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Thermal Conductivity, Thermal Diffusivity, and Heat Capacity of Gaseous Argon and Nitrogen[1]

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Low-pressure thermal conductivity and thermal diffusivity measurements are reported for argon and nitrogen in the temperature range from 295 to 350 K at pressures from 0.34 to 6.9 MPa using an absolute transient hot-wire instrument. Thermal conductivity measurements were also made with the same instrument in its steady-state mode of operation. The measurements are estimated to have an uncertainty of 1% for the transient thermal conductivity, 3% for the steady-state thermal conductivity, and 4% for thermal diffusivity. The values of isobaric specific heat, derived from the measured thermal conductivity and thermal diffusivity, are considered accurate to 5% although this is dependent upon the uncertainty of the equation of state utilized.

KEY WORDS: argon; heat capacity; nitrogen; steady-state hot-wire technique; thermal conductivity; thermal diffusivity; transient hot-wire technique.

1. INTRODUCTION

The transient hot-wire method is widely accepted as the primary technique for precise thermal-conductivity measurements of fluids. Though theoretically feasible, its practical simultaneous use for thermal diffusivity measurements has been, to date, limited due to the lack of reproducibility and an apparent dependence of the determined thermal diffusivity on the power employed [1, 2]. New measurements have been undertaken on a wide variety of fluids, e.g., argon [1], liquid *n*-pentane [2], and toluene [3] with a transient hot-wire instrument employing bare and coated

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12.7μm (nominal) diameter platinum wires where this uncertainty has been presumably removed [4]; the details are given in the references.

In the present paper, new low-pressure measurements of the thermal conductivity and thermal diffusivity of argon and nitrogen are reported using the same instrument as used earlier; over 400 thermal conductivity and thermal diffusivity measurements are reported for each fluid. From these, the temperature dependence of the thermal conductivity and the power-corrected and power-independent thermal-diffusivity values are then used to determine the isobaric specific heats for both, using densities calculated with the equation of state of Ref. 5; this resulted in 35 and 39 results of thermal diffusivity and isobaric specific heat for argon and nitrogen, respectively. The uncertainties in the measured thermal conductivity and thermal diffusivity are estimated to be between 1 and 4%, respectively; the uncertainty of the derived isobaric specific heat is estimated to be 5%.

New steady-state measurements of the thermal conductivity of both fluids are also reported with the same transient hot-wire instrument. The uncertainty in these results, free from the influence of natural convection, is estimated to be about 3%. Both the steady-state and transient thermal-conductivity results agree to within their mutual uncertainty.

2. THEORY FOR TRANSIENT MEASUREMENTS

The use of the transient hot-wire method for the simultaneous measurement of thermal diffusivity and thermal conductivity has been limited due to a lack of reproducibility in the obtained thermal diffusivity results; for example, there appears to be some dependence of the measurements on power applied to the wire [2]. The ideal working equation for the thermal conductivity is based on the transient solution of Fourier's law for an infinite line source [6]. Here the ideal temperature rise of the fluid at the wire–fluid interface, $r = a$, at time t is

$$\Delta T = \frac{q}{4\pi\lambda(\rho, T)} \ln \frac{4\alpha t}{a^2 C}, \tag{1}$$

where

$$\Delta T = \Delta T_{\mathrm{w}} + \Sigma \delta T_i, \tag{2}$$

and $\Sigma \delta T_i$ are appropriate corrections to the measured temperature rise of the wire, ΔT_{w}; q is the power per unit length to the wire, λ is the thermal conductivity, $\alpha = \lambda/(\rho C_p)$ is the thermal diffusivity, ρ is the density, and C_p is the isobaric heat capacity, with $C = 1.781\ldots$ the exponential of Euler's constant.

The value of the thermal conductivity is determined from the slope of the linear regression of the ΔT vs. $\ln(t)$ data set obtained via Eq. (1) referred to a reference temperature T_{ref} [6],

$$T_{\text{ref}} = T_0 + \frac{1}{2}\left[\Delta T(t_1) + \Delta T(t_2)\right]. \tag{3}$$

This is so since the measured properties are functions of temperature and these increase during the measurement period. Here $\Delta T(t_1)$ and $\Delta T(t_2)$ represent the temperature differences at the commencement, t_1, and end, t_2, times of the fitted interval.

The thermal diffusivity of the fluid is often (e.g., Ref. 7) obtained directly from the same measurements for thermal conductivity through use of Eq. (1) as

$$\alpha = \frac{a^2 C}{4t'} \exp\left[4\pi\lambda \Delta T(a, t')/q\right]. \tag{4}$$

The thermal diffusivity, α, is determined from values of λ and ΔT and the fit of a line at an arbitrarily chosen time t'. This time is normally selected to be 1 s in most data reduction programs.

The changes with temperature of the thermophysical properties of the fluid cause the temperature difference to be expressed approximately as [6]

$$\Delta T = -\frac{1}{2}\chi \Delta T^2 + \frac{q}{4\pi\lambda(\rho, T_0)} \ln \frac{4\alpha t}{a^2 C} + \left(\frac{q}{4\pi\lambda}\right)^2 (\chi - \varphi)\ln 4, \tag{5}$$

where the subscript "0" denotes the initial steady-state temperature (both temperature) and χ and φ are the temperature coefficients of thermal conductivity and heat capacity, respectively. In Eq. (5) the last term is generally much smaller than the second and can be initially ignored [1]. Equation (5) can therefore be simplified to

$$\Delta T' = \Delta T\left(1 + \frac{1}{2}\chi \Delta T\right) = \frac{q}{4\pi\lambda_0} \ln \frac{4\lambda_0 t/(\rho_0 C_p)}{a^2 C} = \frac{q}{4\pi\lambda_0} \ln \frac{4\alpha t}{a^2 C}, \tag{6}$$

where $\Delta T'$ denotes the temperature rise after the correction for the influence of χ. If this temperature coefficient is known in advance, or can be determined from thermal-conductivity measurements, then the thermal diffusivity can be more precisely determined via use of Eq. (6) than from Eq. (4). The influence on ΔT of the temperature variation of properties over the measurement period is usually small—typically only 10's of mK—but, as discussed in Refs. 1–4, its influence on the experimental thermal diffusivity data is significant and must be taken into account. Thus, in this work to determine the thermal diffusivity at the bath reference temperature, measurements of both thermal conductivity and thermal diffusivity at a series of different power levels are employed. In this way the thermal conductivity of the fluid, at a variety of different reference temperatures, is used to obtain the temperature coefficient of the thermal conductivity. Then a thermal conductivity and its temperature coefficient at the bath or reference temperature can be determined by fitting the thermal conductivity value vs. the reference temperature. These in turn are used to correct for χ to obtain a thermal diffusivity value at the reference temperature. These values are next used, via the power dependency, to establish an effective bridge imbalance, or zero offset-temperature difference, and thus establish a precise, power independent value of thermal diffusivity at the reference temperature written as [1–4],

$$\alpha = \frac{a^2 C}{4t'} e^G, \tag{7}$$

where $G = 4\pi\lambda_0 \frac{\partial \Delta T'}{\partial q}$.

The influence of thermal radiation has been studied in detail in Refs. 2–4, 6, and 9. For a fluid that is transparent to thermal radiation, such as argon and nitrogen, the correction for thermal radiation can be calculated using the Stephan–Boltzmann equation, which can be written as

$$\delta T_{\mathrm{r}} = \frac{8\pi a T_0^3 \varepsilon_{\mathrm{PT}} \sigma \Delta T^2}{q}, \tag{8}$$

where δT_{r} denotes the temperature correction due to thermal radiation, σ denotes the Stephan–Boltzmann constant, and $\varepsilon_{\mathrm{PT}}$ denotes the emissivity of platinum (~0.045 at 300 K).

The influence of the thermophysical properties of the hot wire on the measured thermal conductivity was also reconsidered, e.g., Ref. 4. On the basis of the first-order analysis by Healy et al. [6], a new correction for this influence was obtained in expansion form as

$$\Delta T_1 = \left(\frac{q_1}{q} - \frac{q_2}{q} \right) \Delta T_1 + \delta T, \tag{9}$$

where δT denotes the first-order correction for this influence given by Healy et al. [6], q_1 and q_2 are two higher-order terms accounting for the influence of wire properties written as

$$q_1 = \frac{\lambda_{\mathrm{w}} \pi a^2 c_1}{t^2} \left(c_3 - c_2 \ln \frac{4\alpha}{a^2 C} - 1 + \frac{r^2}{2a^2} \right) \tag{10}$$

and

$$q_2 = \left[\frac{\Delta T_w}{q\alpha_w} \left(\frac{2q_1}{t} + \frac{\lambda_w \pi a^2 c_1 c_2}{t^3} \right) + \frac{2\pi \Delta T_w \lambda_w c_1}{qt^2} - \frac{c_1 a}{rt^2} \right] \times \pi a^2 \lambda_w, \quad (11)$$

where

$$c_1 = \frac{qa^2}{8\pi \lambda \alpha_w^2}, \quad c_2 = \frac{\lambda_w}{\lambda} - \frac{\alpha_w}{\alpha}, \quad c_3 = \frac{\lambda_w}{\lambda}, \quad (12)$$

λ_w and α_w denote the thermal conductivity and thermal diffusivity of the hot wire, respectively, and λ and α denote the thermal conductivity and thermal diffusivity of the test fluid, respectively; the details for these expressions can also be found in Ref. 4.

In order to establish the validity of the above expression, a thermal conductivity result for argon at 1.225 MPa and 142 K is used as an example for comparison with the equations used in Refs. 6 and 10 and with Eq. (9) in this work. The thermal-conductivity and thermal-diffusivity results are $0.01068\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$ and $0.426 \times 10^{-6} \mathrm{m^2 \cdot s^{-1}}$, respectively. The comparison for this result is shown in Fig. 1 which illustrates the errors in the measured thermal conductivity when different initial times are used for the first point when fitting the straight line of $\Delta T_1'$ vs. $\ln(t)$ with an end point

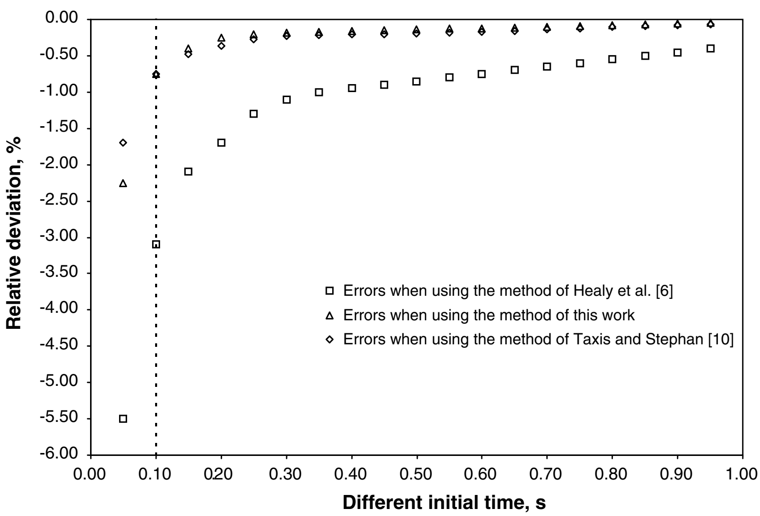

Fig. 1. Comparisons among different equations to correct for the influence of the thermo-physical properties of the hot wire.

of 1 s; it can be seen that the result obtained employing Eq. (10) provides the best method to correct for this.

With the transient line-source instrument, convection-free measurements can only be obtained over some initial time period. At large times, convection effects appear that result in a reduction of the temperature rise with respect to time [11]. The influence of convection on the ΔT vs. $\ln(t)$ plot may initially appear similar to that produced by the radiation effect and hence it may be difficult to distinguish between the two influences. In order to check for the onset of natural convection, the following criterion was utilized [11]:

$$Ra = g\beta \Delta T \delta^3 \Big/ (\nu\alpha) \leqslant 10^5, \tag{13}$$

where Ra is the Rayleigh number and $\delta = (28\alpha t)^{1/2}$ is the thermal boundary layer thickness.

To verify Eq. (13), a measurement for argon at 323 K and 20.92 MPa was performed using platinum wires with $q = 0.1394\,\mathrm{W \cdot m^{-1}}$ and $a = 6.53\,\mu\mathrm{m}$ with a measurement time out to 3 s. The deviation of the temperature rise from the linear fit of the temperature rise prior to 1.7 s vs. the logarithm of time is shown in Fig. 2. The values of α, ν, and β for argon at this state are $1.235 \times 10^{-7}\mathrm{m^2 \cdot s^{-1}}$, $9.81 \times 10^{-8}\ \mathrm{m^2 s^{-1}}$, and $0.0031\,\mathrm{K^{-1}}$,

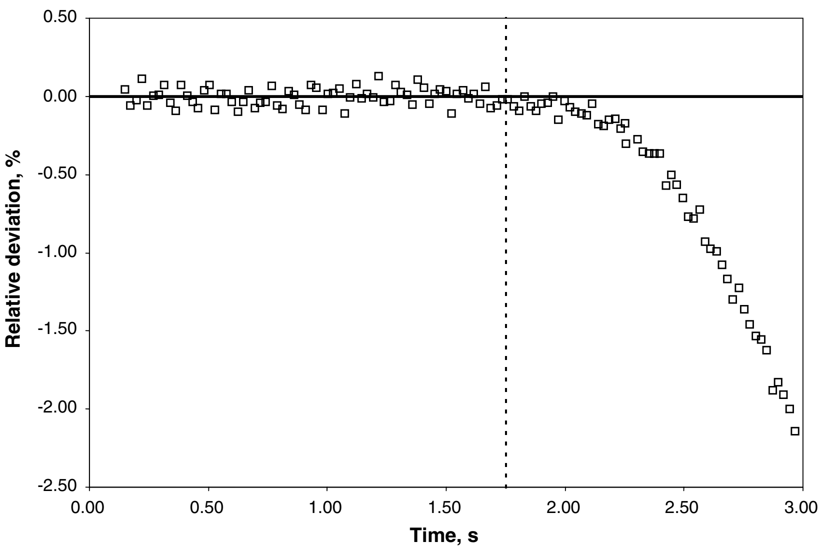

Fig. 2. Deviations in the temperature rise from the best linear fit for the measurement of argon at 323 K and 20.9 MPa.

respectively. As shown in Fig. 2 the maximum temperature rise that is free of the influence of natural convection is only out to 1.7 s at which point the temperature rise is only 3.6 K. The thermal boundary layer thickness at this time is only about 0.00242 m and $Ra = 1.28 \times 10^5$, a value that agrees well with that predicted by Eq. (13).

3. EXPERIMENT

The transient hot-wire technique utilized two wires, both with a nominal diameter of 12.70 μm, though with different lengths; this was used to compensate for the influence of end effects. The wires were calibrated *in situ* over the temperature and pressure ranges of measurement. The actual diameter of the wire was determined by a scanning electron microscope (SEM) examination to be 13.06 μm. The wire specifications, lengths, and calibration coefficients are given in Table I along with the purity of the argon and nitrogen used. The diameter of the cell containing the fluid was measured to be 4.97 mm. Using the hot wire along the cylindrical axis of the cell, the variation of the radius of the cell is within ±0.2 mm, which will introduce an uncertainty of the measured thermal conductivity of about ±0.8% in the measurements using the steady-state technique presuming wire concentricity.

Table I. Wire and Test Fluid Specifications

(a) Calibration equation: $R = a_0 + a_1 T + a_2 T^2 + bP$; T (°C), P (MPa)		
(b) Wire specification and calibration coefficients; long and short wires		
Mass purity (%)	99.999	99.999
Length (m)	0.08500 ± 0.00001	0.02826 ± 0.00001
Diameter (μm)	13.06 ± 0.01	13.06 ± 0.01
R_0	64.0327	21.4107
a_1	0.249593	0.0833068
a_2	-5.08635×10^{-5}	-1.58719×10^{-5}
b	-1.75154×10^{-3}	-5.58667×10^{-4}
(c) Test fluid: argon; M = 39.944 with mass purity of 99.999%		
T_{cr} (150.86 K)	P_{cr} (5.00 MPa)	ρ_{cr} (536 kg·m^{-3})
(d) Test fluid: nitrogen; M = 28.016 with mass purity of 99.99%		
T_{cr} (150.26 K)	P_{cr} (3.396 MPa)	ρ_{cr} (304 kg·m^{-3})

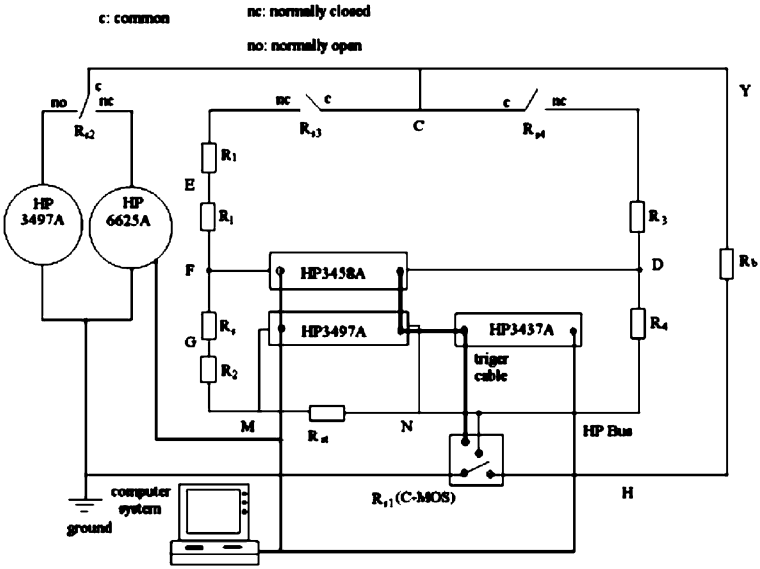

Fig. 3. Schematic of the experimental apparatus.

The measurement circuit is shown in Fig. 3 [4]. Here the HP3497A is a data acquisition/control unit, HP6625A is a dc power supply, HP3458A is an integrating voltmeter which provides integration for times of 0 up to 16667 ms, HP3437A is an external trigger unit, and C-MOS is a digital switch used to switch from the 'dummy' to the 'measurement' circuit. The HP3497A unit provides a constant current of 1 and 0.1–0.01 mA, respectively, for use when calibrating the wires and balancing the bridge. The unit also provides an integrating voltmeter with integration times of 0.167, 1.67, and 16.67 ms. The unit as well provides digital and analog switches used in the circuit, under computer control, during the preliminary balancing and final measurement processes. The HP6625A provides a high-stability fast-response dc power supply from 0 to 16 V for the heating of the wires. The HP3437A is used to provide an external signal to trigger the HP3497A, HP3458A, and the C-MOS switch to connect the circuit and to trigger both the HP3497A and HP3458A instruments to begin simultaneous measurements of both current and voltage across bridge elements.

The HP3497A is used to measure the voltage across the standard resistance, R_{st}, in order to determine the current though the hot wires. The unit is also utilized to provide a current of 1 mA when balancing the bridge. The HP3458A is used to measure the transient imbalance of the bridge, which is introduced by the temperature change of the hot wires, and to measure the voltages of the other branches of the bridge and the standard resistance. R_1 to R_4 and R_b are adjustable resistance boxes, and R_{st} is a standard resistance with a value of 25 Ω.

As indicated in Refs. 1–4, every attempt is made to accurately balance the bridge; however, some small residual bridge imbalance always exists. Although the value of the temperature correction due to this influence is only 10's of mK, a correction for its influence is essential in order to achieve good reproducibility and values of thermal diffusivity that are independent of the applied power and thus accurate. The methods used and the determination of an effective "zero"-time residual bridge imbalance are presented in detail elsewhere [1–4]; however, the procedure to process the measured temperature data will be briefly outlined.

First, as mentioned in Refs. 1–4, the temperature coefficient of the measured thermal conductivity near the bath temperature and test pressure is obtained by using several different heating powers to measure the thermal conductivity at different reference temperatures. The thermal conductivity and thermal diffusivity of the fluid corresponding to the initial base temperature are then determined using Eq. (7). However, a systematic and nearly constant temperature "offset" will still exist in the values of the thermal diffusivity. To obtain this correction, the temperature rise at a given instant is linearly regressed as a function of $q/(4\pi\lambda_0)$ and the intercept at zero power obtained. This correction represents a zero-time effective bridge imbalance. In addition, when initially processing the primarily individual measured temperature data, the thermal-conductivity and thermal-diffusivity data involved in the various corrections are estimated for the measurement and an iterative technique is employed to remove this, i.e., after the thermal conductivity and thermal diffusivity data are obtained, they are then substituted back for the previous estimates of both thermal conductivity and thermal diffusivity and the data set reprocessed. Typically, some $10-12$ thermal conductivity values are obtained at one nominal temperature and pressure by systematically raising the wire power from 0.02 to $0.3\,\text{W}\cdot\text{m}^{-1}$; these values are then used to extract the first estimates for the temperature coefficient of thermal conductivity and thermal diffusivity at the measurement temperature. Then some 430 measurements (~ 140 per nominal isotherm) are then used to determine a corrected thermal diffusivity and specific heat — thus only 38–39 derived measurements of the temperature coefficient of thermal conductivity, the thermal diffusivity, and its derived specific heat as a function of temperature and pressure are reported for each fluid.

In Eq. (1), the energy input per unit length of the wire is assumed constant. However, this changes due to the change in the resistance of the wire with time as the measurement progresses. The influence of this must now be corrected. For the bridge employed in this work, the correction can be written as [4]

$$\Delta T_9 = -\frac{q_0 f a^2}{8\pi\lambda_2}\left(1-\frac{\alpha_w}{\alpha}\right)+\frac{q_0 a^2 f}{16\pi\lambda}\ln\frac{4\alpha t}{a^2 C} + \frac{q_0\lambda_w a^2 f}{16\pi\lambda^2}\left(\ln^2\frac{4\alpha_w t}{a^2 C}-\frac{\pi^2}{6}\right), \quad (14)$$

where

$$f = \frac{q_0\alpha\,(m-1)}{\pi a^2\lambda_w\,(m+1)}, \quad (15)$$

and

$$m = \frac{R_1+R_2+R_{st}}{R_{l0}+R_{s0}}, \quad (16)$$

where R_{l0} ad R_{s0} denote the resistances of the hot wire at the bath temperature. From Eqs. (14) and (15), it can be seen that if $m=1$, the influence of variable power versus time can be ignored. The details of these equations can be found in Ref. 4.

4. RESULTS

The thermal conductivity and thermal diffusivity of argon and nitrogen were measured along three nominal isotherms: 296, 322, and 343 K at pressures from 0.34 to 6.9 MPa. The measurements for argon and nitrogen with the transient technique are tabulated in Tables II and III, respectively, along with their corresponding equilibrium values highlighted in bold-faced type. The density values were obtained using the equation of state for pure fluids [5].

The measurements for the thermal conductivity of argon and nitroen with the steady-state method are tabulated in Tables IV and V, respectively, where the results in bold-faced type indicate measurements considered free of the influence fo free convection. In these tables the viscosity used to calculated th *Ra* number is also noted.

4.1. Thermal Conductivity

The thermal-conductivity values were correlated with an equation of the form

$$\lambda\left(\mathrm{W\cdot m^{-1}\cdot K^{-1}}\right) = \lambda_0(T) + b_1\rho\left(\mathrm{kg\cdot m^{-3}}\right) + b_2\left(\rho\left(\mathrm{kg\cdot m^{-3}}\right)\right)^2, \quad (17)$$

Table II. Thermal Conductivity, Thermal Diffusivity, and Specific Heat of Argon

ID No.	T (K)	P (kPa)	ρ ($kg \cdot m^{-3}$)	q ($W \cdot m^{-1}$)	λ ($W \cdot m \cdot K^{-1}$)	χ (10^{-3} K^{-1})	α (10^{-8} $m^2 \cdot s^{-1}$)	C_p ($J \cdot kg^{-1} \cdot K$)
	296.23	**169**	**2.744036**		**0.017803**	**2.822**	**125.0**	**519.0**
A20_2A1	297.748	169	2.729973	0.027700	0.017789			
A20_2B1	298.197	169	2.725841	0.036130	0.017941			
A20_2C1	298.712	169	2.721117	0.04577	0.017919			
A20_2A2	299.304	169	2.715708	0.056500	0.017947			
A20_2B2	299.956	169	2.709774	0.06838	0.018093			
A20_2C2	300.658	169	2.703415	0.081390	0.01805			
A20_2D2	301.422	169	2.696528	0.095560	0.01808			
A20_2E2	302.206	169	2.689498	0.110837	0.018098			
A20_2A3	303.136	169	2.681206	0.127312	0.018139			
A20_2B3	304.076	169	2.672876	0.144881	0.018159			
	296.22	**344**	**5.59196**		**0.017958**	**1.636**	**603.0**	**532.6**
A20_5A1	297.673	344	5.564373	0.027700	0.018037			
A20_5B1	298.102	344	5.556281	0.036150	0.018007			
A20_5C1	298.614	344	5.546653	0.045800	0.018020			
A20_5A2	299.163	344	5.536368	0.056520	0.018029			
A20_5B2	299.778	344	5.524891	0.068420	0.018050			
A20_5C2	300.451	344	5.512387	0.081440	0.018069			
A20_5D2	301.184	344	5.498833	0.095620	0.018094			
A20_5E2	301.963	344	5.484502	0.110883	0.018164			
A20_5A3	302.819	344	5.468841	0.127340	0.018160			
A20_5B3	303.647	344	5.453379	0.144937	0.018176			
A20_5C3	304.600	344	5.436545	0.163752	0.018221			
	296.22	**512**	**8.331839**		**0.017984**	**2.091**	**401.5**	**537.6**
A20_7A1	297.608	512	8.292362	0.027710	0.018036			
A20_7B1	298.030	512	8.280435	0.036150	0.018044			
A20_7C1	298.515	512	8.266770	0.045800	0.018095			
A20_7A2	299.044	512	8.251917	0.056500	0.018128			
A20_7B2	299.637	512	8.235332	0.068430	0.018085			
A20_7C2	300.282	512	8.217369	0.081440	0.018116			
A20_7D2	300.986	512	8.197853	0.095630	0.018129			
A20_7E2	301.691	512	8.178404	0.110877	0.018200			
A20_7A3	302.499	512	8.156228	0.127403	0.018207			
A20_7B3	303.355	512	8.132867	0.144948	0.018277			
A20_7C3	304.272	512	8.107991	0.163742	0.018291			
	296.21	**687**	**11.19243**		**0.018034**	**2.360**	**299.8**	**537.4**
A20_01A1	297.560	687	11.14056	0.027700	0.018091			
A20_01B1	297.978	687	11.12460	0.036160	0.018068			
A20_01A2	298.955	687	11.08748	0.056530	0.018154			
A20_01B2	299.527	687	11.06586	0.068460	0.018220			
A20_01C2	300.155	687	11.04223	0.081450	0.018219			
A20_01D2	300.156	687	11.04219	0.081450	0.018218			
A20_01E2	300.838	687	11.01664	0.095650	0.018213			
A20_01F2	301.571	687	10.98932	0.110889	0.018233			
A20_01A3	302.294	687	10.96250	0.127410	0.018310			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ ($kg{\cdot}m^{-3}$)	q ($W{\cdot}m^{-1}$)	λ ($W{\cdot}m{\cdot}K^{-1}$)	χ ($10^{-3}\,K^{-1}$)	α ($10^{-8}\,m^2{\cdot}s^{-1}$)	C_p ($J{\cdot}kg^{-1}{\cdot}K$)
A20_01B3	303.135	687	10.93147	0.144973	0.018313			
A20_01C3	304.023	687	10.89890	0.163766	0.018368			
	296.21	**1379**	**22.56337**		**0.018282**	**2.284**	**146.0**	**555**
A20_02A1	297.438	1379	22.46621	0.027700	0.018371			
A10_01B1	297.829	1379	22.43516	0.036160	0.018327			
A20_02C1	298.265	1379	22.40127	0.045780	0.018311			
A20_02A2	298.735	1379	22.36453	0.056530	0.018406			
A20_02B2	299.269	1379	22.32294	0.068430	0.018422			
A20_02C2	299.847	1379	22.27811	0.081440	0.018450			
A20_02D2	300.479	1379	22.22930	0.095640	0.018470			
A20_02E2	301.154	1379	22.17742	0.110899	0.018466			
A20_02A3	301.828	1379	22.12586	0.127394	0.018533			
A20_02B3	302.590	1379	22.06787	0.144976	0.018556			
A20_02C3	303.370	1379	22.00883	0.163733	0.018567			
	296.21	**2069**	**33.99485**		**0.018528**	**2.272**	**95.76**	**569.2**
A20_03A1	297.403	2069	33.84968	0.027720	0.018542			
A20_03B1	297.750	2069	33.80770	0.036170	0.018625			
A20_03C1	298.158	2069	33.75848	0.045800	0.018591			
A20_03A2	298.633	2069	33.70137	0.056510	0.018619			
A20_03B2	299.115	2069	33.64362	0.068470	0.018679			
A20_03C2	299.657	2069	33.57894	0.081420	0.018680			
A20_03D2	300.253	2069	33.50811	0.095660	0.018712			
A20_03E2	300.842	2069	33.43842	0.110896	0.018701			
A20_03A3	301.518	2069	33.35882	0.127392	0.018780			
A20_03B3	302.233	2069	33.27506	0.144952	0.018780			
A20_03C3	303.036	2069	33.18151	0.163670	0.018792			
	296.22	**2753**	**45.41331**		**0.018832**	**1.889**	**72.60**	**571.2**
A20_04A1	297.373	2753	45.22210	0.027710	0.018878			
A20_04B1	297.685	2753	45.17065	0.036190	0.018906			
A20_04C1	298.083	2753	45.10521	0.045810	0.018908			
A20_04A2	298.524	2753	45.03293	0.056520	0.018916			
A20_04B2	298.999	2753	44.95536	0.068440	0.018912			
A20_04C2	299.518	2753	44.87093	0.081420	0.018918			
A20_04D2	300.093	2753	44.77779	0.09563	0.018970			
A20_04E2	300.710	2753	44.67830	0.110903	0.018982			
A20_04A3	301.311	2753	44.58185	0.127360	0.019013			
A20_04B3	302.003	2753	44.47134	0.144901	0.019020			
A20_04C3	302.702	2753	44.36031	0.163669	0.019098			
	296.23	**3452**	**57.16723**		**0.019107**	**1.805**	**57.32**	**583.1**
A20_05A1	297.308	3452	56.93763	0.02771	0.019114			
A20_05B1	297.642	3452	56.86690	0.03615	0.019187			
A20_05C1	298.015	3452	56.78813	0.0458	0.019147			
A20_05A2	298.442	3452	56.69826	0.05651	0.019187			
A20_05B2	298.902	3452	56.60178	0.06843	0.019205			
A20_05C2	299.402	3452	56.49732	0.0814	0.019225			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A20_05D2	299.955	3452	56.38227	0.09558	0.019246			
A20_05E2	300.534	3452	56.26237	0.110839	0.019237			
A20_05A3	301.123	3452	56.14095	0.12735	0.019301			
A20_05B3	301.837	3452	55.99454	0.144844	0.019314			
A20_05C3	302.506	3452	55.8581	0.163612	0.019294			
	296.25	**4142**	**68.84635**		**0.019422**	**1.423**	**47.55**	**593.3**
A20_06A1	297.617	4142	68.48944	0.036150	0.019490			
A20_06B1	297.981	4142	68.39509	0.045790	0.019451			
A20_06A2	298.376	4142	68.29303	0.056490	0.019484			
A20_06B2	298.823	4142	68.17794	0.068420	0.019470			
A20_06C2	299.308	4142	68.05355	0.081380	0.019514			
A20_06D2	299.862	4142	67.91208	0.095610	0.019519			
A20_06E2	300.409	4142	67.77303	0.110791	0.019516			
A20_06A3	300.968	4142	67.63157	0.127312	0.019577			
A20_06B3	301.657	4142	67.45811	0.144822	0.019560			
A20_06C3	302.259	4142	67.30736	0.163546	0.019598			
	296.26	**4833**	**80.61776**		**0.019723**	**1.246**	**40.52**	**603.8**
A20_07A1	297.587	4833	80.20445	0.036170	0.019736			
A20_07B1	297.933	4833	80.09746	0.045800	0.019780			
A20_07A2	298.329	4833	79.97540	0.056480	0.019762			
A20_07B2	298.760	4833	79.84303	0.068410	0.019808			
A20_07C2	299.224	4833	79.70107	0.081390	0.019792			
A20_07D2	299.739	4833	79.54417	0.095590	0.019824			
A20_07E2	300.293	4833	79.37615	0.110772	0.019801			
A20_07A3	300.827	4833	79.21494	0.127243	0.019846			
A20_07B3	301.453	4833	79.02690	0.144772	0.019836			
A20_07C3	302.130	4833	78.82465	0.163543	0.019874			
	296.28	**5518**	**92.34965**		**0.020062**	**1.034**	**35.40**	**613.7**
A20_08A1	297.418	5518	91.93606	0.031760	0.020096			
A20_08B1	297.818	5518	91.79168	0.043250	0.020037			
A20_08A2	298.287	5518	91.62304	0.056510	0.020075			
A20_08B2	298.269	5518	91.62950	0.056500	0.020091			
A20_08C2	299.400	5518	91.22565	0.088350	0.020112			
A20_08D2	300.057	5518	90.99289	0.106893	0.020138			
A20_08E2	300.762	5518	90.74462	0.127273	0.020145			
A20_08A3	301.473	5518	90.49578	0.149394	0.020188			
A20_08B3	302.304	5518	90.20689	0.173296	0.020099			
A20_08C3	303.065	5518	89.94416	0.198827	0.020030			
	296.31	**6228**	**104.5676**		**0.020341**	**1.166**	**31.05**	**626.5**
A20_09A1	297.414	6228	104.1051	0.031750	0.020380			
A20_09B1	297.806	6228	103.9420	0.043270	0.020385			
A20_09A2	298.254	6228	103.7564	0.056500	0.020388			
A20_09B2	298.766	6228	103.5451	0.071520	0.020408			
A20_09C2	299.338	6228	103.3103	0.088320	0.020398			
A20_09D2	299.966	6228	103.0538	0.106914	0.020404			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A20_09E2	300.604	6228	102.7948	0.127259	0.020438			
A20_09A3	301.347	6228	102.4950	0.149359	0.020434			
A20_09B3	302.105	6228	102.1912	0.173266	0.020492			
A20_09C3	302.886	6228	101.8803	0.198783	0.020520			
	296.36	**6828**	**114.9236**		**0.020637**	**0.7893**	**28.34**	**633.6**
A20_10A1	297.455	6828	114.4123	0.031800	0.020616			
A20_10B1	297.818	6828	114.2439	0.043300	0.020681			
A20_10A2	298.257	6828	114.0411	0.056540	0.020669			
A20_10B2	298.753	6828	113.8129	0.071550	0.020675			
A20_10C2	299.313	6828	113.5565	0.088380	0.020704			
A20_10D2	299.914	6828	113.2829	0.106963	0.020716			
A20_10E2	300.543	6828	112.9981	0.127320	0.020725			
A20_10A3	301.263	6828	112.6742	0.149416	0.020694			
A20_10B3	302.096	6828	112.3021	0.173344	0.020717			
A20_10C3	302.832	6828	111.9756	0.198839	0.020744			
	322.17	**168**	**2.507167**		**0.019079**	**3.669**	**148.7**	**511.8**
A50_2A1	323.713	168	2.495168	0.030230	0.019132			
A50_2B1	324.191	168	2.491474	0.039450	0.019220			
A50_2C1	324.739	168	2.487253	0.049960	0.019263			
A50_2A2	325.343	168	2.482617	0.061640	0.019280			
A50_2B2	326.031	168	2.477357	0.074610	0.019324			
A50_2C2	326.720	168	2.472112	0.088750	0.019363			
A50_2D2	327.494	168	2.466246	0.104213	0.019385			
A50_2E2	328.351	168	2.459784	0.120757	0.019398			
	322.17	**338**	**5.047684**		**0.019114**	**3.432**	**708.7**	**534.3**
A50_5A1	323.655	338	5.024334	0.030240	0.019124			
A50_5B1	324.100	338	5.017379	0.039460	0.019200			
A50_5C1	324.616	338	5.009339	0.049960	0.019172			
A50_5A2	325.182	338	5.000550	0.061650	0.019226			
A50_5B2	325.827	338	4.990571	0.074620	0.019274			
A50_5C2	326.527	338	4.979788	0.088770	0.019303			
A50_5D2	327.257	338	4.968591	0.01042	0.019333			
A50_5E2	328.015	338	4.957019	0.120781	0.019317			
A50_5A3	328.903	338	4.943531	0.138761	0.019436			
A50_5B3	329.826	338	4.929590	0.157841	0.019450			
A50_5C3	330.749	338	4.915728	0.178245	0.019547			
A50_5D3	331.762	338	4.900604	0.199773	0.019590			
	322.16	**512**	**7.651817**		**0.019128**	**3.087**	**468.3**	**533.8**
A50_7A1	323.632	512	7.616581	0.030240	0.019223			
A50_7B1	324.037	512	7.606944	0.039450	0.019212			
A50_7C1	324.509	512	7.595744	0.049960	0.019288			
A50_7A2	325.073	512	7.582404	0.061630	0.019298			
A50_7B2	325.693	512	7.567795	0.074640	0.019320			
A50_7C2	326.340	512	7.552610	0.088810	0.019391			
A50_7D2	327.080	512	7.535317	0.104242	0.019408			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A50_7E2	327.886	512	7.516573	0.120856	0.019485			
A50_7A3	328.726	512	7.497139	0.138851	0.019520			
A50_7B3	329.528	512	7.478678	0.157951	0.019572			
A50_7C3	330.463	512	7.457272	0.178345	0.019617			
A50_7D3	331.460	512	7.434582	0.199897	0.019665			
	322.2	**693**	**10.36305**		**0.019211**	**2.920**	**342.3**	**541.6**
A50_01A1	323.563	693	10.31866	0.030220	0.019295			
A50_01B1	323.993	693	10.30474	0.039430	0.019309			
A50_01C1	324.475	693	10.28918	0.049960	0.019356			
A50_01A2	325.040	693	10.27100	0.061600	0.019370			
A50_01B2	325.625	693	10.25224	0.074630	0.019404			
A50_01C2	326.278	693	10.23139	0.088720	0.019416			
A50_01D2	327.003	693	10.20833	0.104177	0.019479			
A50_01E2	327.754	693	10.18456	0.120809	0.019517			
A50_01A3	328.498	693	10.16113	0.138737	0.019585			
A50_01B3	329.371	693	10.13377	0.157811	0.019601			
A50_01C3	330.287	693	10.10522	0.178212	0.019664			
A50_01D3	331.190	693	10.07724	0.19978	0.019720			
	322.19	**1409**	**21.12949**		**0.019504**	**2.664**	**169.8**	**543.6**
A50_02A1	323.467	1409	21.04323	0.030220	0.019597			
A50_02B1	323.867	1409	21.01636	0.039450	0.019611			
A50_02C1	324.327	1409	20.98555	0.049930	0.019631			
A50_02A2	324.803	1409	20.95376	0.061610	0.019636			
A50_02B2	325.370	1409	20.91603	0.07460	0.019668			
A50_02C2	325.968	1409	20.87638	0.088740	0.019711			
A50_02D2	326.628	1409	20.83281	0.10416	0.019719			
A50_02E2	327.320	1409	20.78732	0.120784	0.019757			
A50_02A3	327.988	1409	20.74360	0.138733	0.019805			
A50_02B3	328.778	1409	20.69214	0.157863	0.019839			
A50_02C3	329.583	1409	20.63998	0.178239	0.019914			
A50_02D3	330.483	1409	20.58198	0.199717	0.01993			
	322.2	**2065**	**31.04159**		**0.019782**	**2.420**	**116.3**	**548**
A50_03A1	323.410	2065	30.91967	0.030210	0.019797			
A50_03B1	323.794	2065	30.88119	0.039420	0.019832			
A50_03C1	324.211	2065	30.83951	0.049940	0.019858			
A50_03A2	324.703	2065	30.79049	0.061610	0.019874			
A50_03B2	325.219	2065	30.73925	0.074580	0.019947			
A50_03C2	325.783	2065	30.68345	0.088750	0.019977			
A50_03D2	326.420	2065	30.62068	0.104182	0.019942			
A50_03E2	327.078	2065	30.55612	0.120827	0.020012			
A50_03A3	327.743	2065	30.49116	0.138749	0.020023			
A50_03B3	328.485	2065	30.41903	0.157773	0.020031			
A50_03C3	329.212	2065	30.34869	0.178167	0.020092			
A50_03D3	330.057	2065	30.26737	0.199681	0.020114			
	322.18	**2759**	**41.57888**		**0.01998**	**2.351**	**85.56**	**561.6**

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ ($kg \cdot m^{-3}$)	q ($W \cdot m^{-1}$)	λ ($W \cdot m \cdot K^{-1}$)	χ ($10^{-3}\,K^{-1}$)	α ($10^{-8}\,m^2 \cdot s^{-1}$)	C_p ($J \cdot kg^{-1} \cdot K$)
A50_04A1	323.385	2759	41.41369	0.030210	0.020000			
A50_04B1	323.734	2759	41.36610	0.039440	0.020089			
A50_04C1	324.131	2759	41.31211	0.049960	0.020055			
A50_04A2	324.585	2759	41.25055	0.061610	0.020113			
A50_04B2	325.079	2759	41.18379	0.074580	0.020121			
A50_04C2	325.619	2759	41.11108	0.088730	0.020135			
A50_04D2	326.219	2759	41.03060	0.104169	0.020175			
A50_04E2	326.861	2759	40.94486	0.120759	0.020190			
A50_04A3	327.472	2759	40.86364	0.138684	0.020239			
A50_04B3	328.201	2759	40.76711	0.157765	0.020255			
A50_04C3	328.992	2759	40.66295	0.178127	0.020282			
A50_04D3	329.730	2759	40.56628	0.199668	0.020347			
	322.15	**3446**	**52.05745**		**0.020249**	**2.096**	**68.14**	**570.8**
A50_05A1	323.283	3446	51.85998	0.030230	0.020305			
A50_05B1	323.611	3446	51.80311	0.039430	0.020309			
A50_05C1	324.006	3446	51.73480	0.049930	0.020327			
A50_05A2	324.468	3446	51.65515	0.061600	0.020357			
A50_05B2	324.945	3446	51.57319	0.074600	0.020345			
A50_05C2	325.472	3446	51.48297	0.088760	0.020402			
A50_05D2	326.055	3446	51.38355	0.104157	0.020403			
A50_05E2	326.660	3446	51.28081	0.120785	0.020444			
A50_05A3	327.268	3446	51.17801	0.138693	0.020487			
A50_05B3	327.956	3446	51.06221	0.157785	0.020485			
A50_05C3	328.703	3446	50.93711	0.178119	0.020519			
A50_05D3	329.466	3446	50.81001	0.199627	0.020567			
	322.16	**4140**	**62.67706**		**0.020535**	**1.684**	**56.84**	**576.4**
A50_06A1	323.295	4140	62.43538	0.030230	0.020591			
A50_06B1	323.649	4140	62.36041	0.039430	0.020550			
A50_06C1	323.995	4140	62.28733	0.049920	0.020657			
A50_06A2	324.429	4140	62.19592	0.061580	0.020594			
A50_06B2	324.883	4140	62.10061	0.074580	0.020625			
A50_06C2	325.380	4140	61.99663	0.088710	0.020671			
A50_06D2	325.908	4140	61.88659	0.104126	0.020639			
A50_06E2	326.502	4140	61.76329	0.120723	0.020677			
A50_06A3	327.141	4140	61.63124	0.138638	0.020670			
A50_06B3	327.742	4140	61.50761	0.157714	0.020729			
A50_06C3	328.485	4140	61.35551	0.178098	0.020764			
A50_06D3	329.271	4140	61.19548	0.199601	0.020803			
	322.17	**4830**	**73.2707**		**0.020792**	**1.714**	**48.75**	**582.1**
A50_07A1	323.246	4830	72.99899	0.030190	0.020876			
A50_07B1	323.561	4830	72.91987	0.039430	0.020820			
A50_07C1	323.928	4830	72.82792	0.049910	0.020842			
A50_07A2	324.340	4830	72.72500	0.061570	0.020822			
A50_07B2	324.801	4830	72.61021	0.074560	0.020892			
A50_07C2	325.287	4830	72.48964	0.088670	0.020915			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A50_07D2	325.842	4830	72.35248	0.104107	0.020932			
A50_07E2	326.425	4830	72.20901	0.120638	0.020948			
A50_07A3	327.049	4830	72.05614	0.138590	0.020975			
A50_07B3	327.633	4830	71.91371	0.157656	0.020987			
A50_07C3	328.323	4830	71.74622	0.177954	0.021002			
A50_07D3	329.060	4830	71.56827	0.199427	0.021040			
	322.18	**5523**	**83.94108**		**0.021095**	**1.448**	**42.31**	**594**
A50_08A1	323.530	5523	83.54559	0.039420	0.021153			
A50_08B1	323.895	5523	83.43937	0.049920	0.021131			
A50_08A2	324.272	5523	83.32997	0.061560	0.021165			
A50_08B2	324.744	5523	83.19345	0.074600	0.021186			
A50_08C2	325.228	5523	83.05398	0.088690	0.021197			
A50_08D2	325.777	5523	82.89640	0.104088	0.021174			
A50_08E2	326.315	5523	82.74262	0.120703	0.021222			
A50_08A3	326.926	5523	82.56873	0.138590	0.021227			
A50_08B3	327.487	5523	82.40979	0.157626	0.021270			
A50_08C3	328.175	5523	82.21579	0.177990	0.021266			
A50_08D3	328.896	5523	82.01357	0.199467	0.021317			
	322.18	**6213**	**94.59431**		**0.021339**	**1.682**	**37.68**	**598.7**
A50_09A1	323.512	6213	94.14872	0.039420	0.021401			
A50_09B1	323.511	6213	94.14906	0.039450	0.021360			
A50_09A2	323.860	6213	94.03308	0.049910	0.021397			
A50_09B2	324.222	6213	93.91313	0.061610	0.021408			
A50_09C2	324.662	6213	93.76778	0.074590	0.021432			
A50_09D2	325.139	6213	93.61079	0.088700	0.021445			
A50_09E2	326.196	6213	93.26499	0.120734	0.021473			
A50_09A3	326.191	6213	93.26661	0.120727	0.021515			
A50_09B3	326.789	6213	93.07223	0.138619	0.021514			
A50_09C3	327.421	6213	92.86778	0.157688	0.021543			
A50_09D3	328.022	6213	92.67428	0.177995	0.021541			
A50_09E3	328.711	6213	92.45356	0.199464	0.021552			
	322.25	**6837**	**104.2209**		**0.021598**	**2.090**	**34.63**	**598.4**
A50_10A1	323.523	6837	103.7464	0.039450	0.021659			
A50_10B1	323.848	6837	103.6260	0.049950	0.021667			
A50_10A2	324.221	6837	103.4882	0.06162	0.021661			
A50_10B2	324.650	6837	103.3303	0.074590	0.021752			
A50_10C2	325.158	6837	103.1440	0.088740	0.021730			
A50_10D2	325.659	6837	102.9610	0.104175	0.021760			
A50_10E2	326.184	6837	102.7700	0.120758	0.021750			
A50_10A3	326.784	6837	102.5527	0.138691	0.021815			
A50_10B3	327.357	6837	102.3461	0.157739	0.021816			
A50_10C3	327.94	6837	102.1369	0.178075	0.021824			
A50_10D3	328.64	6837	101.887	0.199631	0.021921			
	342.09	**168**	**2.360640**		**0.019904**	**4.393**	**158.8**	**531.0**
A70_2E1	344.685	168	2.342808	0.053020	0.019974			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A70_2A2	345.286	168	2.338716	0.065400	0.020077			
A70_2B2	345.980	168	2.334009	0.079160	0.020119			
A70_2C2	346.714	168	2.329052	0.094180	0.020161			
A70_2D2	347.507	168	2.323720	0.110575	0.020274			
A70_2E2	348.342	168	2.318131	0.128121	0.020387			
	342.06	**341**	**4.794232**		**0.019944**	**3.944**	**790.7**	**526.1**
A70_5A1	343.586	341	4.772792	0.032130	0.019983			
A70_5B1	344.061	341	4.766157	0.041880	0.020038			
A70_5C1	344.585	341	4.758860	0.053050	0.020147			
A70_5A2	345.161	341	4.750864	0.065460	0.020184			
A70_5B2	345.805	341	4.741957	0.079230	0.020231			
A70_5C2	346.481	341	4.732643	0.094250	0.020181			
A70_5D2	347.221	341	4.722490	0.110606	0.020283			
A70_5E2	348.016	341	4.711630	0.128217	0.020324			
A70_5A3	348.895	341	4.699682	0.147238	0.020430			
A70_5B3	349.811	341	4.687295	0.167453	0.020467			
A70_5C3	350.735	341	4.674866	0.189067	0.020514			
A70_5D3	351.777	341	4.660930	0.211901	0.020650			
	342.07	**513**	**7.215577**		**0.019978**	**3.910**	**526.1**	**526.3**
A70_7A1	343.560	513	7.183959	0.032140	0.020105			
A70_7B1	343.984	513	7.175012	0.041910	0.020060			
A70_7C1	344.524	513	7.163651	0.053050	0.020187			
A70_7A2	345.041	513	7.152808	0.065460	0.020244			
A70_7B2	345.655	513	7.139973	0.079230	0.020229			
A70_7C2	346.372	513	7.125043	0.094240	0.020335			
A70_7D2	347.108	513	7.109784	0.110615	0.020390			
A70_7E2	347.911	513	7.093210	0.128229	0.020458			
A70_7A3	348.716	513	7.076674	0.147267	0.020501			
A70_7B3	349.597	513	7.058665	0.167483	0.020562			
A70_7C3	350.591	513	7.038457	0.189092	0.020636			
A70_7D3	351.589	513	7.018286	0.211960	0.020705			
	342.09	**689**	**9.695067**		**0.020047**	**3.508**	**391.1**	**528.7**
A70_01A1	343.534	689	9.653747	0.032120	0.020158			
A70_01B1	343.946	689	9.642024	0.041920	0.020154			
A70_01C1	344.417	689	9.628656	0.053060	0.020222			
A70_01A2	344.993	689	9.612360	0.065470	0.020250			
A70_01B2	345.650	689	9.593840	0.079240	0.020302			
A70_01C2	346.319	689	9.575056	0.094290	0.020333			
A70_01D2	347.041	689	9.554867	0.110678	0.020429			
A70_01E2	347.737	689	9.535487	0.128255	0.020428			
A70_01A3	348.579	689	9.512147	0.147295	0.020506			
A70_01B3	349.498	689	9.486805	0.167559	0.020570			
A70_01C3	350.426	689	9.461354	0.189178	0.020608			
A70_01D3	351.369	689	9.435632	0.212002	0.020717			
	342.06	**1375**	**19.38376**		**0.020329**	**3.408**	**196.0**	**535.1**

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A70_02A1	343.387	1375	19.30678	0.032120	0.020385			
A70_02B1	343.787	1375	19.2837	0.041920	0.020427			
A70_02C1	344.253	1375	19.25688	0.053070	0.02054			
A70_02A2	344.731	1375	19.22945	0.065480	0.02053			
A70_02B2	345.305	1375	19.19662	0.079280	0.020546			
A70_02C2	345.960	1375	19.15929	0.094280	0.020586			
A70_02D2	346.607	1375	19.12257	0.110723	0.020672			
A70_0 2E2	347.331	1375	19.08165	0.128304	0.020679			
A70_02A3	348.149	1375	19.03563	0.147377	0.020737			
A70_02B3	348.874	1375	18.99503	0.167573	0.020813			
A70_02C3	349.725	1375	18.94760	0.189203	0.020854			
A70_02D3	350.615	1375	18.89826	0.212052	0.020922			
	342.05	**2064**	**29.14605**		**0.02063**	**2.986**	**132.6**	**533.8**
A70_03A1	343.343	2064	29.03176	0.032150	0.020732			
A70_03B1	343.693	2064	29.00098	0.041960	0.020792			
A70_03C1	344.107	2064	28.96466	0.053070	0.020703			
A70_03A2	344.602	2064	28.92136	0.065500	0.020755			
A70_03B2	345.146	2064	28.87393	0.079300	0.020814			
A70_03C2	345.785	2064	28.81842	0.094280	0.020873			
A70_03D2	346.414	2064	28.76400	0.110687	0.020905			
A70_03E2	347.081	2064	28.70652	0.128278	0.020907			
A70_03A3	347.729	2064	28.65091	0.147324	0.021004			
A70_03B3	348.493	2064	28.58563	0.167556	0.021021			
A70_03C3	349.301	2064	28.51692	0.189154	0.021055			
A70_03D3	350.141	2064	28.44586	0.211993	0.021160			
	342.07	**2761**	**39.04724**		**0.020836**	**2.804**	**97.51**	**547.2**
A70_04A1	343.303	2761	38.89931	0.032120	0.020906			
A70_04B1	343.644	2761	38.8586	0.041940	0.020951			
A70_04C1	344.081	2761	38.80657	0.053080	0.020919			
A70_04A2	344.538	2761	38.75231	0.065490	0.021012			
A70_04B2	345.065	2761	38.68994	0.079290	0.020991			
A70_04C2	345.610	2761	38.62563	0.094360	0.021063			
A70_04D2	346.243	2761	38.55128	0.110708	0.021071			
A70_04E2	346.870	2761	38.47991	0.128345	0.021142			
A70_04A3	347.589	2761	38.39413	0.147359	0.021162			
A70_04B3	348.339	2761	38.30714	0.167568	0.021185			
A70_04C3	349.056	2761	38.22437	0.189192	0.021230			
A70_04D3	349.879	2761	38.12982	0.212022	0.021319			
	342.09	**3465**	**49.07221**		**0.0211**	**2.574**	**77.50**	**554.8**
A70_05A1	343.284	3465	48.88987	0.032120	0.021105			
A70_05B1	343.634	3465	48.83669	0.041900	0.021133			
A70_05C1	344.008	3465	48.78000	0.053040	0.021170			
A70_05A2	344.504	3465	48.70504	0.065490	0.021276			
A70_05B2	344.973	3465	48.63438	0.079240	0.021253			
A70_5C2	345.533	3465	48.55030	0.094260	0.021271			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A70_05D2	346.144	3465	48.45892	0.11067	0.021320			
A70_05E2	346.765	3465	48.36641	0.128274	0.021336			
A70_05A3	347.425	3465	48.26850	0.147335	0.021374			
A70_05B3	348.165	3465	48.45922	0.167576	0.021445			
A70_05C3	348.860	3465	48.05707	0.189159	0.021466			
A70_05D3	349.567	3465	47.95362	0.211943	0.021521			
	342.1	**4137**	**58.66254**		**0.021336**	**2.600**	**64.70**	**562.1**
A70_06A1	343.197	4137	58.45985	0.032120	0.021420			
A70_06B1	343.575	4137	58.39036	0.041930	0.021448			
A70_06C1	343.994	4137	58.31354	0.05308	0.021422			
A70_06A2	344.396	4137	58.24004	0.06547	0.021456			
A70_06B2	344.884	4137	58.15108	0.07925	0.021457			
A70_06C2	345.428	4137	58.05225	0.09427	0.021493			
A70_06D2	345.987	4137	57.95108	0.110655	0.021544			
A70_06E2	346.542	4137	57.85100	0.128207	0.021613			
A70_06A3	347.315	4137	57.71224	0.147243	0.021633			
A70_06B3	347.934	4137	57.60163	0.167433	0.021672			
A70_06C3	348.725	4137	57.46095	0.189041	0.021711			
A70_06D3	349.457	4137	57.33141	0.211849	0.021740			
	342.11	**4838**	**68.68391**		**0.02158**	**2.757**	**55.77**	**563.4**
A70_07A1	343.544	4838	68.37039	0.041910	0.021716			
A70_07B1	343.941	4838	68.28414	0.053080	0.021690			
A70_07A2	344.356	4838	68.19423	0.065490	0.021696			
A70_07B2	344.811	4838	68.09595	0.079260	0.021746			
A70_07C2	345.331	4838	67.98401	0.094260	0.021744			
A70_07D2	345.886	4838	67.86497	0.110628	0.021800			
A70_07E2	346.482	4838	67.73764	0.128302	0.021811			
A70_07A3	347.153	4838	67.5949	0.147264	0.021823			
A70_07B3	347.862	4838	67.44479	0.167455	0.021970			
A70_07C3	348.492	4838	67.31201	0.189100	0.021979			
A70_07D3	349.221	4838	67.15907	0.211942	0.022012			
	342.07	**5513**	**78.35907**		**0.021813**	**2.393**	**48.26**	**576.8**
A70_08A1	343.471	5513	78.00567	0.041900	0.021852			
A70_08B1	343.851	5513	77.91041	0.053080	0.021944			
A70_08A2	344.259	5513	77.80842	0.065480	0.021957			
A70_08B2	344.709	5513	77.69627	0.07925	0.02191			
A70_08C2	345.24	5513	77.56439	0.09424	0.021999			
A70_08D2	345.79	5513	77.4283	0.110688	0.022006			
A70_08E2	346.384	5513	77.28192	0.128245	0.022052			
A70_08A3	346.986	5513	77.13418	0.147246	0.022049			
A70_08B3	347.61	5513	76.98169	0.167471	0.022057			
A70_08C3	348.359	5513	76.79952	0.1891	0.022175			
A70_08D3	349.116	5513	76.61636	0.211882	0.022186			
	342.07	**6238**	**88.75216**		**0.022041**	**2.894**	**42.50**	**584.3**
A70_09A1	343.445	6238	88.3548	0.04191	0.022105			

Table II. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
A70_09B1	343.824	6238	88.24597	0.05306	0.022152			
A70_09A2	344.202	6238	88.13771	0.06547	0.022184			
A70_09B2	344.651	6238	88.0095	0.07925	0.022216			
A70_09C2	345.128	6238	87.87375	0.09426	0.022229			
A70_09D2	345.655	6238	87.72431	0.110668	0.02227			
A70_09E2	346.307	6238	87.54019	0.128258	0.022286			
A70_09A3	346.891	6238	87.376	0.14727	0.022346			
A70_09B3	347.448	6238	87.22003	0.167453	0.022404			
A70_09C3	348.126	6238	87.03101	0.189098	0.022413			
A70_09D3	348.811	6238	86.84095	0.211935	0.022462			
	342.06	**6845**	**97.46221**		**0.022327**	**2.331**	**38.94**	**588.3**
A70_10A1	343.383	6845	97.03841	0.04191	0.022390			
A70_10B1	343.730	6845	96.92793	0.05305	0.022382			
A70_10A2	344.122	6845	96.80347	0.06547	0.022443			
A70_10B2	344.544	6845	96.66987	0.07927	0.022430			
A70_10C2	345.050	6845	96.51022	0.09427	0.022518			
A70_10D2	345.626	6845	96.3292	0.110674	0.022576			
A70_10E2	346.166	6845	96.16018	0.128248	0.022519			
A70_10A3	346.806	6845	95.96071	0.147276	0.022580			
A70_10B3	347.350	6845	95.79188	0.167502	0.022605			
A70_10C3	348.006	6845	95.58917	0.189061	0.022606			
A70_10D3	348.678	6845	95.38250	0.211892	0.022674			

where λ_0 is the ideal-gas thermal conductivity of argon, obtained by correcting the measured thermal conductivity to the isothermal temperatures and extrapolating the measured thermal conductivity to zero density with the values fitted vs. temperature as

$$\lambda_0 = a_0 + a_1(T(\mathrm{K})) + a_2(T(\mathrm{K}))^2. \quad (18)$$

The coefficients for Eqs. (17) and (18) are listed in Table VI. The ideal-gas thermal conductivities of argon and nitrogen are listed in Table VII.

4.1.1. Argon

The deviations from Eq. (17) of all the considered measurements are indicated in Fig. 4. From this it can be seen that the maximum deviation in the present measurements of thermal conductivity from Eq. (17) is less than 2% with a standard deviation of about 0.5%.

From Fig. 4, it can also be seen that the thermal conductivity data for all the considered argon data sets deviate by less than 3% from

Table III. Thermal Conductivity, Thermal Diffusivity, and Specific Heat of Nitrogen

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
	295.72	**340**	**3.876508**		**0.026234**	**1.656**	**626.6**	**1080.0**
N20_5A1	296.711	340	3.863447	0.027670	0.026263			
N20_5B1	297.015	340	3.859459	0.036120	0.026390			
N20_5C1	297.362	340	3.854916	0.045730	0.026253			
N20_5A2	297.743	340	3.849941	0.056440	0.026262			
N20_5B2	298.161	340	3.844497	0.068320	0.026397			
N20_5C2	298.616	340	3.838589	0.081310	0.026344			
N20_5D2	299.120	340	3.832067	0.095440	0.026345			
N20_5E2	299.659	340	3.825116	0.110674	0.026403			
N20_5A3	300.244	340	3.817600	0.127155	0.026457			
N20_5B3	300.859	340	3.809731	0.144621	0.026444			
N20_5C3	301.523	340	3.801272	0.163308	0.026481			
N20_5D3	302.221	340	3.792421	0.183087	0.026534			
	295.7	**513**	**5.851386**		**0.026317**	**1.255**	**413.1**	**1089.0**
N20_7A1	296.659	513	5.832222	0.027680	0.026297			
N20_7B1	296.946	513	5.826512	0.036120	0.026453			
N20_7C1	297.277	513	5.81994	0.045730	0.026390			
N20_7A2	297.645	513	5.812651	0.056410	0.026371			
N20_7B2	298.051	513	5.804631	0.068320	0.026440			
N20_7C2	298.491	513	5.795964	0.081240	0.026358			
N20_7D2	298.995	513	5.786069	0.095420	0.026391			
N20_7E2	299.539	513	5.775428	0.110606	0.026371			
N20_7A3	300.053	513	5.765409	0.127091	0.026463			
N20_7B3	300.706	513	5.752732	0.144606	0.026493			
N20_7C3	301.266	513	5.741905	0.163278	0.026514			
N20_7D3	301.961	513	5.728526	0.183069	0.026558			
	295.70	**687**	**7.838682**		**0.026325**	**2.03**	**303.8**	**1105.4**
N20_01A1	296.625	687	7.813809	0.027670	0.026350			
N20_01B1	296.911	687	7.806151	0.036120	0.026385			
N20_01C1	297.227	687	7.797707	0.045720	0.026396			
N20_01A2	297.587	687	7.788110	0.056420	0.026403			
N20_01B2	297.975	687	7.777794	0.068310	0.026448			
N20_01C2	298.411	687	7.766235	0.081280	0.026458			
N20_01D2	298.874	687	7.753999	0.095460	0.026495			
N20_01E2	299.381	687	7.740644	0.110662	0.026543			
N20_01A3	299.927	687	7.726315	0.127145	0.026534			
N20_01B3	300.497	687	7.711413	0.144614	0.026558			
N20_01C3	301.105	687	7.695582	0.163334	0.026582			
N20_01D3	301.718	687	7.679687	0.183108	0.026648			
	295.7	**1407**	**16.07366**		**0.026744**	**1.382**	**150.9**	**1101.9**
N20_02A1	296.558	1407	16.02550	0.027670	0.026804			
N20_02B1	296.817	1407	16.01103	0.036110	0.026701			
N20_02C1	297.117	1407	15.99429	0.045740	0.026835			
N20_02A2	297.442	1407	15.9762	0.056420	0.026918			
N20_02B2	297.806	1407	15.95599	0.068310	0.026761			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N20_02C2	298.194	1407	15.93451	0.081280	0.026827			
N20_02D2	298.635	1407	15.91017	0.095430	0.026853			
N20_02E2	299.096	1407	15.88480	0.110671	0.026851			
N20_02A3	299.606	1407	15.85683	0.127121	0.026870			
N20_02B3	300.142	1407	15.82755	0.144588	0.026896			
N20_02C3	300.722	1407	15.79599	0.163314	0.026928			
N20_02D3	301.327	1407	15.76321	0.183043	0.026985			
	295.7	**2070**	**23.6695**		**0.027042**	**1.227**	**102.9**	**1109.2**
N20_03A1	296.515	2070	23.60109	0.027660	0.027044			
N20_03B1	296.758	2070	23.58077	0.036110	0.027063			
N20_03C1	297.048	2070	23.55658	0.045740	0.027142			
N20_03A2	297.359	2070	23.53068	0.056420	0.027142			
N20_03B2	297.698	2070	23.50253	0.068330	0.027088			
N20_03C2	298.085	2070	23.47048	0.081300	0.027150			
N20_03D2	298.498	2070	23.43637	0.095470	0.027103			
N20_03E2	298.962	2070	23.39818	0.110658	0.027111			
N20_03A3	299.420	2070	23.36060	0.127104	0.027124			
N20_03B3	299.924	2070	23.31940	0.144590	0.027170			
N20_03C3	300.420	2070	23.27901	0.163310	0.027216			
N20_03D3	301.017	2070	23.23058	0.183041	0.027254			
	295.7	**2761**	**31.59384**		**0.027416**	**0.656**	**77.26**	**1123.1**
N20_04A1	296.707	2761	31.47937	0.036110	0.027471			
N20_04B1	296.986	2761	31.44781	0.045690	0.027493			
N20_04A2	297.288	2761	31.41373	0.056400	0.027512			
N20_04B2	297.617	2761	31.37669	0.068290	0.027361			
N20_04C2	297.971	2761	31.33693	0.081250	0.027458			
N20_04D2	298.383	2761	31.29080	0.095400	0.027418			
N20_04E2	298.803	2761	31.24393	0.110597	0.027453			
N20_04A3	299.266	2761	31.19242	0.127005	0.027434			
N20_04B3	299.782	2761	31.13524	0.144501	0.027436			
N20_04C3	300.221	2761	31.08676	0.163244	0.027505			
N20_04D3	300.774	2761	31.02593	0.182927	0.027541			
N20_04E3	301.349	2761	30.96294	0.203940	0.027576			
	295.66	**3457**	**39.5837**		**0.027703**	**1.052**	**62.47**	**1120.3**
N20_05A1	296.656	3457	39.43974	0.036100	0.027667			
N20_05B1	296.917	3457	39.40220	0.045720	0.027802			
N20_05A2	297.197	3457	39.36202	0.056390	0.027780			
N20_05B2	297.519	3457	39.31592	0.068270	0.027731			
N20_05C2	297.872	3457	39.26551	0.081280	0.027803			
N20_05D2	298.254	3457	39.21113	0.095370	0.027762			
N20_05E2	298.685	3457	39.14996	0.110592	0.027776			
N20_05A3	299.107	3457	39.09026	0.127000	0.027799			
N20_05B3	299.580	3457	39.02359	0.144467	0.027792			
N20_05C3	300.032	3457	38.96010	0.163156	0.027840			
N20_05D3	300.562	3457	38.88595	0.182851	0.027839			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N20_05E3	301.119	3457	38.80834	0.203890	0.027879			
	295.66	**4158**	**47.62292**		**0.028077**	**0.722**	**51.78**	**1138.6**
N20_06A1	296.610	4158	47.45540	0.036090	0.028090			
N20_06B1	296.869	4158	47.40995	0.04570	0.028077			
N20_06A2	297.147	4158	47.36127	0.056390	0.028100			
N20_06B2	297.467	4158	47.30538	0.06830	0.028144			
N20_06C2	297.821	4158	47.24371	0.081250	0.028175			
N20_06D2	298.173	4158	47.18257	0.095400	0.028087			
N20_06E2	298.575	4158	47.11295	0.110564	0.028165			
N20_06A3	299.001	4158	47.03942	0.127013	0.028122			
N20_06B3	299.455	4158	46.96134	0.144485	0.028122			
N20_06C3	299.891	4158	46.88662	0.163222	0.028178			
N20_06D3	300.402	4158	46.79937	0.182899	0.028155			
N20_06E3	300.946	4158	46.70688	0.203836	0.028203			
	295.66	**4834**	**55.36653**		**0.028475**	**0.044**	**44.54**	**1154.7**
N20_07A1	296.586	4834	55.17428	0.036080	0.028534			
N20_07B1	296.844	4834	55.12098	0.045700	0.028444			
N20_07A2	297.115	4834	55.06511	0.056370	0.028547			
N20_07B2	297.412	4834	55.00403	0.068290	0.028464			
N20_07C2	297.759	4834	54.93286	0.081230	0.028488			
N20_07D2	298.120	4834	54.85903	0.095370	0.028403			
N20_07E2	298.484	4834	54.78481	0.110544	0.028443			
N20_07A3	298.900	4834	54.70025	0.126940	0.028435			
N20_07B3	299.352	4834	54.60871	0.144455	0.028478			
N20_07C3	299.824	4834	54.51348	0.163102	0.028459			
N20_07D3	300.267	4834	54.42443	0.182796	0.028507			
N20_07E3	300.798	4834	54.31812	0.203696	0.028533			
	295.67	**5508**	**63.07064**		**0.028773**	**0.511**	**39.18**	**1164.4**
N20_08A1	296.575	5508	62.85407	0.036100	0.028791			
N20_08B1	296.789	5508	62.80311	0.045720	0.028793			
N20_08A2	297.077	5508	62.73466	0.056410	0.028780			
N20_08B2	297.389	5508	62.66070	0.068340	0.028829			
N20_08C2	297.695	5508	62.58835	0.081230	0.028774			
N20_08D2	298.046	5508	62.50559	0.095370	0.028806			
N20_08E2	298.427	5508	62.41604	0.110551	0.028844			
N20_08A3	298.826	5508	62.32256	0.126981	0.028799			
N20_08B3	299.258	5508	62.22170	0.144447	0.028818			
N20_08C3	299.716	5508	62.11517	0.163067	0.028805			
N20_08D3	300.152	5508	62.01413	0.182813	0.028858			
N20_08E3	300.660	5508	61.89687	0.203751	0.028857			
	295.68	**6215**	**71.13021**		**0.029178**	**0.133**	**34.6**	**1185.6**
N20_09A1	296.654	6215	70.86443	0.036120	0.029235			
N20_09B1	296.805	6215	70.82343	0.045700	0.029197			
N20_09A2	297.062	6215	70.75376	0.056390	0.029191			
N20_09B2	297.339	6215	70.67885	0.068280	0.029115			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ ($kg{\cdot}m^{-3}$)	q ($W{\cdot}m^{-1}$)	λ ($W{\cdot}m{\cdot}K^{-1}$)	χ ($10^{-3}\,K^{-1}$)	α ($10^{-8}\,m^2{\cdot}s^{-1}$)	C_p ($J{\cdot}kg^{-1}{\cdot}K$)
N20_09C2	297.619	6215	70.60331	0.081250	0.029232			
N20_09D2	297.997	6215	70.50162	0.095360	0.029148			
N20_09E2	298.363	6215	70.40346	0.110579	0.029165			
N20_09A3	298.759	6215	70.29762	0.127002	0.029173			
N20_09B3	299.178	6215	70.18601	0.144465	0.029168			
N20_09C3	299.628	6215	70.06659	0.163117	0.029190			
N20_09D3	300.048	6215	69.95554	0.182795	0.029197			
N20_09E3	300.547	6215	69.82412	0.203769	0.029245			
	295.7	**6879**	**78.6705**		**0.029571**	**−0.06**	**31.47**	**1194.4**
N20_10A1	296.455	6879	78.44018	0.031750	0.029575			
N20_10B1	296.788	6879	78.33908	0.045710	0.029624			
N20_10A2	297.035	6879	78.26428	0.056440	0.029558			
N20_10B2	297.321	6879	78.17787	0.068310	0.029594			
N20_10C2	297.626	6879	78.08596	0.081270	0.029544			
N20_10D2	297.957	6879	77.98650	0.095390	0.029544			
N20_10E2	298.314	6879	77.87954	0.110599	0.029526			
N20_10A3	298.701	6879	77.76398	0.127007	0.029536			
N20_10B3	299.140	6879	77.63335	0.144497	0.029555			
N20_10C3	299.553	6879	77.51092	0.163134	0.029566			
N20_10D3	299.961	6879	77.3904	0.182833	0.029585			
N20_10E3	300.449	6879	77.2468	0.203843	0.029592			
	322.04	**347**	**3.630597**		**0.028001**	**2.194**	**728.4**	**1058.8**
N50_5A1	323.390	347	3.615339	0.039420	0.028103			
N50_5B1	323.728	347	3.611539	0.049910	0.028079			
N50_5A2	324.126	347	3.607075	0.061580	0.028132			
N50_5B2	324.542	347	3.602421	0.074560	0.028194			
N50_5C2	324.987	347	3.597456	0.088650	0.028146			
N50_5D2	325.538	347	3.591327	0.104131	0.028221			
N50_5E2	326.087	347	3.585241	0.120655	0.028265			
N50_5A3	326.663	347	3.578878	0.138574	0.028243			
N50_5B3	327.295	347	3.571923	0.157678	0.028353			
N50_5C3	327.975	347	3.56447	0.177994	0.028351			
N50_5D3	328.723	347	3.556308	0.199475	0.028413			
N50_5E3	329.429	347	3.548638	0.222312	0.028464			
	322.06	**513**	**5.367167**		**0.028003**	**2.55**	**488.7**	**1067.6**
N50_7A1	323.333	513	5.345826	0.039410	0.028058			
N50_7B1	323.701	513	5.339689	0.049910	0.028175			
N50_7A2	324.073	513	5.333500	0.061580	0.028157			
N50_7B2	324.502	513	5.326380	0.074530	0.028138			
N50_7C2	324.967	513	5.318684	0.088670	0.028241			
N50_7D2	325.456	513	5.310616	0.104129	0.028218			
N50_7E2	325.982	513	5.301964	0.120699	0.028259			
N50_7A3	326.539	513	5.292834	0.138623	0.028318			
N50_7B3	327.161	513	5.282675	0.157696	0.028397			
N50_7C3	327.827	513	5.271842	0.178041	0.028441			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N50_7D3	328.512	513	5.260747	0.199565	0.028468			
N50_7E3	329.196	513	5.249714	0.222393	0.028486			
	322.07	**686**	**7.176949**		**0.028124**	**2.328**	**365.8**	**1071.2**
N50_01A1	323.338	686	7.148432	0.039390	0.028253			
N50_01B1	323.665	686	7.141115	0.049880	0.028218			
N50_01A2	324.031	686	7.132944	0.061540	0.028202			
N50_01B2	324.431	686	7.124035	0.074510	0.028312			
N50_01C2	324.862	686	7.114462	0.088640	0.028324			
N50_01D2	325.363	686	7.103365	0.104085	0.028302			
N50_01E2	325.897	686	7.091577	0.120652	0.028372			
N50_01A3	326.451	686	7.079389	0.138588	0.028418			
N50_01B3	327.047	686	7.066325	0.157636	0.028447			
N50_01C3	327.684	686	7.052415	0.178001	0.028471			
N50_01D3	328.288	686	7.039278	0.199482	0.028525			
N50_01E3	329.010	686	7.023639	0.222315	0.028609			
	322.05	**1396**	**14.60439**		**0.028508**	**1.798**	**182.6**	**1069.0**
N50_02A1	323.203	1396	14.55091	0.039420	0.028623			
A50_02B1	323.518	1396	14.53637	0.049900	0.028617			
N50_02A2	323.858	1396	14.52071	0.061550	0.028570			
N50_02B2	324.255	1396	14.50247	0.074540	0.028551			
N50_02C2	325.107	1396	14.46348	0.104098	0.028771			
N50_02D2	325.591	1396	14.44143	0.120648	0.028644			
N50_02E2	326.128	1396	14.41705	0.138577	0.028703			
N50_02A3	326.666	1396	14.39270	0.157665	0.028705			
N50_02B3	327.267	1396	14.36560	0.177994	0.028761			
N50_02C3	327.262	1396	14.36583	0.177991	0.028763			
N50_02D3	327.942	1396	14.33529	0.199487	0.028817			
N50_02E3	328.500	1396	14.31033	0.222338	0.028856			
	322.08	**2075**	**21.69964**		**0.028784**	**1.738**	**123.1**	**1077.6**
N50_03A1	323.190	2075	21.62224	0.039420	0.028863			
N50_03B1	323.498	2075	21.60086	0.049890	0.028921			
N50_03A2	323.820	2075	21.57856	0.061590	0.028838			
N50_03B2	324.180	2075	21.55369	0.074500	0.028922			
N50_03C2	324.580	2075	21.52612	0.088630	0.028850			
N50_03D2	325.007	2075	21.49677	0.104081	0.028894			
N50_03E2	325.457	2075	21.46593	0.120640	0.028936			
N50_03A3	325.985	2075	21.42987	0.138576	0.028959			
N50_03B3	326.486	2075	21.39576	0.157563	0.028981			
N50_03C3	327.084	2075	21.35520	0.177953	0.029056			
N50_03D3	327.574	2075	21.32208	0.222279	0.029091			
N50_03E3	328.249	2075	21.27664	0.199444	0.029105			
	322.07	**2765**	**28.90286**		**0.029023**	**2.126**	**92.31**	**1087.8**
N50_04A1	323.112	2765	28.80495	0.039410	0.029082			
N50_04B1	323.426	2765	28.77559	0.049880	0.029126			
N50_04A2	323.738	2765	28.74647	0.061560	0.029115			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N50_04B2	324.08	2765	28.71462	0.074530	0.029180			
N50_04C2	324.462	2765	28.67914	0.088660	0.029149			
N50_04D2	324.887	2765	28.63977	0.104105	0.029163			
N50_04E2	325.324	2765	28.59941	0.120647	0.029231			
N50_04A3	325.801	2765	28.55550	0.138558	0.029267			
N50_04B3	326.305	2765	28.50925	0.157588	0.029273			
N50_04C3	326.855	2765	28.45896	0.177946	0.029294			
N50_04D3	327.376	2765	28.41149	0.199438	0.029376			
N50_04E3	327.982	2765	28.35649	0.222314	0.029394			
	322.07	**3461**	**36.1545**		**0.02933**	**1.869**	**74.12**	**1094.5**
N50_05A1	323.113	3461	36.03057	0.039400	0.029420			
N50_05B1	323.378	3461	35.99923	0.049890	0.029375			
N50_05A2	323.673	3461	35.96441	0.061570	0.029373			
N50_05B2	324.024	3461	35.92307	0.074540	0.029486			
N50_05C2	325.218	3461	35.78321	0.120653	0.029469			
N50_05D2	325.676	3461	35.72987	0.138515	0.029535			
N50_05E2	326.171	3461	35.67241	0.157565	0.029557			
N50_05A3	326.708	3461	35.61030	0.177926	0.029602			
N50_05B3	327.700	3461	35.49616	0.177934	0.029609			
N50_05C3	327.265	3461	35.54612	0.199482	0.029594			
N50_05D3	327.262	3461	35.54646	0.199374	0.029602			
N50_05E3	327.768	3461	35.48837	0.222199	0.029646			
	322.06	**4149**	**43.30692**		**0.029588**	**2.268**	**61.61**	**1108.9**
N50_06A1	323.070	4149	43.16170	0.039400	0.029619			
N50_06B1	323.354	4149	43.12106	0.049890	0.029659			
N50_06A2	323.624	4149	43.08249	0.061570	0.029689			
N50_06B2	323.950	4149	43.03603	0.074530	0.029729			
N50_06C2	324.297	4149	42.98669	0.088690	0.029755			
N50_06D2	324.697	4149	42.92997	0.104099	0.029810			
N50_06E2	325.140	4149	42.86734	0.120629	0.029812			
N50_06A3	325.569	4149	42.80687	0.138518	0.029827			
N50_06B3	326.047	4149	42.73972	0.157572	0.029855			
N50_06C3	326.571	4149	42.66636	0.177899	0.029853			
N50_06D3	327.035	4149	42.60163	0.199382	0.029925			
N50_06E3	327.606	4149	42.52226	0.222186	0.029956			
	322.07	**4839**	**50.45604**		**0.029927**	**1.936**	**53.04**	**1118.3**
N50_07A1	323.067	4839	50.28744	0.039400	0.029996			
N50_07B1	323.307	4839	50.24704	0.049890	0.029956			
N50_07A2	323.615	4839	50.19529	0.061550	0.030032			
N50_07B2	323.929	4839	50.14265	0.074510	0.030010			
N50_07C2	324.259	4839	50.08747	0.088640	0.030095			
N50_07D2	324.634	4839	50.02491	0.104007	0.030078			
N50_07E2	325.042	4839	49.95705	0.120648	0.030096			
N50_07A3	325.475	4839	49.88525	0.138501	0.030118			
N50_07B3	325.948	4839	49.80707	0.157517	0.030166			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N50_07C3	326.445	4839	49.72521	0.177893	0.030183			
N50_07D3	326.915	4839	49.64806	0.199325	0.030220			
N50_07E3	327.458	4839	49.55926	0.222138	0.030214			
	322.07	**5542**	**57.71546**		**0.030326**	**1.251**	**46.65**	**1126.3**
N50_08A1	323.027	5542	57.52865	0.039390	0.030381			
N50_08B1	323.270	5542	57.48142	0.049860	0.030342			
N50_08A2	323.573	5542	57.42266	0.061550	0.030426			
N50_08B2	323.882	5542	57.36287	0.074510	0.030442			
N50_08C2	324.212	5542	57.29916	0.088610	0.030366			
N50_08D2	324.592	5542	57.22599	0.104049	0.030414			
N50_08E2	324.999	5542	57.14786	0.120594	0.030419			
N50_08A3	325.425	5542	57.06632	0.138498	0.030404			
N50_08B3	325.850	5542	56.98523	0.157524	0.030454			
N50_08C3	326.340	5542	56.89206	0.177853	0.030500			
N50_08D3	326.795	5542	56.80583	0.199304	0.030535			
N50_08E3	327.319	5542	56.70689	0.222114	0.030538			
	322.07	**6209**	**64.57535**		**0.030642**	**1.323**	**41.94**	**1131.4**
N50_09A2	323.510	6209	64.25892	0.061550	0.030731			
N50_09B2	323.833	6209	64.18842	0.074500	0.030673			
N50_09C2	324.155	6209	64.11830	0.088620	0.030718			
N50_09D2	324.539	6209	64.03490	0.104034	0.030777			
N50_09E2	324.915	6209	63.95348	0.120604	0.030803			
N50_09A3	325.320	6209	63.86602	0.138497	0.030723			
N50_09B3	325.753	6209	63.77282	0.157518	0.030742			
N50_09C3	326.281	6209	63.65957	0.177823	0.030825			
N50_09D3	326.231	6209	63.67028	0.177823	0.030828			
N50_09E3	326.704	6209	63.56916	0.199318	0.030837			
N50_09A4	327.217	6209	63.45990	0.222046	0.030835			
N50_09B4	327.767	6209	63.34322	0.246050	0.030891			
	322.05	**6886**	**71.51179**		**0.030949**	**1.458**	**37.93**	**1141.0**
N50_10A2	323.447	6886	71.16923	0.06157	0.03105			
N50_10B2	323.753	6886	71.09468	0.07453	0.030988			
N50_10C2	324.084	6886	71.01424	0.08867	0.031027			
N50_10D2	324.442	6886	70.92747	0.104082	0.031051			
N50_10E2	324.831	6886	70.83345	0.120638	0.031099			
N50_10A3	325.232	6886	70.73682	0.138544	0.031103			
N50_10B3	325.670	6886	70.63160	0.157595	0.031101			
N50_10C3	326.161	6886	70.51407	0.177888	0.031111			
N50_10D3	326.598	6886	70.40983	0.199386	0.031162			
N50_10E3	327.109	6886	70.28838	0.222164	0.031193			
N50_10A4	327.637	6886	70.16337	0.246078	0.031202			
N50_10B4	328.155	6886	70.04121	0.27128	0.03122			
	343.27	**347**	**3.404732**		**0.029442**	**2.081**	**839**	**1030.7**
N70_5A1	344.633	347	3.391194	0.042090	0.029486			
N70_5B1	345.008	347	3.387488	0.053270	0.029528			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N70_5A2	345.401	347	3.383613	0.065680	0.029576			
N70_5B2	345.841	347	3.379286	0.079540	0.029653			
N70_5C2	346.319	347	3.374597	0.094600	0.029676			
N70_5D2	346.843	347	3.369472	0.11105	0.029622			
N70_5E2	347.414	347	3.363905	0.128726	0.029703			
N70_5A3	348.023	347	3.357988	0.147809	0.029742			
N70_5B3	348.679	347	3.351637	0.168083	0.029758			
N70_5C3	349.333	347	3.345330	0.189758	0.029803			
	343.3	**518**	**5.081234**		**0.029371**	**3.156**	**549.4**	**1052.1**
N70_7A1	344.636	518	5.061378	0.042050	0.029493			
N70_7B1	344.995	518	5.056070	0.053280	0.029547			
N70_7A2	345.347	518	5.050875	0.065730	0.029519			
N70_7B2	345.793	518	5.044309	0.079550	0.029599			
N70_7C2	346.262	518	5.037423	0.094640	0.029655			
N70_7D2	346.794	518	5.029635	0.111070	0.029720			
N70_7E2	347.348	518	5.021551	0.128721	0.029793			
N70_7A3	347.934	518	5.013028	0.147813	0.029758			
N70_7B3	348.549	518	5.004114	0.168101	0.029827			
N70_7C3	349.234	518	4.994224	0.189832	0.029926			
N70_7D3	349.944	518	4.984015	0.212738	0.029991			
N70_7E3	350.621	518	4.974319	0.237007	0.030054			
	343.29	**688**	**6.747784**		**0.029436**	**3.129**	**410.3**	**1063.2**
N70_01A1	347.570	688	6.663827	0.042100	0.029561			
N70_01B1	344.917	688	6.715617	0.053270	0.029544			
N70_01A2	345.314	688	6.707815	0.065740	0.029625			
N70_01B2	345.742	688	6.699425	0.079560	0.029657			
N70_01C2	346.192	688	6.690626	0.094620	0.029725			
N70_01D2	346.684	688	6.681032	0.111072	0.029785			
N70_01E2	347.221	688	6.670593	0.128751	0.029773			
N70_01A3	347.814	688	6.659104	0.147848	0.029861			
N70_01B3	348.409	688	6.647616	0.168151	0.029922			
N70_01C3	349.057	688	6.635151	0.189827	0.029961			
N70_01D3	349.715	688	6.622541	0.212727	0.030026			
N70_01E3	350.354	688	6.610342	0.237052	0.030073			
	343.29	**1388**	**13.60167**		**0.029824**	**2.459**	**208.7**	**1050.6**
N70_02A1	344.522	1388	13.55201	0.042100	0.029976			
N70_02B1	344.827	1388	13.53977	0.053290	0.029967			
N70_02A2	345.168	1388	13.52612	0.065730	0.029948			
N70_02B2	345.559	1388	13.51050	0.079590	0.029989			
N70_02C2	345.981	1388	13.49368	0.094630	0.029971			
N70_02D2	346.44	1388	13.47543	0.111079	0.029978			
N70_02E2	346.942	1388	13.45554	0.147921	0.030056			
N70_02A3	347.481	1388	13.43424	0.168193	0.030171			
N70_02B3	348.048	1388	13.41192	0.189868	0.030198			
N70_02C3	348.640	1388	13.38868	0.237082	0.030209			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N70_02D3	348.950	1388	13.37655	0.128753	0.030324			
N70_02E3	349.261	1388	13.3644	0.212723	0.030276			
	343.3	**2068**	**20.24488**		**0.030115**	**2.286**	**140.9**	**1055.0**
N70_03A1	344.419	2068	20.17709	0.042090	0.030219			
N70_03B1	344.742	2068	20.15761	0.053290	0.030229			
N70_03A2	345.080	2068	20.13727	0.065740	0.030246			
N70_03B2	345.452	2068	20.11493	0.079560	0.030223			
N70_03C2	345.891	2068	20.08863	0.094650	0.030319			
N70_03D2	346.327	2068	20.06258	0.111096	0.030277			
N70_03E2	346.798	2068	20.03452	0.128756	0.030347			
N70_03A3	347.319	2068	20.00358	0.147853	0.030383			
N70_03B3	347.854	2068	19.97191	0.168204	0.030432			
N70_03C3	348.421	2068	19.93845	0.189837	0.030454			
N70_03D3	348.987	2068	19.90517	0.212739	0.030521			
N70_03E3	349.642	2068	19.86680	0.23708	0.030567			
	343.31	**2765**	**27.03613**		**0.030318**	**2.703**	**104.4**	**1074.1**
N70_04A2	345.030	2765	26.89597	0.065730	0.030514			
N70_04B2	345.397	2765	26.86626	0.079560	0.030461			
N70_04C2	345.794	2765	26.83420	0.094640	0.030494			
N70_04D2	346.208	2765	26.80085	0.111082	0.030573			
N70_04E2	346.655	2765	26.76494	0.128784	0.030563			
N70_04A3	347.151	2765	26.72522	0.147840	0.030661			
N70_04B3	347.689	2765	26.68227	0.168161	0.030677			
N70_04C3	348.239	2765	26.63851	0.189898	0.030721			
N70_04D3	348.828	2765	26.59181	0.212751	0.030755			
N70_04E3	349.393	2765	26.54718	0.237089	0.030799			
N70_04A4	350.041	2765	26.49618	0.262584	0.030876			
N70_04B4	350.661	2765	26.44758	0.289483	0.030943			
	343.33	**3431**	**33.50432**		**0.030591**	**2.586**	**85.12**	**1072.7**
N70_05A2	344.998	3431	33.33448	0.065720	0.030738			
N70_05B2	345.347	3431	33.29918	0.079520	0.030735			
N70_05C2	345.742	3431	33.25931	0.094640	0.030791			
N70_05D2	346.137	3431	33.21955	0.111076	0.030845			
N70_05E2	346.585	3431	33.17458	0.128745	0.030845			
N70_05A3	347.060	3431	33.12703	0.147802	0.030868			
N70_05B3	347.553	3431	33.07783	0.168122	0.030903			
N70_05C3	348.110	3431	33.02244	0.189807	0.030949			
N70_05D3	348.671	3431	32.96684	0.212709	0.031007			
N70_05E3	349.298	3431	32.90494	0.237038	0.031068			
N70_05A4	349.870	3431	32.84868	0.262491	0.031132			
N70_05B4	350.533	3431	32.78372	0.289428	0.031164			
	343.34	**4146**	**40.42459**		**0.030869**	**2.518**	**69.79**	**1094.2**
N70_06A2	344.945	4146	40.22574	0.065690	0.030961			
N70_06B2	345.268	4146	40.18598	0.079530	0.031050			
N70_06C2	345.671	4146	40.13648	0.094620	0.031052			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N70_06D2	346.089	4146	40.08528	0.111052	0.031081			
N70_06E2	346.520	4146	40.03264	0.128715	0.031106			
N70_06A3	346.984	4146	39.97613	0.147784	0.031168			
N70_06B3	347.469	4146	39.91724	0.168071	0.031174			
N70_06C3	348.004	4146	39.85249	0.189791	0.031259			
N70_06D3	348.547	4146	39.78701	0.212653	0.031247			
N70_06E3	349.073	4146	39.72379	0.237015	0.031329			
N70_06A4	349.695	4146	39.64932	0.262478	0.031366			
N70_06B4	350.271	4146	39.58061	0.289346	0.031397			
	343.33	**4855**	**47.26127**		**0.031073**	**2.984**	**59.79**	**1099.6**
N70_07A2	344.924	4855	47.02861	0.065680	0.03115			
N70_07B2	345.251	4855	46.98118	0.079540	0.031254			
N70_07C2	345.614	4855	46.92866	0.094600	0.031303			
N70_07D2	346.003	4855	46.87251	0.111027	0.031323			
N70_07E2	346.410	4855	46.81392	0.128694	0.031408			
N70_07A3	346.868	4855	46.74818	0.147788	0.031440			
N70_07B3	347.343	4855	46.68020	0.168084	0.031449			
N70_07C3	347.873	4855	46.60461	0.189737	0.031490			
N70_07D3	348.415	4855	46.52758	0.212649	0.031531			
N70_07E3	348.929	4855	46.45478	0.236936	0.031578			
N70_07A2	349.511	4855	46.37264	0.262426	0.031634			
N70_07A2	350.092	4855	46.29096	0.289279	0.031700			
	343.35	**5517**	**53.61233**		**0.03141**	**2.716**	**52.99**	**1105.6**
N70_08A1	344.318	5517	53.45065	0.042070	0.031507			
N70_08B1	344.599	5517	53.40392	0.053250	0.031464			
N70_08A2	345.223	5517	53.30046	0.079540	0.031570			
N70_08B2	345.597	5517	53.23866	0.094580	0.031571			
N70_08C2	346.396	5517	53.10715	0.128699	0.031747			
N70_08D2	346.853	5517	53.03224	0.147811	0.031725			
N70_08E2	347.285	5517	52.96165	0.168093	0.031755			
N70_08A3	347.785	5517	52.88019	0.189774	0.031776			
N70_08B3	348.252	5517	52.80436	0.212638	0.031838			
N70_08C3	348.815	5517	52.71325	0.236925	0.031895			
N70_08D3	349.450	5517	52.61090	0.262406	0.031893			
N70_08E3	349.951	5517	52.53045	0.289397	0.031962			
	343.35	**6218**	**60.30848**		**0.031796**	**2.021**	**47.13**	**1118.7**
N70_09A2	344.826	6218	60.02984	0.065680	0.031904			
N70_09B2	345.158	6218	59.96756	0.079530	0.031986			
N70_09C2	345.522	6218	59.89943	0.094600	0.031977			
N70_09D2	345.899	6218	59.82905	0.111043	0.031883			
N70_09E2	346.298	6218	59.75475	0.128687	0.031954			
N70_09A3	346.722	6218	59.67603	0.147741	0.031963			
N70_09B3	347.194	6218	59.58865	0.168066	0.032026			
N70_09C3	347.714	6218	59.49272	0.189737	0.032078			
N70_09D3	348.221	6218	59.39951	0.212638	0.032115			

Table III. *(Continued)*

ID No.	T (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m·K^{-1})	χ (10^{-3} K^{-1})	α (10^{-8} m^2·s^{-1})	C_p (J·kg^{-1}·K)
N70_09E3	348.703	6218	59.31119	0.236893	0.032137			
N70_09A4	349.270	6218	59.20766	0.26240	0.032196			
N70_09B4	349.832	6218	59.10543	0.289257	0.032234			
	343.31	**6889**	**66.69293**		**0.032077**	**2.129**	**43.21**	**1113.1**
N70_10A2	344.796	6889	66.38090	0.065730	0.032195			
N70_10B2	345.090	6889	66.31954	0.079550	0.032221			
N70_10C2	345.408	6889	66.25332	0.094610	0.032183			
N70_10D2	345.778	6889	66.17645	0.111032	0.032271			
N70_10E2	346.198	6889	66.08943	0.128703	0.032282			
N70_10A3	346.628	6889	66.00060	0.147772	0.032326			
N70_10B3	347.083	6889	65.90690	0.16807	0.032285			
N70_10C3	347.576	6889	65.80569	0.189725	0.03233			
N70_10D3	348.082	6889	65.70217	0.212606	0.032396			
N70_10E3	348.613	6889	65.59392	0.236933	0.032424			
N70_10A4	349.132	6889	65.48850	0.262399	0.032499			
N70_10B4	349.729	6889	65.36769	0.289245	0.032542			

Eq. (17). The previous data of Ref. 1 almost coincide with the data of this work, and this confirms the stability and reproducibility of the employed instrument.

The data of NIST [7, 12–14], were also obtained using a transient hot-wire technique with a claimed uncertainty of 1%; some results from Ref. 14 were obtained using a steady-state variation with a transient hot-wire instrument. From Fig. 4, it can be seen that the majority of these data deviate from Eq. (17) by less than 2% with a maximum deviation of about 2.5%.

The data of Millat et al. [15] were obtained using a transient hot-wire technique also with a claimed uncertainty of 1%. From Fig. 4 it can be seen that the maximum deviation for this data set is less than 2.5% with most data deviating by less than 2%. The data of Kestin et al. [16] were measured using the hot-wire technique with a claimed uncertainty better than 1%. These data are generally 2% lower than those given by Eq. (17). The data of Mardolcar et al. [17] were obtained by the transient hot-wire technique with an estimated uncertainty of 0.5%. From Fig. 4, it can be seen that the maximum deviation of this data set from Eq. (17) is also less than 2%.

The data obtained by Yorizane et al. [18] were measured using a vertical coaxial cylindrical cell with an estimated uncertainty of only 2.5%. From Fig. 5 the data appear to be about 2.5% lower than that given by

Table IV. Thermal Conductivity of Argon Measured with the Steady-State Technique

ID No.	T_0 (K)	T_r (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m^{-1}·K^{-1})	ΔT (K)	t (s)	$\mu \times 10^6$ (Pa≅s)	Ra $\times 10^5$
A20_2A1	296.226	297.063	269	4.358176	0.027694	0.017422	1.680	1.8	22.64	0.085
A20_5A1	296.219	297.056	344	5.591979	0.027698	0.017494	1.668	3.0	22.65	0.258
A20_7A1	296.210	297.042	512	8.308414	0.027702	0.017603	1.664	4.4	22.68	0.553
A20_01A1	296.205	297.033	687	11.16075	0.027701	0.017692	1.596	5.8	22.72	0.933
A20_02A1	296.207	296.999	1379	22.50085	0.027692	0.018484	1.586	7.2	22.86	1.332
A20_03A1	296.214	296.968	2069	33.90246	0.027712	0.019432	1.508	7.3	23.01	2.019
A20_04A1	296.223	296.947	2753	57.99746	0.027709	0.020224	1.490	6.0	23.35	1.780
A20_05A1	296.236	296.936	3451	68.66673	0.027704	0.020974	1.401	5.6	23.54	1.670
A20_06A1	296.250	297.115	4142	68.62003	0.036149	0.022084	1.730	4.9	23.54	1.860
A20_07A1	296.269	297.112	4833	80.35185	0.036165	0.022670	1.686	4.4	23.74	1.660
A20_08A1	296.294	297.014	5518	92.08241	0.031762	0.023312	1.440	5.0	23.94	1.810
A20_09A1	296.323	297.024	6228	104.2679	0.031751	0.023936	1.402	4.4	24.17	1.528
A20_10A1	296.379	297.068	6828	114.5924	0.031796	0.024387	1.378	4.2	24.37	1.460
A50_2A1	322.152	323.016	168	2.500574	0.030229	0.018450	1.727	1.7	24.25	0.069
A50_5A1	322.155	323.014	338	5.034386	0.030235	0.018611	1.718	3.0	24.28	0.223
A50_7A1	322.190	323.040	512	7.630713	0.030233	0.018796	1.700	4.1	24.32	0.471
A50_01A1	322.163	323.006	693	10.33675	0.030219	0.018943	1.686	5.3	24.35	0.794
A50_02A1	322.184	323.003	1409	21.07449	0.030214	0.019591	1.638	7.1	24.49	1.570
A50_03A1	322.191	322.982	2065	31.96268	0.030209	0.020182	1.582	7.2	24.62	1.600
A50_04A1	322.191	322.946	2759	41.47371	0.030210	0.021145	1.510	6.0	24.77	1.550
A50_05A1	322.142	322.872	3446	51.93142	0.030227	0.021881	1.460	5.8	24.92	1.580
A50_06A1	322.192	322.899	4140	62.51497	0.030230	0.022612	1.413	4.9	25.09	1.310
A50_07A1	322.188	322.873	4831	73.10827	0.030186	0.023287	1.370	5.2	25.26	1.480
A50_08A1	322.168	323.026	5523	83.69276	0.039416	0.024291	1.715	4.1	25.44	1.380
A50_09A1	322.196	323.034	6213	94.30808	0.039420	0.024873	1.675	4.2	25.63	1.480
A50_10A1	322.223	323.041	6837	103.9255	0.039447	0.025499	1.635	4.0	25.81	1.402
A70_2A1	342.068	342.946	168	2.354728	0.032104	0.019323	1.756	1.7	25.47	0.061
A70_5A1	342.074	342.942	341	4.781816	0.032128	0.019571	1.735	3.4	25.50	0.244
A70_7A1	342.085	342.950	513	7.196869	0.032133	0.019631	1.730	4.0	25.53	0.381
A70_01A1	342.100	342.960	689	9.670129	0.032112	0.019732	1.720	4.8	25.56	0.576
A70_02A1	342.061	342.896	1375	19.33519	0.032117	0.020326	1.670	6.0	25.68	1.100
A70_03A1	342.078	342.888	2064	29.07187	0.032142	0.020970	1.620	7.1	25.81	1.690
A70_04A1	342.088	342.866	2761	39.95160	0.03212	0.021831	1.555	6.5	25.95	1.630
A70_05A1	342.105	342.860	3465	49.95455	0.032122	0.022483	1.510	6.3	26.10	1.710
A70_06A1	342.070	342.805	4137	58.53211	0.032113	0.023089	1.470	5.8	26.25	1.570
A70_07A1	342.102	343.017	4838	68.48525	0.041903	0.024201	1.830	5.1	26.41	1.750
A70_08A1	342.064	342.957	5513	78.13492	0.041911	0.024816	1.785	4.5	26.57	1.480
A70_09A1	342.075	342.950	6238	88.49740	0.041903	0.025307	1.750	4.8	26.75	1.690
A70_10A1	342.036	342.891	6845	97.19553	0.041908	0.025902	1.710	4.2	26.90	1.900

the correlation. The data obtained by Haran et al. [19] were measured with the transient hot-wire technique with an estimated uncertainty of 0.5%. In Fig. 4, it can be seen that the maximum deviation is as large as +2%.

Table V. Thermal Conductivity of Nitrogen Measured with the Steady-State Technique

ID No.	T_0 (K)	T_r (K)	P (kPa)	ρ (kg·m^{-3})	q (W·m^{-1})	λ (W·m^{-1}·K^{-1})	ΔT (K)	t (s)	$\mu\times10^6$ (Pa≅s)	Ra $\times10^5$
N20_5A1	295.719	296.299	340	3.868866	0.027669	0.025652	1.140	3.0	17.73	0.159
N20_7A1	295.697	296.262	513	5.840140	0.027674	0.025792	1.134	3.8	17.76	0.276
N20_01A1	295.694	296.259	687	7.823631	0.027667	0.025877	1.130	5.3	17.79	0.520
N20_02A1	295.695	296.238	1407	16.04343	0.027664	0.026948	1.085	6.2	17.91	0.906
N20_03A1	295.692	296.217	2070	23.62065	0.027662	0.027843	1.050	6.3	18.02	1.090
N20_04A1	295.687	296.346	2761	31.52030	0.036105	0.028952	1.318	6.4	18.15	1.600
N20_05A1	295.659	296.152	3457	39.51245	0.027665	0.029654	0.986	6.5	18.28	1.370
N20_06A1	295.659	296.274	4158	47.51450	0.036090	0.031011	1.230	6.1	18.41	1.690
N20_07A1	295.659	296.257	4834	55.24242	0.036078	0.031909	1.195	5.1	18.55	1.340
N20_08A1	295.669	296.253	5508	62.93093	0.036100	0.032731	1.168	5.2	18.69	1.430
N20_09A1	295.682	296.254	6215	70.97331	0.036113	0.033393	1.143	5.6	18.84	1.650
N20_10A1	295.700	296.196	6879	78.51901	0.031750	0.033827	0.992	5.6	18.99	1.500
N50_5A1	322.043	322.806	347	3.621924	0.039418	0.027319	1.525	3.4	18.93	0.223
N50_7A1	322.041	322.799	513	5.354757	0.039409	0.027493	1.515	5.4	18.95	0.536
N50_01A1	322.087	322.840	686	7.159604	0.039391	0.027662	1.505	5.2	18.98	0.582
N50_02A1	322.042	322.778	1396	14.57058	0.039419	0.028322	1.471	7.6	19.09	1.160
N50_03A1	322.084	322.797	2075	21.64957	0.039418	0.029236	1.425	8.0	19.19	1.823
N50_04A1	322.051	322.737	2765	28.84011	0.039402	0.030353	1.372	7.4	19.30	1.790
N50_05A1	322.082	322.745	3461	36.07419	0.039398	0.031426	1.325	6.2	19.42	1.480
N50_06A1	322.072	322.715	4149	43.21262	0.039396	0.032378	1.286	6.0	19.54	1.480
N50_07A1	322.084	322.710	4839	50.34767	0.039397	0.033258	1.252	5.5	19.66	1.360
N50_08A1	322.075	322.688	5541	57.58439	0.039390	0.033985	1.225	5.1	19.79	1.270
N50_09A2	322.072	322.670	6209	64.44309	0.039416	0.034861	1.195	5.1	19.92	1.300
N50_10A2	322.053	322.641	6886	71.36643	0.039412	0.035451	1.175	5.0	20.05	1.300
N70_5A1	343.287	344.062	347	3.396852	0.042090	0.028700	1.550	2.9	19.86	0.160
N70_7A1	343.306	344.076	518	5.069682	0.042051	0.028860	1.540	3.7	19.89	0.278
N70_01A1	343.280	344.047	688	6.732779	0.042093	0.029020	1.533	4.4	19.91	0.411
N70_02A1	343.326	344.079	1388	13.56982	0.042095	0.029562	1.505	7.2	20.01	1.030
N70_03A1	343.271	344.006	2068	20.20206	0.042082	0.030256	1.470	8.0	20.11	1.690
N70_04A2	343.325	344.034	2765	26.97694	0.042074	0.031382	1.417	7.4	20.21	1.640
N70_05A2	343.322	344.015	3431	33.43435	0.042066	0.032101	1.385	7.4	20.32	1.800
N70_06A2	343.316	343.987	4146	40.34418	0.042060	0.033149	1.341	7.4	20.43	1.890
N70_07A2	343.306	343.960	4855	47.16902	0.042061	0.033987	1.308	6.8	20.54	1.750
N70_08A2	343.334	343.973	5517	53.50815	0.042063	0.034786	1.278	6.4	20.66	1.650
N70_09A2	343.316	343.941	6218	60.19657	0.042071	0.035572	1.250	5.8	20.78	1.470
N70_10A2	343.308	343.923	6889	66.56382	0.042064	0.036144	1.230	5.5	20.90	1.400

The data obtained by Michels et al. [20] were measured with the steady-state technique with an estimated uncertainty of 1%. In Fig. 4, it can be seen that the maximum spread in the data is as large as 2.9%; the majority of the data however agree within −0.4%. The data obtained by Clifford et al. [21] were measured with the transient hot-wire technique

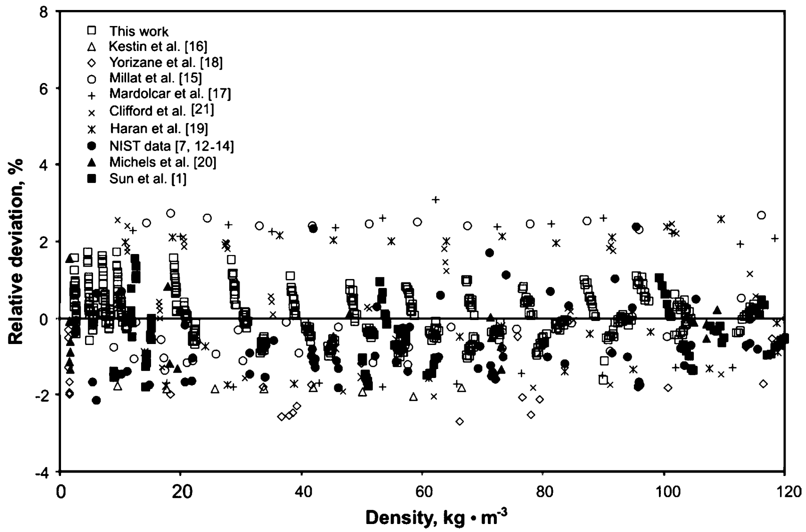

Fig. 4. Deviations in the experimental thermal conductivity of argon from Eq. (17).

Table VI. Coefficients for Equations: $\lambda_0 = a_0 + a_1 T + a_2 T^2$ and $\Delta\lambda = b_1\rho + b_2\rho^2$

a_0	a_1	a_2	b_1	b_2
Argon				
-9.7039×10^{-3}	1.3400×10^{-4}	-1.4000×10^{-7}	2.8785×10^{-5}	-3.4655×10^{-8}
Nitrogen				
-1.9553×10^{-2}	2.2680×10^{-4}	-2.4750×10^{-7}	4.4652×10^{-5}	-1.0893×10^{-8}

Table VII. Ideal-Gas Thermal Conductivity for Argon and Nitrogen

T (K)	λ (W·m^{-1}·K^{-1})
Argon	
300	0.0179
320	0.0188
340	0.0197
Nitrogen	
300	0.0262
320	0.0277
340	0.0289

Table VIII. Thermal Conductivity of Argon after Correcting to 300, 320, and 340 K

T (K)	P (kPa)	ρ (kg·m^{-3})	λ(W·m^{-1}·K^{-1})
300	169	2.709	0.01799
300	344	5.520	0.01807
300	512	8.225	0.01813
300	687	11.048	0.01820
300	1379	22.266	0.01844
300	2069	33.538	0.01869
300	2753	44.792	0.01900
300	3452	56.372	0.01924
300	4142	67.876	0.01953
300	4833	79.464	0.01982
300	5518	91.013	0.02014
300	6228	103.040	0.02043
300	6828	113.243	0.02070
320	168	2.500	0.01893
320	338	5.034	0.01901
320	512	7.631	0.01900
320	693	10.336	0.01909
320	1409	21.074	0.01939
320	2065	30.960	0.01968
320	2759	41.466	0.01988
320	3446	51.909	0.02016
320	4140	62.498	0.02046
320	4830	73.060	0.02072
320	5523	83.700	0.02103
320	6213	94.550	0.02126
320	6837	103.940	0.02150
340	168	2.354	0.01972
340	341	4.781	0.01978
340	513	7.195	0.01981
340	689	9.668	0.01990
340	1375	19.329	0.02021
340	2064	29.061	0.02050
340	2761	38.935	0.02072
340	3465	48.933	0.02099
340	4137	58.496	0.02122
340	4838	68.488	0.02145
340	5513	78.124	0.02171
340	6238	88.482	0.02191
340	6845	97.160	0.02222

with an estimated uncertainty of 1%. In Fig. 4, it can be seen that this set of data agrees very well with Eq. (17) and again the maximum deviation is less than 2%.

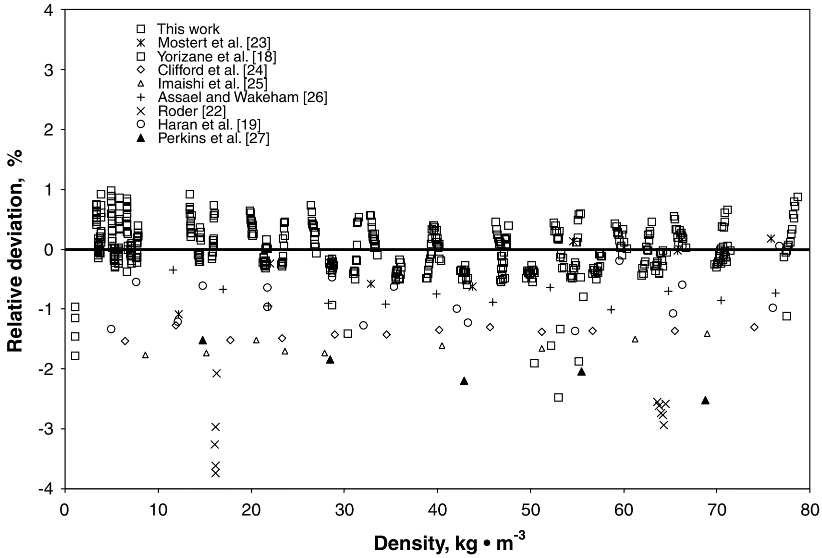

Fig. 5. Deviations in the experimental thermal conductivity of nitrogen from Eq. (17).

From the above comparisons, it can be seen that within the temperature and pressure ranges considered, the maximum deviation among the considered thermal conductivity data sets is less than 2.5% compared to the correlation of Eq. (17). Most of the data sets from the literature obtained using absolute transient hot-wire instruments deviate less than 2% from the correlation.

4.1.2. Nitrogen

The deviations from Eq. (17) of the thermal conductivity for nitrogen from the different sources considered are shown in Fig. 5. From this figure it can be seen that the maximum deviation in thermal conductivity for nitrogen of the present data set is about 1.0% with a standard deviation of about 0.33%. Most of the data from other sources indicate values that are smaller than the present data set with most data deviating from Eq. (17) by less than −2% except for the data of Roder [22], which were obtained using a transient hot-wire instrument with a claimed uncertainty of 1%. From Fig. 5 it can be seen that the maximum deviation of these data from Eq. (17) is up to −4%. The data by Mostert et al. [23], measured using a parallel-plate instrument with a claimed uncertainty of 2%, however, deviate from Eq. (17) by less than −1%. The data by Yorizane et al. [18], measured using a coaxial cylindrical cell instrument, deviate

Table IX. Thermal Conductivity of Nitrogen after Correcting to 300, 320, and 340 K

T (K)	P (kPa)	ρ (kg·m^{-3})	λ(W·m^{-1}·K^{-1})
300	340	3.820	0.02642
300	513	5.766	0.02646
300	687	7.724	0.02656
300	1407	15.835	0.02690
300	2070	23.313	0.02718
300	2761	31.111	0.02749
300	3457	38.964	0.02783
300	4158	46.867	0.02817
300	4834	54.478	0.02848
300	5508	62.049	0.02884
300	6215	69.968	0.02920
300	6879	77.378	0.02956
320	347	3.653	0.02789
320	513	5.402	0.02786
320	686	7.224	0.02799
320	1396	14.700	0.02840
320	2075	21.846	0.02868
320	2765	29.099	0.02890
320	3461	36.401	0.02922
320	4149	43.606	0.02945
320	4839	50.810	0.02981
320	5542	58.124	0.03025
320	6209	65.036	0.03056
320	6886	72.021	0.03086
340	347	3.437	0.02924
340	518	5.130	0.02907
340	688	6.813	0.02913
340	1388	13.736	0.02958
340	2068	20.447	0.02989
340	2765	27.310	0.03005
340	3431	33.848	0.03033
340	4146	40.845	0.03061
340	4855	47.755	0.03086
340	5517	54.180	0.03112
340	6218	60.951	0.03158
340	6889	67.399	0.03185

from Eq. (17) by 2.5% at most, with the majority of the data deviating by less than 2%. The data by Clifford et al. [24] and by Imaishi et al. [25] were both obtained with a transient hot-wire instrument and are systematically lower by about 2%. The data by Assael and Wakeham [26] and Haran et al. [19] were also measured using a transient hot-wire instrument

Table X. Coefficients for Linear Regression; $\lambda = A\rho + B$

Temperature (K)	$A\,(\mathrm{W{\cdot}m^2{\cdot}kg^{-1}{\cdot}K^{-1}})$	$B\,(\mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}})$
Argon		
300	2.429×10^{-5}	0.01791
320	2.561×10^{-5}	0.01885
340	2.604×10^{-5}	0.01967
Nitrogen		
300	4.240×10^{-5}	0.02621
320	4.348×10^{-5}	0.02768
340	4.194×10^{-5}	0.02894

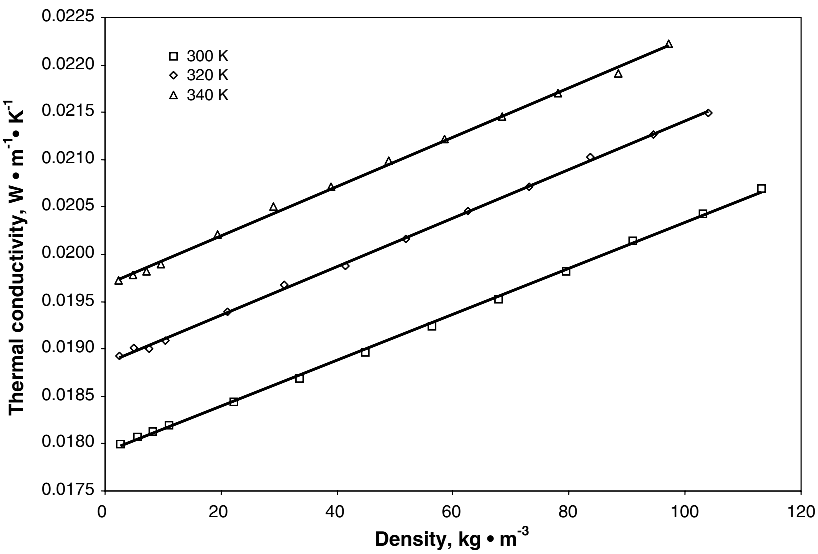

Fig. 6. Obtained thermal conductivity of argon at nominal temperatures.

and deviate from Eq. (17) systematically by −1%. The data by Perkins et al. [27] were measured using a hot-wire instrument and deviate from Eq. (17) by less than 2.5%.

The thermal-conductivity values of argon and nitrogen along each nominal isotherm, 296, 323, and 343 K, at different densities were obtained by correcting for the influence of the temperature coefficient and are listed

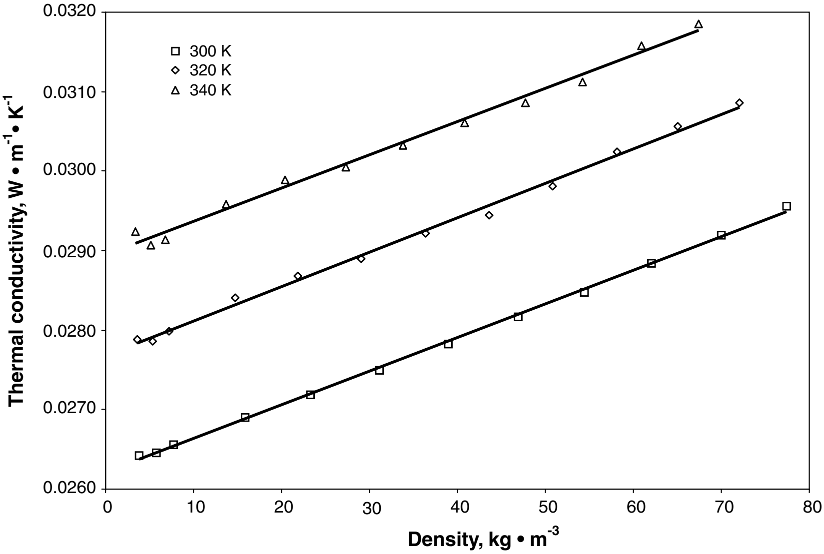

Fig. 7. Obtained thermal conductivity of nitrogen at nominal temperatures.

in Tables VIII and IX, respectively. The obtained thermal-conductivity values for argon and nitrogen along each isotherm were fitted with the form,

$$\lambda = A\rho + B \tag{19}$$

with the linearly regressed coefficients obtained indicated in Table X. The values along the different isotherms as functions of density are shown in Figs 6 and 7, respectively. The thermal-conductivity data from all other sources are then compared to the values given by Eq. (19), and the deviations, as functions of density, are shown in Figs. 8–10 for argon and in Figs. 11–13 for nitrogen. From these comparisons it can be seen that for argon most deviations are within ±2.5% and that all the results distribute evenly across the baseline. While for nitrogen, most deviations are within 3% and the data from this work distribute evenly across the baseline; most of the other results are however below the baseline.

4.2. Thermal Diffusivity

The thermal diffusivities for argon and nitrogen were measured as well along the three isotherms, and the isobaric specific heats were calculated using the measured thermal conductivities and densities determined using the equation of state of Ref. 5. To derive ideal-gas specific heats for

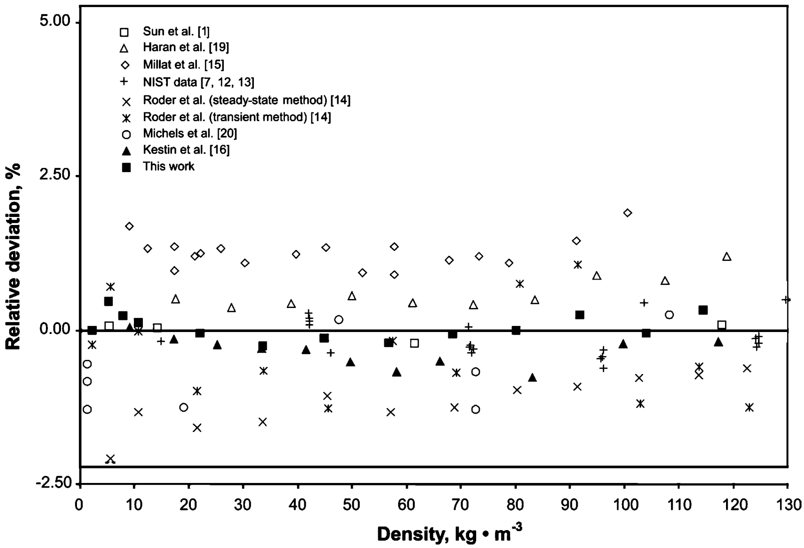

Fig. 8. Deviations in the thermal conductivity of argon at 300 K from the linear fit.

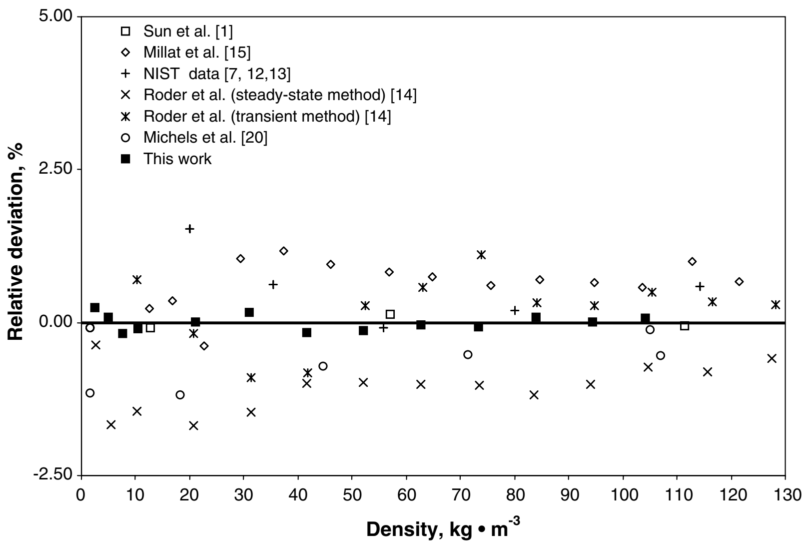

Fig. 9. Deviations in the thermal conductivity of argon at 320 K from the linear fit.

argon and nitrogen, and thus make a comparison to theoretical values, the low-density data were extrapolated linearly to zero density for each isotherm. The deviations of the experimental ideal-gas specific-heat values for argon and nitrogen from the theoretical values [5] are shown in Figs. 14

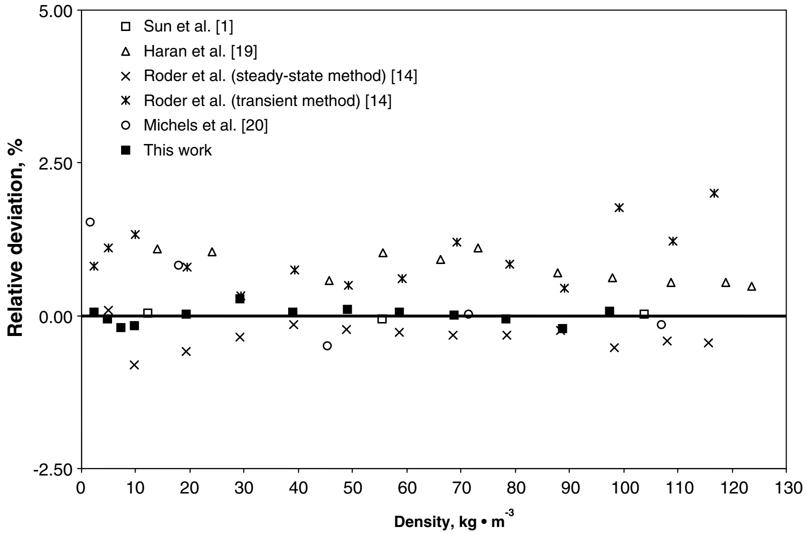

Fig. 10. Deviations in the thermal conductivity of argon at 340 K from the linear fit.

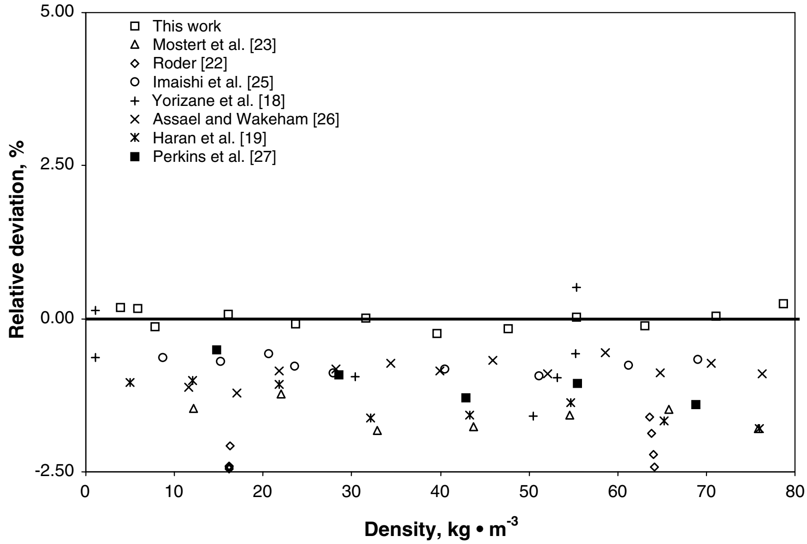

Fig. 11. Deviations in the thermal conductivity of nitrogen at 300 K from the linear fit.

and 15, respectively. For argon the maximum deviation does not exceed 3% with a standard deviation of less than 2%; for nitrogen the maximum deviation is about 2% with a standard deviation of less than 1.5%. The mean extrapolated zero-density values agree with theory to better than

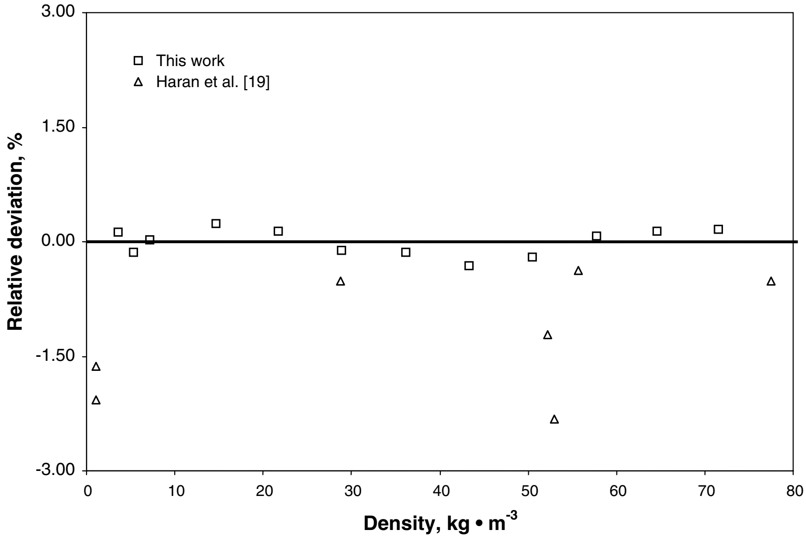

Fig. 12. Deviations in the thermal conductivity of nitrogen at 320 K from the linear fit.

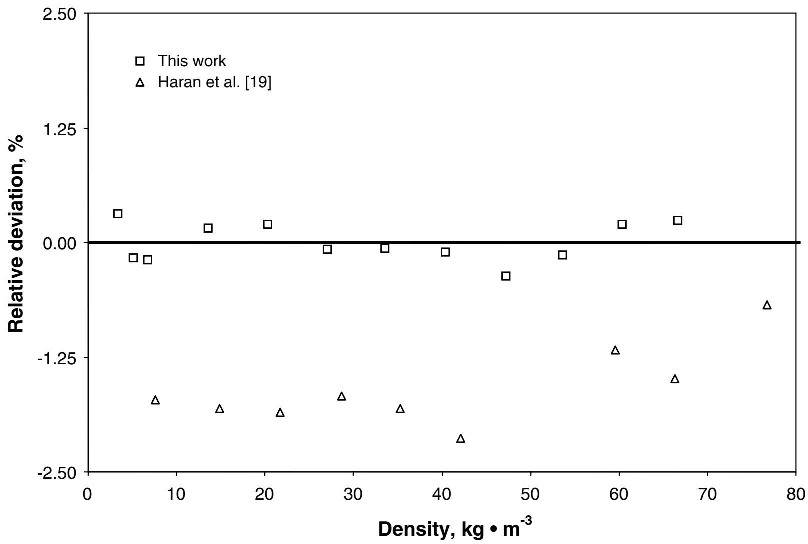

Fig. 13. Deviations in the thermal conductivity of nitrogen at 340 K from the linear fit.

+1% for argon and +2% for nitrogen. The noted corrections for bridge imbalance and the temperature variation of thermal conductivity are thus seen as essential in the successful determination of the thermal diffusivity, and hence the specific heat [1–4], using the transient hot-wire technique.

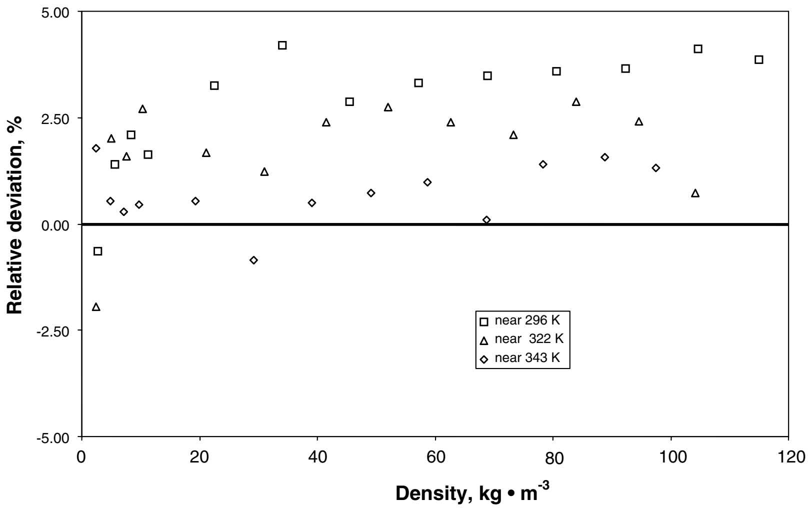

Fig. 14. Deviations in the experimental isobaric specific heat of argon from those calculated using the equation of state.

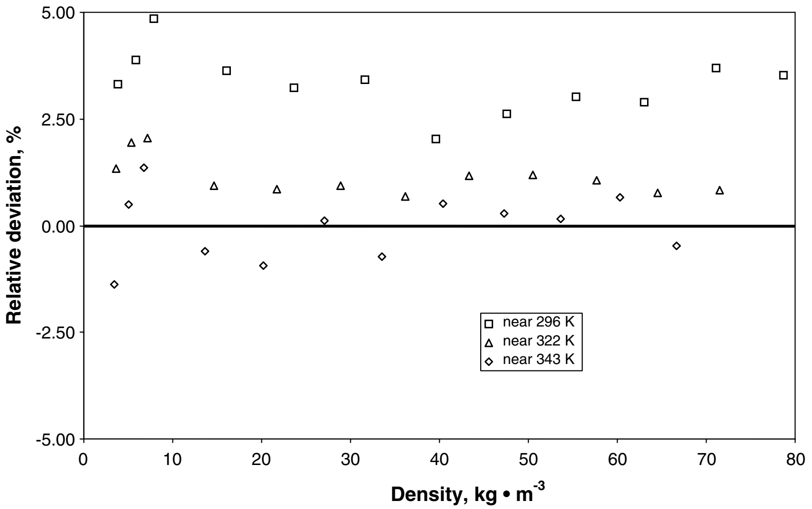

Fig. 15. Deviations in the experimental isobaric specific heat of nitrogen from those calculated using the equation of state.

4.3. Measurements of Thermal Conductivity by the Steady-State Method

The steady-state method [14] was attempted for measurements along the three isotherms, and the measurements for each thermodynamic reference state point were obtained using a single power. A typical

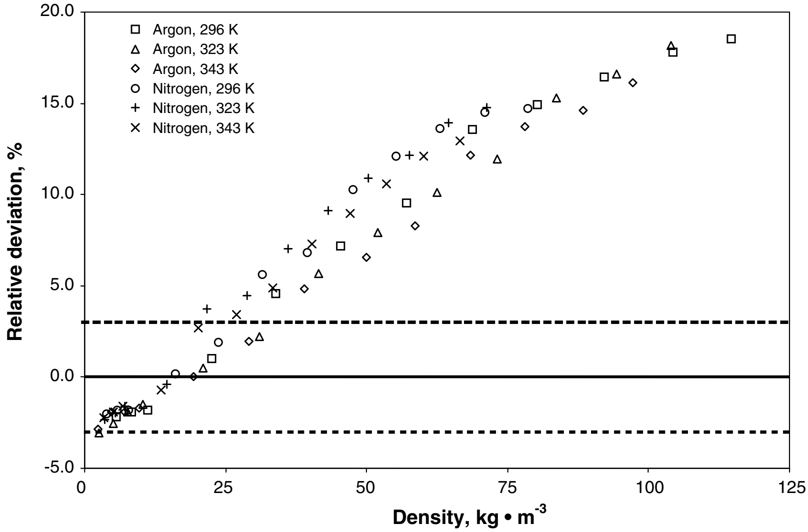

Fig. 16. Deviations in the thermal conductivity of argon and nitrogen obtained using the steady-state method from Eq. (17) as a function of density.

time–temperature rise of the hot wire as a function of time can be found in Ref. 1. The steady-state temperature rise is associated with those points where the thermal wave reaches the outer cell boundary. The thermal conductivity was obtained via the usual expression for conduction between infinite concentric cylinders;

$$\lambda = \frac{q \ln \left(b/a\right)}{2\pi \left(T_1 - T_2\right)}, \tag{20}$$

where b is the radius of the cell enclosure, a is the radius of the wire, and $\Delta T = T_1 – T_2$ is the temperature difference between the wire and its surrounding cell wall at steady-state conditions. The measured thermal conductivity corresponds to a mean temperature of

$$\overline{T} = \frac{T_1 + T_2}{2}. \tag{21}$$

Since the heating period for the steady-state measurement is much greater than that used for the transient state measurement, free convection may occur before a steady-state heat conduction state is achieved. The measured steady-state thermal-conductivity data for argon and nitrogen are listed in Tables IV and V, respectively, along with their corresponding

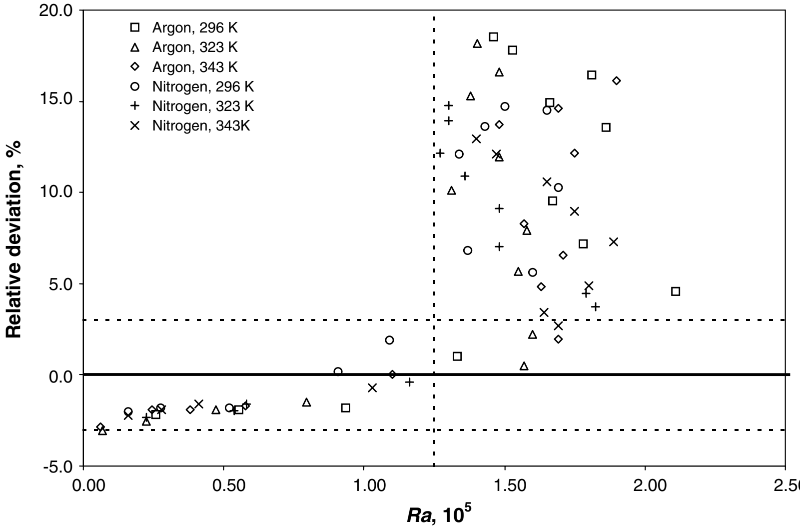

Fig. 17. Deviations in the thermal conductivity of argon and nitrogen obtained using the steady-state method from Eq. (17) as a function of *Ra* number.

Raleigh numbers, *Ra*. The deviations in the measured steady-state thermal-conductivity values from Eq. (17) are shown in Fig. 16. From this it can be seen that the data that deviate from Eq. (17) by less than 3% are limited and the absolute values of the deviations have a tendency to increase significantly with density. The deviation in the thermal conductivity measured using the steady-state method from Eq. (17) as a function of *Ra* number are also shown in Fig. 17, and from this, it can be seen that if the measurement *Ra* number is greater than about 1.3×10^5, the measurements agree with Eq. (17) within 3%; however, if *Ra* is greater than this, the data deviate from Eq. (17) by significant amounts and thus indicate free convection. Referring to Fig. 2, it can be seen that Eq. (13) can be used to accurately judge the occurrence of free convection. The convection-free thermal-conductivity values agree with the transient values to no better than −2% up to $Ra = 1 \times 10^5$. A similar trend is noticed in the steady-state results obtained by NIST for argon.

5. CONCLUSION

In summary, the thermal conductivity and thermal diffusivity of argon and nitrogen in the range of 296–250 K and up to 6.9 MPa have been measured using an absolute transient hot-wire instrument. A critical analysis of some of the factors that influence the measurements are presented, and these suggest an estimated uncertainty of less than 1% for the reported transient thermal-conductivity data and less than 4% for the thermal-diffusivity data; the uncertainty in any derived specific heats is less than 5%, although this is dependent on the accuracy of the equation of state used.

The steady-state method was used to measure the thermal conductivity of gaseous argon and nitrogen in the same temperature and pressure region as the transient measurements. The uncertainty of the convection-free results is estimated to be less than ±3%. The empirical standard to judge the occurrence of free convection when using this method is suggested to be $Ra \leqslant 1 \times 10^5$.

The present measurements of thermal conductivity were used to establish a correlation in the temperature range of 296–350 K and up to 6.9 MPa with an estimated uncertainty of ±2%. The thermal conductivity data from all other data sources considered are in good agreement with this correlation with uncertainties of less than 3%. The derived zero-density specific-heat results agree with theoretical values to within about +1 and +2% for argon and nitrogen, respectively.

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