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Thermal Conductivity and Speed of Sound Measurements of Liquid Hydrazine (N_2H_4) at 293.15K and 0.101 MPa to 2.068 MPa

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14. ABSTRACT

The thermal conductivity of liquid hydrazine was measured by the steady-state hot-wire method at 293.15K and 0.101 MPa. Eight pure organic liquids were used as reference liquids to calibrate the experimental apparatus. The thermal conductivity was determined to be $\lambda = 0.32 \pm 0.03$ W m^{-1}°C^{-1}. The current measurement is in agreement with one recent measurement. However, the current measurement disagrees with the most recent measurement as well as several previous measurements and estimation methods. The thermal conductivity was determined to change very little over the pressure range of 0.101–2.068 MPa. The current observed pressure dependence is in agreement with one previous pressure dependence measurement. The speed of sound in liquid hydrazine was measured to be 2092 $\pm$ 12 m s^{-1}, in agreement with previous measurements. There are large inaccuracies obtained when estimating the thermal conductivity of hydrazine by using standard estimation methods that utilize speed of sound data.

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Nomenclature

λ = thermal conductivity, $Wm^{-1} {}^{\circ}C^{-1}$

N_A = Avogadro constant, 6.02214×10^{-23} mol^{-1}

V_η = molar volume, m^3 mol^{-1}

k = Boltzmann constant, 1.38066×10^{-23} J K^{-1}

c_N = Speed of sound, m s^{-1}

MMH = monomethyl hydrazine

UDMH = unsymmetric dimethyl hydrazine

T = temperature, K

I_c = constant current, A

V_f = voltage, V

Δf = liquid resonance frequency difference, Hz

L = pathlength, m

R = resistance, Ω

A,B = thermal conductivity constants of measurement cell

P = pressure, Pa

υ = specific volume, kg

V_c = critical volume, m^3 kg^{-1}

R = gas constant

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1. Introduction

Hydrazine (N_2H_4) is a propellant often used in propulsion systems for orbital maneuvering on manned and unmanned spacecraft. The thermal properties of pure liquid hydrazine are of major interest when designing processing equipment, spacecraft, and propulsion engines. The thermal conductivity is an indispensable parameter in engineering work that involves heat transfer applications. Also, it is important to understand the pressure dependence of the thermal properties of hydrazine since it is usually stored under pressure. Despite the importance of this thermal property, there is very little agreement in the literature among reliable data sources. The current literature disagrees by an order of magnitude from the first experimental measurements to the most recent measurements on the thermal conductivity of liquid hydrazine.[1–5]

Hydrazine is hydroscopic and can potentially contain other manufacturing impurities such as aniline. These impurities could potentially have major effects on the measured thermal conductivity of hydrazine. This is particularly true of water and ammonia impurities since liquid water and liquid ammonia have large thermal conductivities compared to most liquids at 293.15K and 0.101 MPa. There are several previous experimental measurements that have determined a thermal conductivity value for liquid hydrazine in various solvents. The thermal conductivity of hydrazine (95% N_2H_4, 5% H_2O) was determined previously by the Ralph M. Parsons Corporation ($\lambda = 0.50\ Wm^{-1}{}^{\circ}C^{-1}$) at 293K.[1] However, there are few details on how this value was obtained or the purity of the hydrazine used in the experiment. Bachmaier measured the thermal conductivity of hydrazine/methanol mixtures.[2] A slightly larger value than the Ralph M. Parsons Corporation number was determined by Bachmaier ($\lambda = 0.54\ Wm^{-1}{}^{\circ}C^{-1}$) for pure hydrazine in the mixtures studied. Once again, there was very little detail in the report on how this value was obtained or the purity of hydrazine used in the experiment. Safarov and Zaripova measured the thermal conductivity of hydrazine-water mixtures as a function of temperature and pressure using a cylindrical bicalorimeter.[3] They obtained a lower thermal conductivity than the two older measurements for 90% hydrazine in water ($\lambda = 0.395\ Wm^{-1}{}^{\circ}C^{-1}$) at 293K. Their extrapolated 100% hydrazine value was $\lambda = 0.328\ Wm^{-1}{}^{\circ}C^{-1}$ at 293K and 0.101 MPa. The purity of the hydrazine used in their experiments was not stated. The Safarov and Zaripova value agrees with the value in the most recent *Chemical Properties Handbook* ($\lambda\ (Wm^{-1}K^{-1}) = 0.4008 - 1.5493 \times 10^{-4}\ T - 4.8625 \times 10^{-7}\ T^2$, T in K) at 293K ($\lambda = 0.314\ Wm^{-1}{}^{\circ}C^{-1}$).[4] There is no reference in the handbook regarding the origin of the thermal conductivity value other than it was based on unspecified experimental and calculated values. The most recent measurement from Grebenkov et al. is an order of magnitude smaller than the older measurements at 295K and 0.101 MPa ($\lambda = 0.0499\ Wm^{-1}{}^{\circ}C^{-1}$). This value is on the low end of thermal conductivity of most measured liquids. Grebenkov used a steady-state hot-wire method with anhydrous hydrazine.[5]

For most pure liquids, the thermal conductivity can be estimated by using the modified Bridgman equation.[6,7]

$$\lambda = 2.8\left(\frac{N_A}{V_\eta}\right)^{2/3} k\, c_N \tag{1}$$

In Eq. (1), N_A is Avogadro's number, V_η is the molar volume, k is Boltzmann's constant, and c_N is the speed of sound in the fluid. For liquid water, the speed of sound is 1496.70 m s^{-1} at 298.15K. The speed of sound in hydrazine, MMH and UDMH, were previously measured by Kretschmar (c_N = 2074 m s^{-1} (N_2H_4), c_N = 1548 m s^{-1} (MMH), c_N = 1247 m s^{-1} (UDMH)) at 298.15 K.[8–11] The thermal conductivity of hydrazine estimated by the Bridgman equation is 0.569 $Wm^{-1}{}^\circ C^{-1}$ at 298.15K. The Bridgman equation suggests the older measurements of thermal conductivity are correct. Even though these older measurements have ~5% water added, which most likely increased the thermal conductivity measured.

Gibek and Maisonneuve[12] recently measured the speed of sound in liquid hydrazine by measuring the waterhammer overpressure levels in flowing hydrazine pipes. They obtained a speed of sound of MMH of 1530 m s^{-1}, in good agreement with the Kretschmar value. However, they measured a speed of sound in liquid hydrazine of 1293 m s^{-1} at 298K. This value is significantly lower than the Kretschmar value. Using the Gibek and Maisonneuve value for the speed of sound in hydrazine in Eq. (1) yields an estimated thermal conductivity value of 0.354 $Wm^{-1}{}^\circ C^{-1}$. This estimated value is in agreement with the current measurements of the hydrazine thermal conductivity by Safarov and Zaripova.[3]

This work investigated the thermal conductivity of hydrazine at 293.5K and 0.101 MPa to 2.068 MPa by using the steady-state hot-wire method.[13] The thermal conductivity apparatus was calibrated by using eight reference liquids that have well-known thermal conductivities.[4,8] The thermal conductivity was determined to be $\lambda = 0.32 \pm 0.03$ $Wm^{-1}{}^\circ C^{-1}$ at 293.5K and 0.101 MPa, in agreement with the previous measurements of Safarov and Zaripova[3] and the recommended value in the *Chemical Properties Handbook*. The pressure dependence of the thermal conductivity was found to not vary within error of the experiment from 0.101 MPa to 2.068 MPa. The observations are in agreement with the previous pressure trends observed by Safarov and Zaripova[3] for mixtures of hydrazine and water over the pressure range of interest.

The speed of sound in hydrazine at 293.5K was measured using an ultrasonic interferometry technique.[14] The speed of sound in liquid hydrazine was found to be 2092 ± 12 m s^{-1}. The value is in agreement with previous measurements of 2093 m s^{-1} at 293.15K.[11] The speed of sound result demonstrates that the Bridgman equation does not yield an accurate estimate of the thermal conductivity for liquid hydrazine.

2. Experiment

2.1 Thermal conductivity

The thermal conductivity apparatus was designed to closely follow ASTM standards for the steady-state hot-wire method (see Figure 1).[13] The thermal conductivity cell consists of a 20.0-cm-long Pyrex glass tube that had a 6.5-mm radius with 2.45-mm-thick walls. For high pressure measurements, the thermal conductivity cell consists of a 21.0-cm-long stainless-steel 304L tube that has an inner diameter of 8.05 mm. The tube was threaded for a Teflon plug that had a silicon rubber O-ring seal. This plug allowed the cell to be sealed, thus preventing the hydrazine from reacting with air during testing. For high-pressure tests, a 0.25-in. stainless side arm was fitted with a valve that allowed the tube to be pressurized during testing. The helium (99.995 %) pressure was changed from 0.101 MPa (14.7 psi) to 2.068 MPa (300 psi) during the experiments. A platinum wire (0.06 mm radius) was used as the resistance thermometer (100 Ω, 0.00385 Ω/ Ω/K). The 4 lead-wire was housed in a 1.63-mm-radius, 18.6-cm-long ceramic tube that was inserted through the center of the Teflon plug. Two lead wires were connected to a volt meter to record the voltage during tests. The other two lead wires were connected to a constant current source and an ammeter. When the Teflon plug was screwed into place, the ceramic tube ran down the axis of the tube as seen in Figure 1.

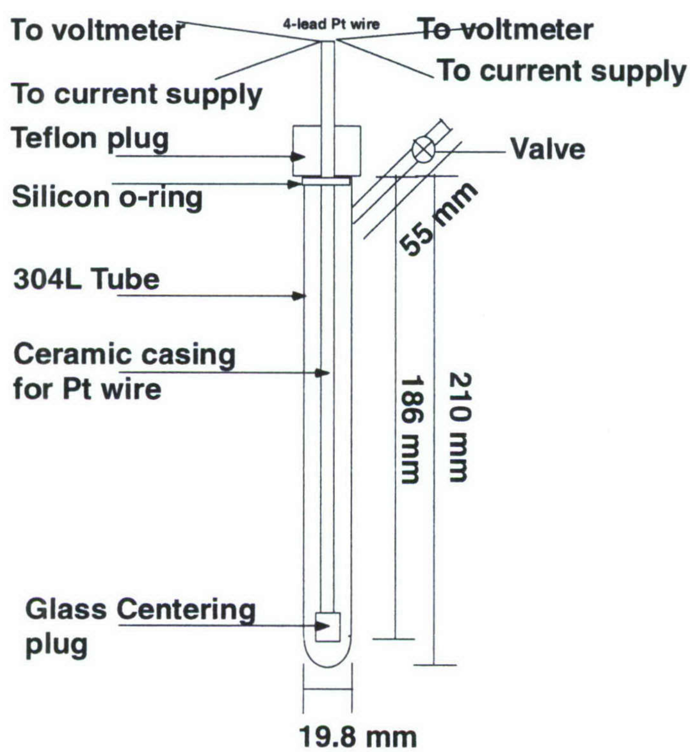

Figure 1. Stainless-steel experimental apparatus used in the thermal conductivity experiments. The glass tube apparatus was similar in design except it lacked the side arm needed for pressurization.

The thermal conductivity cell was filled with the test liquid in a nitrogen-purged chemical handling bag. The cell was filled completely with liquid to remove any dead space that might have potentially been filled with nitrogen gas. The cell was then sealed with the Teflon plug and placed into a temperature-controlled water bath at 293.150K (±0.005K). With this setup, the effective heating pathlength through the test liquid to the temperature-controlled bath was 2.42 mm. A constant current (I_c) was placed on the platinum wire, and the final voltage (V_f) was recorded. When the voltage reached a constant value (~3 min), the current was again changed. The change in temperature is then determined by Eq. (2).

$$\Delta T = \left(\frac{V_f}{I_c} - 100\Omega \right) \Big/ 0.00385\,\Omega/1/K \tag{2}$$

The hydrazine used in the experiment was purchased from Aldrich Chemicals (99.6%, aniline free). The purity of the calibration liquids was as follows: water (99.9%), dimethyl phthalate (99+%), methanol (99.8%), 2-propanol (99.9%), ethanol (99.5%), carbon tetrachloride (99.9%), Chloroform (99%), acetonitrile (99%) and acetone (99.8%).

2.2 Speed of sound Measurements

The experimental setup is similar to that detailed in Han et al. and will only be briefly described here.[14] Two broadband lithium-niobate transducers with a resonance frequency of 1.8–6 MHz were attached to a rectangular cell containing the test liquid. The cell was either a 1-cm-pathlength quartz cuvette or a 3.5-cm-pathlength square plastic bottle. One transducer (speaker) was swept through the frequency range in 1-kHz steps with an excitation voltage ranging from 0.25 V to 2.5 V. Figure 2 shows a picture of the experimental setup for the speed of sound measurements. A computer-con-

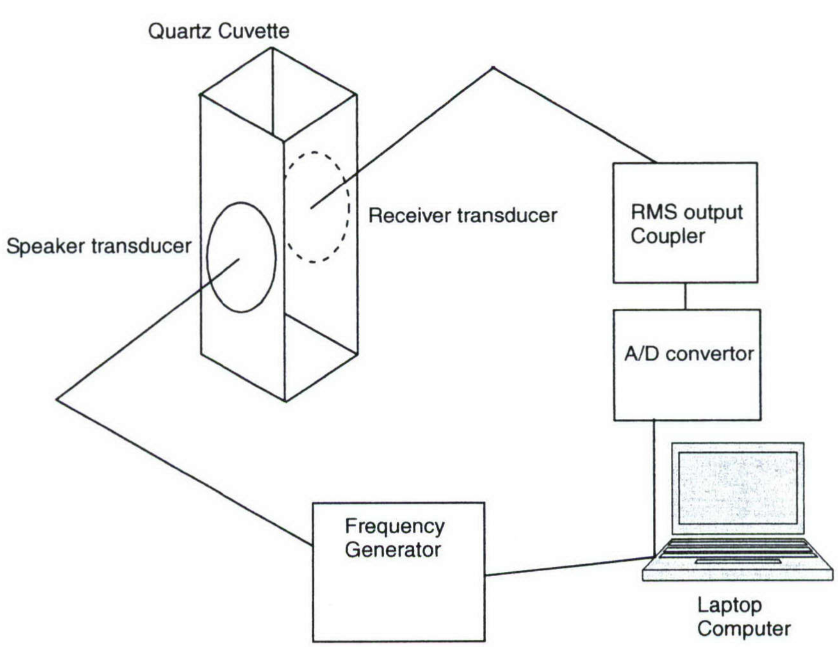

Figure 2. Experimental set up for measuring the speed of sound by using ultrasound.

trolled frequency generator sent the driver frequency signal to the speaker transducer. The generated sound waves then traveled through the liquid in the sample cell. The standing sound wave in the sample cell was then picked up by the receiver transducer on the opposite side of the sample cell. The frequency signal on the receiver transducer was sent through a 10 dB amplifier and then through a high-pass frequency filter inside an output coupler. The root-mean-square amplitude of the signal was then sent to a transient digitizer and recorded by a computer. The amplitude of the standing wave in the cell has a frequency dependence based on the pathlength of the cell (L) and the speed of sound of the liquid in the cell. The liquid resonance frequency difference (Δf), the difference in frequency where the standing wave has a maximum peak amplitude on the receiver signal, can be related to the speed of sound in the liquid (c_N) by Eq. (3).[14]

$$\Delta f = 2\,L\,c_N \tag{3}$$

The liquid resonance frequency difference varies slightly from peak to peak due to interference from the cell walls. Thus, an average of several Δf throughout the driver frequency scanning range had to be used to obtain the speed of sound.

The pathlengths of the two different sample cells were calibrated with liquids that had known speed of sounds. Water, methanol, 2-propanol, acetone, and carbon tetrachloride were used to calibrate the cells. The purity of the calibration liquids was as follows: water (99.9%), methanol (99.8%), 2-propanol (99.9%), carbon tetrachloride (99.9%), and acetone (99.8%).

3. Results

The thermal conductivity (λ) of the hydrazine tested was determined from the change in temperature for a given applied current (I) and resistance of the Pt wire (R).

$$(\Delta T / I_c{}^2 R) = \frac{A}{\lambda} + B \tag{4}$$

A and B in Eq. (4) are essentially constants that depend on the dimensions and construction material of the thermal conductivity cell. Equation (4) can be rearranged to solve for the thermal conductivity if the change in temperature per change in applied current is known.

$$\frac{1}{\lambda} = \frac{(\Delta T / I_c{}^2 R)}{A} - \frac{B}{A} \tag{5}$$

To determine the absolute values of the cell constants (A and B), eight different calibration liquids were used. Figure 3 shows a plot of the temperature as a function of the applied current for water. The slope ($\Delta T/I^2R$) was determined to be ($\Delta T/I^2R = 20.95 \pm 0.16$ K A^{-2} Ω^{-1}). The change in temperature with applied current of eight different liquids (as listed in the experimental section) with known thermal conductivities was measured in the same experimental apparatus. The thermal conductivities used for the calibration curve are listed in Table 1. Figure 4 shows a plot of the inverse of thermal

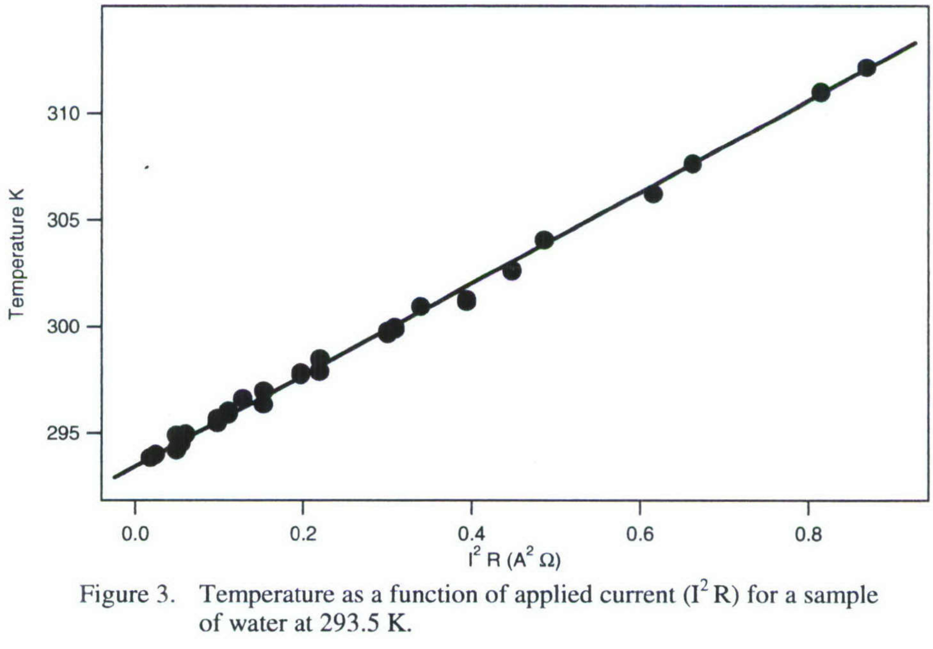

Figure 3. Temperature as a function of applied current (I^2 R) for a sample of water at 293.5 K.

Table 1. Thermal Conductivity ($Wm^{-1}°C^{-1}$) at 293.5K of the Eight Liquids Used to Calibrate the Thermal Conductivity Cell

Substance	λ literature[4,7]	λ From calibration curve
Water	0.5973	0.635 ± (0.046)
Methanol	0.2038	0.198 ± (0.015)
Acetonitrile	0.1900	0.181± (0.014)
Acetone	0.1667	0.162 ± (0.012)
Dimethyl Phthalate	0.1479	0.157 ± (0.012)
2-Propanol	0.1361	0.133 ± (0.010)
Chloroform	0.1180	0.123 ± (0.009)
Carbon Tetrachloride	0.1044	0.103 ± (0.008)

Error is 2 standard deviations from the fit.

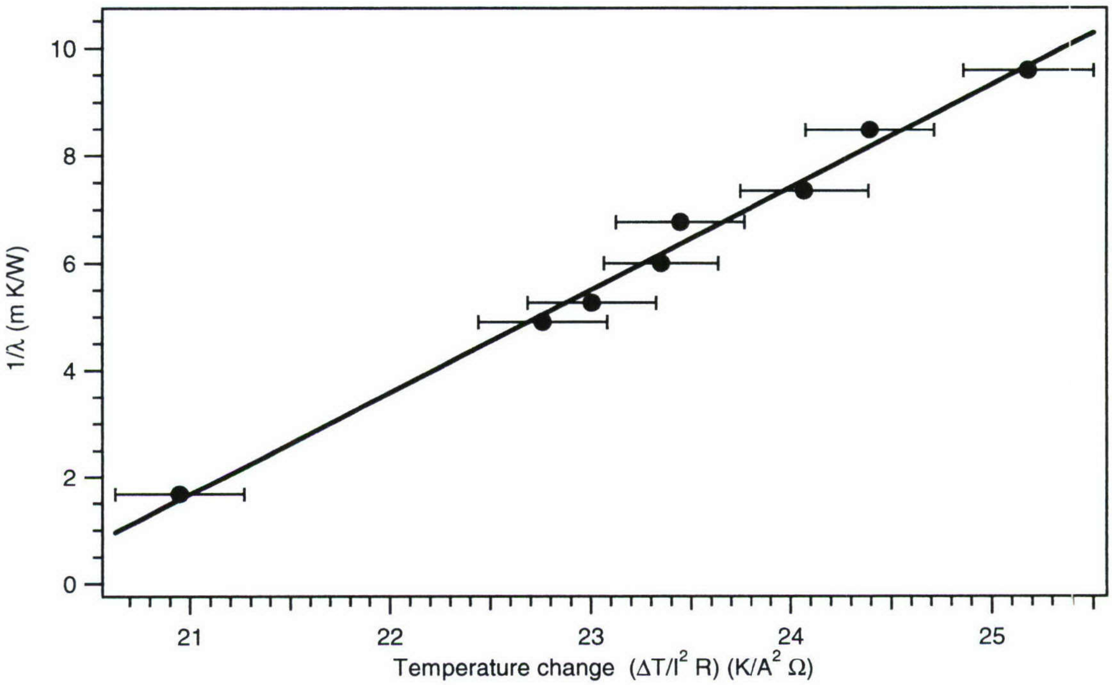

Figure 4. Inverse of the thermal conductivity ($1/\lambda$) of the calibration liquid in the thermal conductivity cell as a function of the measured change in temperature for an applied current ($\Delta T/I^2R$).

conductivity ($1/\lambda$) versus ($\Delta T/I^2R$) for the eight calibration liquids. The values are an average of 5 to 8 measurements for each data point. The A value was found to be ($A = 1.91 \pm 0.08\ Wm^{-1}A^{-2}\Omega^{-1}$) and the B/A value was found to be ($B/A = -38. \pm 2.\ W^{-1}mK$). The best fit to the calibration curve can be used to determine the thermal conductivity of the eight calibration solutions from their measured ($\Delta T/I^2R$) by using Eq. (5). Table 1 shows the thermal conductivity predicted for the eight calibration liquids determined from the calibration curve. There is an average error of 8% from the known literature values.

Figure 5 shows a plot of the temperature as a function of the applied current for eight separate measurement runs of pure hydrazine. The slope was found to be $\Delta T/I^2R = 21.8 \pm 0.2\ KA^{-2}\Omega^{-1}$. The thermal conductivity was found to be $\lambda = 0.32 \pm 0.03\ Wm^{-1}{}^{\circ}C^{-1}$ at 293.15K and 0.101 MPa by using the A and B coefficients and Eq. (4).

Figure 6 shows a plot of the thermal conductivity of liquid hydrazine at 293.15K as a function of the helium pressure. The values plotted in Figure 6 are listed in Table 2. Also shown on Figure 6 is the values obtained from the function of thermal conductivity versus pressure from Safarov and Zaripova.[3] Safarov and Zaripova[3] found that the pressure dependence of the thermal conductivity (in $Wm^{-1}{}^{\circ}C^{-1}$) followed the following function:

$$\lambda_{P,T_1} = [(8.33\times10^{-2}\frac{P}{P_1}) + .917]\times(-8.052\times10^{-5}T_x^2 + 4.943\times10^{-2}T_x - 6.7)\,, \quad (6)$$

where P is the pressure of interest, P_1 is 29.43×10^6 Pa and T_x is the boiling temperature. A linear fit to the current data yields the thermal conductivity ($Wm^{-1}K^{-1}$) as a function of pressure shown in Eq. (7).

$$\lambda = 0.329 + 1.1215\times10^{-9}\,P \quad (7)$$

The thermal conductivity was observed to vary little over the pressure range of the experiment.

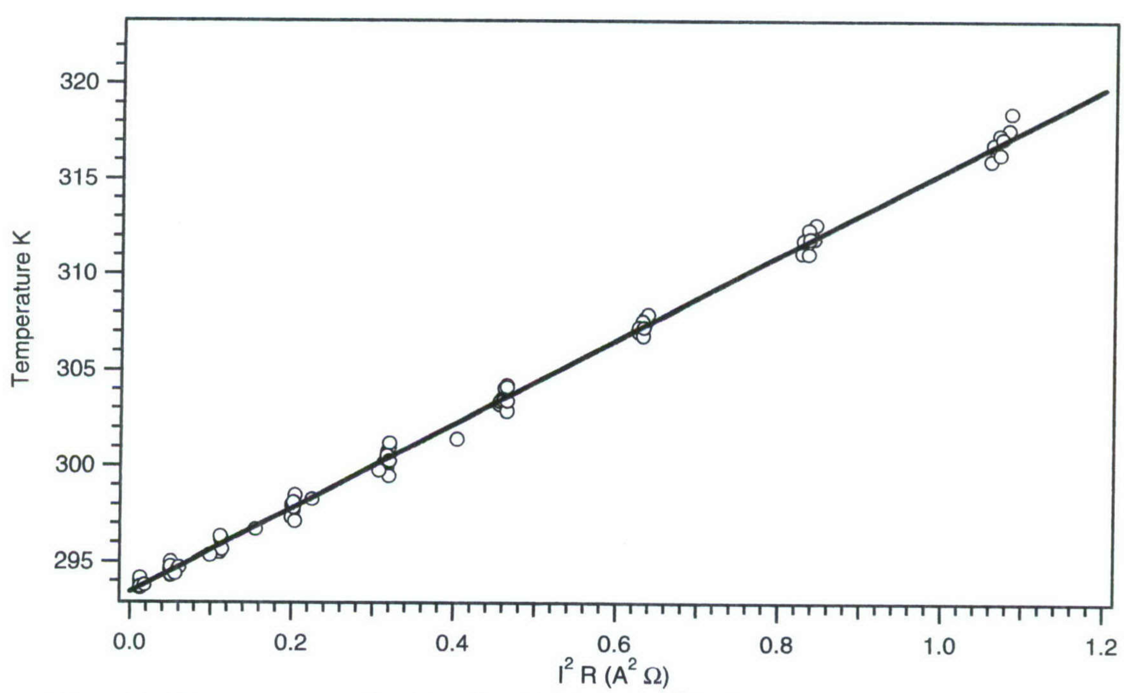

Figure 5. Temperature as a function of applied current (I^2R) for hydrazine at 293.5K. The figure is for the cumulative data for eight separate hydrazine sample runs.

Table 2. Measured Thermal Conductivity ($Wm^{-1}K^{-1}$) at 293.5K of Liquid Hydrazine at Several Different Pressures

Pressure (Mpa)	Pressure (psi)	λ ($W\ m^{-1}\ K^{-1}$)
0.101353	14.7	0.333
0.101353	14.7	0.331
0.101353	14.7	0.334
0.101353	14.7	0.324
0.379212	55	0.337
0.379212	55	0.330
0.482633	70	0.332
0.482633	70	0.321
0.689476	100	0.344
0.689476	100	0.318
0.896318	130	0.323
0.896318	130	0.316
0.965266	140	0.343
1.172109	170	0.328
1.172109	170	0.319
1.378951	200	0.339
1.378951	200	0.317
1.585794	230	0.327
1.585794	230	0.329
1.792637	260	0.336
1.792637	260	0.330
2.068427	300	0.339
2.068427	300	0.333

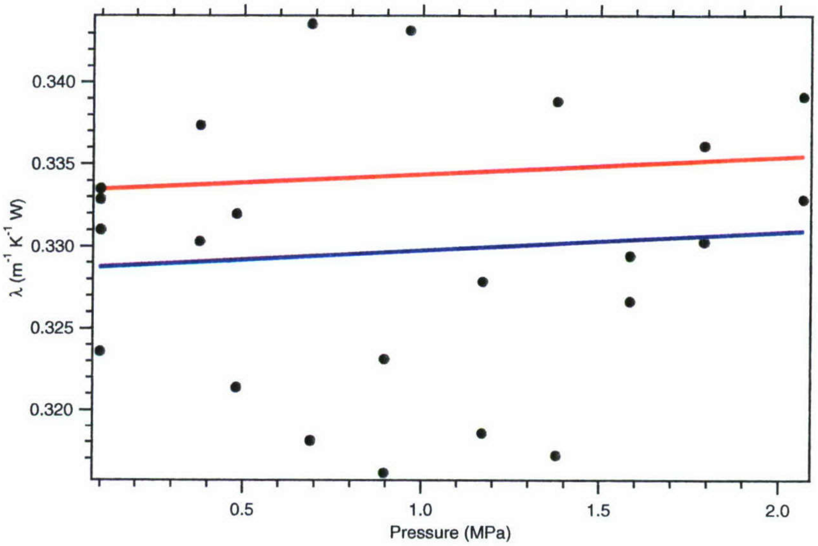

Figure 6. Thermal conductivity (λ) as a function of helium pressure. Closed circles represent current experimental measurements. The red line represents predictions based on Eq. (6). The blue line represents a linear fit of the current experimental results shown in Eq. (7).

Figure 7 shows the amplitude of the frequency spectrum obtained by the receiver transducer with water or hydrazine in the 1-cm-pathlength quartz cell for the speed of sound measurements. The measured speed of sound of several substances determined by Eq. (3) is shown in Table 3. The average speed of sound in liquid hydrazine at 293.15K from the two containers was found to be 2092±12 m s^{-1}. This number is in agreement with previous experimental measurements. The low value observed by Gibek and Maisonneuve could not be reproduced here.

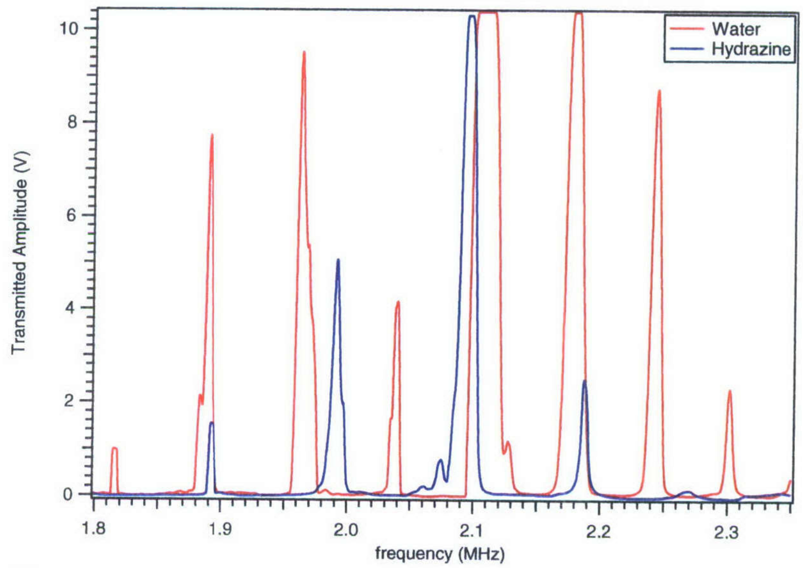

Figure 7. Frequency resonance spectrum for water (red) and hydrazine (blue) in a quartz cell (L= 1.0 cm).

Table 3. Speed of Sound at 293.15K Determined by Eq. (3) for Several Different Liquids and the Two Different Sample Cells

Liquid measured	Speed of sound, 1 cm cell (m s^{-1})	Speed of sound, 3.5 cm cell (m s^{-1})	Literature number[8,15,16,17] (m s^{-1})
Water	1483	1483	1483
Methanol	1109	1103	1121
2-Propanol	1181		1156
Acetone	1208	1136	1203
Tetrachloromethane	938		937
Hydrazine	2083	2102	2093

4. Discussion

The current measurement is in good agreement with the previous determination of Safarov and Zaripova.[3] The current measurement is also in good agreement with the value found in the *Chemical Properties Handbook*.[4] Figure 8 shows a plot of the known measurements of pure hydrazine with the present determination included. Also shown is the thermal conductivity of several similar nitrogen-based liquids (ammonia,[4] MMH,[9,18] UDMH,[9,18] and phenylhydrazine[19] (90% in water). Figure 8 shows a general trend of decreasing thermal conductivity in these ammonia-like compounds with increased substitution. Non-substituted ammonia (NH_3) has the highest thermal conductivity, followed by hydrazine (N_2H_4), mono-substituted hydrazine (CH3N2H3) and finally di-substituted hydrazine ($CH_3NHNHCH_3$). Contamination with water in some of the samples in Figure 8 complicates the picture somewhat. The thermal conductivity of pure phenylhydrazine is most likely lower than the measurement since the measurement was done with 10% water added since water has a large thermal conductivity compared to most organic liquids near 293.15K.

Safarov and Zaripova[3] observed an increase in the thermal conductivity of liquid hydrazine with increased water content (from 10–70% water, which corresponded to $\lambda = 0.395$ $Wm^{-1}{}^{\circ}C^{-1}$ and λ =0.499 $Wm^{-1}{}^{\circ}C^{-1}$, respectively, at 29.43×10^6 Pa). In this current study, several samples were measured with 20% water (by volume) added to the pure hydrazine. The addition of 20% water

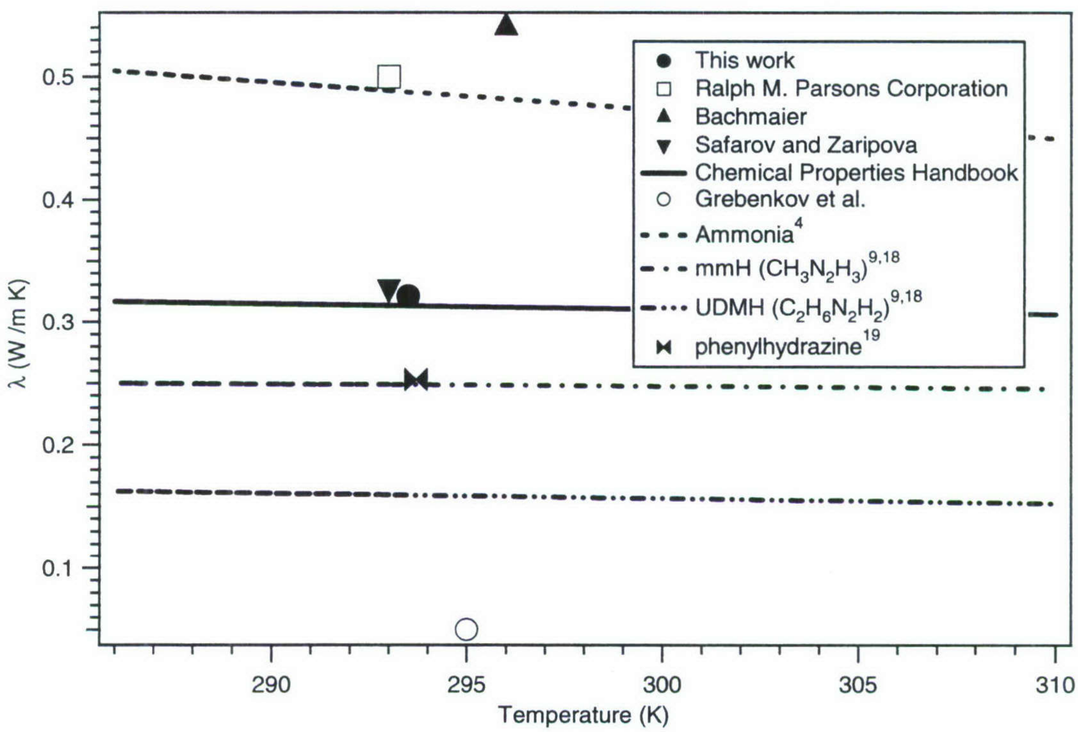

Figure 8. Thermal conductivity of hydrazine compared to other similar nitrogen compounds.

increased the thermal conductivity of the sample to 0.41±0.03 $Wm^{-1}{}^{\circ}C^{-1}$ at 0.101×10^6 Pa. This current observed value is in agreement with the previous measurements from Safarov and Zaripova. Thus, the 5% impurity of water alone is not sufficient to explain the higher values obtained by the Ralph M. Parsons Corporation. There is no explanation for the low value obtained by Grebenkov et al.

The effect of pressure on thermal properties is very low in condensed substances. In general, thermal conductivity is increased slightly with increased pressure.[7,20–22] The results of the current experiment were consistent with this observation. As seen in Figure 6, there is good agreement between the observed pressure dependence and the pressure dependence previously observed by Safarov and Zaripova.[3] The pressure dependence observed in the current experiment is similar to that observed by Grebenkov et al., but Grebenov experimental values are almost an order of magnitude less than accepted values for the thermal conductivity of liquid hydrazine. The pressure is seen to have little effect on the thermal conductivity of water, ammonia, and hydrazine over the pressure range of the current experiment. Under the pressure range typical of on-orbit storage of hydrazine, the thermal conductivity should not change significantly.

Table 4 shows the calculated thermal conductivity of several pure liquids used in this study for which the speed of sound in the medium is well known.[8,9,11,15–17] The speed of sound in hydrazine, MMH and UDMH, were previously measured by Kretschmar (c_N = 2093 m s^{-1} (N_2H_4), c_N = 1548 m s^{-1} (MMH), c_N = 1247 m s^{-1} (UDMH)) at 293.15K. As seen in Table 4, the modified Bridgman equation yields reasonable estimates of the thermal conductivity for all liquids studied in this experiment (an average of 20% error) except hydrazine. Hydrazine has an estimated value of nearly double the measured value. The modified Bridgman equation suggests the older measurements of thermal conductivity are correct. Even though these older measurements have ~5% water added, which most likely somewhat increased the thermal conductivity measured. The current results suggest that the Bridgman equation does a particularly poor job of determining the thermal conductivity of hydrazine. Equations that estimate the speed of sound based on thermo-chemical properties of the liquid often have higher errors when the liquid has strong intermolecular bonding.[7]

The speed of sound (a_N) in a fluid can be calculated by using the parameters from the equation of state.[23–25]

Table 4. Thermal Conductivity ($Wm^{-1}{}^{\circ}C^{-1}$) Calculated by Eq. (1) at 293.15K

Substance	Calculated λ	Literature λ	% difference
Water	0.601	0.597	0.7
Methanol	0.262	0.204	28.4
Acetone	0.189	0.167	13.2
Chloroform	0.151	0.118	28.0
Carbon Tetrachloride	0.123	0.104	18.3
2-propanol	0.177	0.136	30.1
Hydrazine	0.575	0.32	79.7
MMH	0.298	0.249	19.7
UDMH	0.189	0.159	18.9

$$c_N = (-\upsilon^2 (\frac{\partial P}{\partial T})_T)^{0.5} \quad (8)$$

An accurate value for the compressibility factor ($P \upsilon / RT$) of hydrazine is needed to determining correct speed of sound values from the equations of state. The critical temperature and critical pressure of hydrazine are 653.15K and 14.69 MPa. The critical volume is less well known with $\upsilon_c = 3.155$ m^3kg^{-1}, $\upsilon_c = 3.740$ m^3kg^{-1} and $\upsilon_c = 4.323$ m^3kg^{-1}previously used.[24–28] Using the value found in Giordano and Serio[24] ($\upsilon_c = 3.740$ m^3kg^{-1}) a speed of sound of $c_N = 1830$ m s^{-1} was obtained from the Giordano and Serio equation of state. Using the value found in Barragan et al.[25] ($\upsilon_c = 3.710$ m^3kg^{-1}), a speed of sound of $c_N = 1430$ m s^{-1} was obtain from the Giordano and Serio equation of state. This value is slightly lower than the speed of sound obtain from the Barragan et al. equation of state, $c_N =$ 1495 m s^{-1}. The critical volume value of Giordano and Serio only has to be changed by 0.4% ($\upsilon_c =$ 3.755 m^3kg^{-1}) to match the experimental values of $c_N = 2090$ m s^{-1}at 293.15K from the Giordano and Serio equation of state. This demonstrates how sensitive the equations of states are to the critical volume value when determining accurate speed of sound numbers. In processes where the speed of sound is a critical value, such as modeling the waterhammer effect, this dependence should be noted.

5. Conclusion

The thermal conductivity of hydrazine was measured by using the steady-state hot-wire method. The current measurement is consistent with one previous measurement as well as the recommended value in the *Chemical Properties Handbook*. Older measurements that contained 5% water are consistent with the estimated thermal conductivity estimated by using the speed of sound in hydrazine. The modified Bridgman equation was found to be inappropriate for estimating the thermal conductivity of hydrazine. Given the importance of the thermal conductivity, a more modern measurement by transient hot-wire method that included temperature dependence would be appropriate. A measurement of the thermal conductivity of hydrazine as a function pressure by the transient hot-wire method demonstrates that pressures normal to on-orbit storage do not change the thermal conductivity much.

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