theory of heat conduction of multiatomic gases:

a) relation (4) can be used via its extrapolation for obtaining the data on thermal conductivity of molecular (nondissociated) nitrogen for $T > 2500$ K;

b) based on data of relation (4) on thermal conductivity and on reliable data on specific heat it is possible to refine the values of the Eucken factor for nitrogen for $T \geq 300$ K;

c) the established temperature dependence of thermal conductivity of nitrogen can serve as a guideline and a criterion for devising methods of calculating the Eucken factor for diatomic and multiatomic gases. The authors of study [5] have rightly noted that the "best model of heat conduction of multiatomic gases should be selected not only with a view to the level of rigor of the premises therein but, to an even greater extent, proceeding from the results of agreement of theory with experimental data."

NOTATION

T, temperature, K; P, pressure, MPa; λ, thermal conductivity, mW/(m·K); η, dynamic viscosity, mPa·sec; c_p, specific heat at constant volume, J/(kg·K); f_E, Eucken factor; $f_{(\lambda)}^{(3)}$ and $f_{(\eta)}^{(3)}$, corrections, correspondingly, for coefficients of thermal conductivity and viscosity calculated in the third approximation by the Chapman–Enskog method; k, Boltzmann constant, J/K; m, molecular mass, kg; $\Omega^{(2.2)^*}(kT/\varepsilon)$, temperature dependence of the reduced collision integral; ε/k and σ, potential parameters, K and nm; n, exponent of relation (1). The subscript 0 stands for parameters of the reference point used in the theory of the shock-tube method; the superscript * characterizes parameters of the corrected reference point.

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* Thermal conductivity of nitrogen in a certain temperature range below 300 K (for example, up to 0°C) can, probably, be described by relation (4) with a corresponding (higher) error. However, in this work we restrict ourselves to the result obtained.

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