JOURNAL OF
CHEMICAL &
ENGINEERING
DATA

ARTICLE

pubs.acs.org/jced

Density and Speed of Sound Measurements of Two Synthetic Aviation Turbine Fuels

Stephanie L. Outcalt* and Tara J. Fortin

Material Measurement Laboratory Thermophysical Properties Division, Experimental Properties of Fluids Group, National Institute of Standards and Technology, 325 Broadway, Boulder, Colorado 80305-3337, United States

ABSTRACT: Rising costs and the uncertain supply of petroleum-derived aviation fuels have led to an interest in substitute fuels made from nonpetroleum sources. Synthetic isoparaffinic kerosenes (SPKs) are among the most promising alternatives. Two instruments were used to measure the density and speed of sound of two synthetic aviation fuels, one derived from natural gas and one from coal. In one instrument, measurements of density and speed of sound were carried out at ambient pressure (0.083 MPa) from (278.15 to 343.15) K. The second instrument was used to make density measurements of the compressed liquids from (270 to 470) K with pressures up to 50 MPa. The density measurements are correlated within 0.1 % with a modified Tait equation, and adiabatic compressibilities are derived from the density and speed of sound data at ambient pressure. Data reported here are compared to previously reported data for another synthetic aviation fuel, S-8, as well as two petroleum-derived aviation fuels.

1. INTRODUCTION

In the early to mid 1900's, there was a large increase in the demand for fuel in Germany. This was predominantly the result of the large quantities of fuel being used by the German military.[1] During this time, a lack of native petroleum sources combined with an abundance of coal in Germany led Franz Fischer and Hans Tropsch to invent the Fischer–Tropsch (FT) process to convert a synthesis gas (carbon monoxide and hydrogen) into liquid hydrocarbons utilizing coal as a feed stock. The synthesis of hydrocarbons from mixtures of CO and H_2, commonly referred to as the Fischer–Tropsch process, was the object of a comprehensive study by the U.S. Naval Technical Mission in Europe's Petroleum Group in Germany from April through June in 1945. This study disclosed that the process was of secondary importance in the German fuel economy, producing 9.1% of the total German oil supply, but because of a shortage of all types of hydrocarbons the Germans took advantage of the high cetane number (90 to 100) of the FT fuel, adding it to diesel fractions from coal tars with cetane numbers of 10 to 15 and thus increasing their production of 40 to 50 cetane diesel oil.[2] Many refinements and adjustments have been made to the original Fischer–Tropsch process, and it can now be carried out using synthesis gas derived from feedstocks other than coal, for example, natural gas or biomass.[1]

In recent years, the United States and other countries have found themselves in a situation similar to that of Germany in the early to mid 1900s, particularly as it pertains to aviation fuel; demand for fuel is high as are prices, but supply lines are at risk, and the traditional petroleum feedstock may not be available in sufficient quantities within the countries' own borders. Viable alternatives to traditional turbine fuels include the class of fluids known as synthetic paraffinic kerosenes (SPKs).[3,4] SPK fuels are commonly produced via a Fischer–Tropsch process and can make use of feedstocks that are local, less expensive, and more environmentally friendly than petroleum.

The measurements reported here are part of a comprehensive project to characterize aviation fuels and rocket propellants.[5] Tabulated results of density and speed of sound measurements for the two SPKs, one derived from coal and one derived from natural gas, are given. Density is an important fuel parameter directly related to aircraft range.[6] The speed of sound is required in some aircraft fuel gauging systems for operation. Adiabatic compressibilities have been derived from the ambient pressure density and speed of sound data and are also included in the tables. The bulk modulus (the inverse of adiabatic compres-

Table 1. Four Major Components (by Area %) of the CTL, GTL, and S-8 Fuel Samples

component	CAS no.	area percentage
	CTL Fuel	
2,5,6-trimethyl octane	62016-14-2	5.3
x-methyl decane[a]	N/A	3.2
2,3-dimethyl octane	7146-60-3	2.9
3,7-dimethyl nonane	17302-32-8	2.8
	GTL Fuel	
n-decane	124-18-5	14.5
2-methyl nonane	871-83-0	12.3
n-nonane	111-84-2	10.4
2-methyl decane	6975-98-0	8.2
	S-8 Fuel	
n-dodecane	112-40-3	2.6
4-methyl octane	2216-34-4	2.5
n-undecane	1120-21-4	2.4
n-decane	124-18-5	2.1

[a] Note that it is not always possible to determine the position of the methyl substitution, and in these instances the position is indicated with an "*x*".

Received: March 22, 2011
Accepted: June 6, 2011
Published: June 29, 2011

Table 2. Density, Speed of Sound, Adiabatic Compressibility, and Bulk Modulus of the CTL and GTL Samples Measured in the Density and Sound Speed Analyzer[a]

	CTL				GTL			
temperature T	density ρ (± 0.06)	speed of sound w	adiab. compressibility κ_S	bulk modulus	density ρ (± 0.06)	speed of sound w (± 0.5)	adiab. compressibility κ_S	bulk modulus
K	$\mathrm{kg \cdot m^{-3}}$	$\mathrm{m \cdot s^{-1}}$	$\mathrm{TPa^{-1}}$	$\mathrm{N \cdot m^{-2}}$	$\mathrm{kg \cdot m^{-3}}$	$\mathrm{m \cdot s^{-1}}$	$\mathrm{TPa^{-1}}$	$\mathrm{N \cdot m^{-2}}$
278.15	766.24	1315.3 ± 1.4	754.4	1.33	743.90	1310.3	782.9	1.28
283.15	762.54	1294.2 ± 1.2	783.0	1.28	740.13	1289.5	812.6	1.23
288.15	758.85	1273.2 ± 1.0	812.9	1.23	736.35	1268.7	843.7	1.19
293.15	755.14	1252.5 ± 0.8	844.2	1.18	732.57	1248.0	876.4	1.14
298.15	751.43	1232.1 ± 0.6	876.6	1.14	728.78	1227.6	910.5	1.10
303.15	747.72	1212.0 ± 0.6	910.4	1.10	724.98	1207.4	946.1	1.06
308.15	743.99	1192.2 ± 0.5	945.7	1.06	721.16	1187.4	983.5	1.02
313.15	740.26	1172.6 ± 0.5	982.5	1.02	717.34	1167.6	1022.6	0.98
318.15	736.51	1153.2 ± 0.5	1020.9	0.98	713.50	1147.9	1063.7	0.94
323.15	732.76	1134.1 ± 0.5	1061.1	0.94	709.65	1128.3	1006.9	0.90
328.15	728.99	1115.1 ± 0.5	1103.1	0.91	705.78	1108.9	1152.2	0.87
333.15	725.21	1096.4 ± 0.5	1147.1	0.87	701.89	1089.8	1199.7	0.83
338.15	721.42	1077.8 ± 0.5	1193.2	0.84	697.99	1070.9	1249.3	0.80
343.15	717.61	1059.5 ± 0.5	1241.4	0.81	694.07	1052.3	1301.0	0.77

[a] Ambient pressure during the measurements was approximately 0.083 MPa.

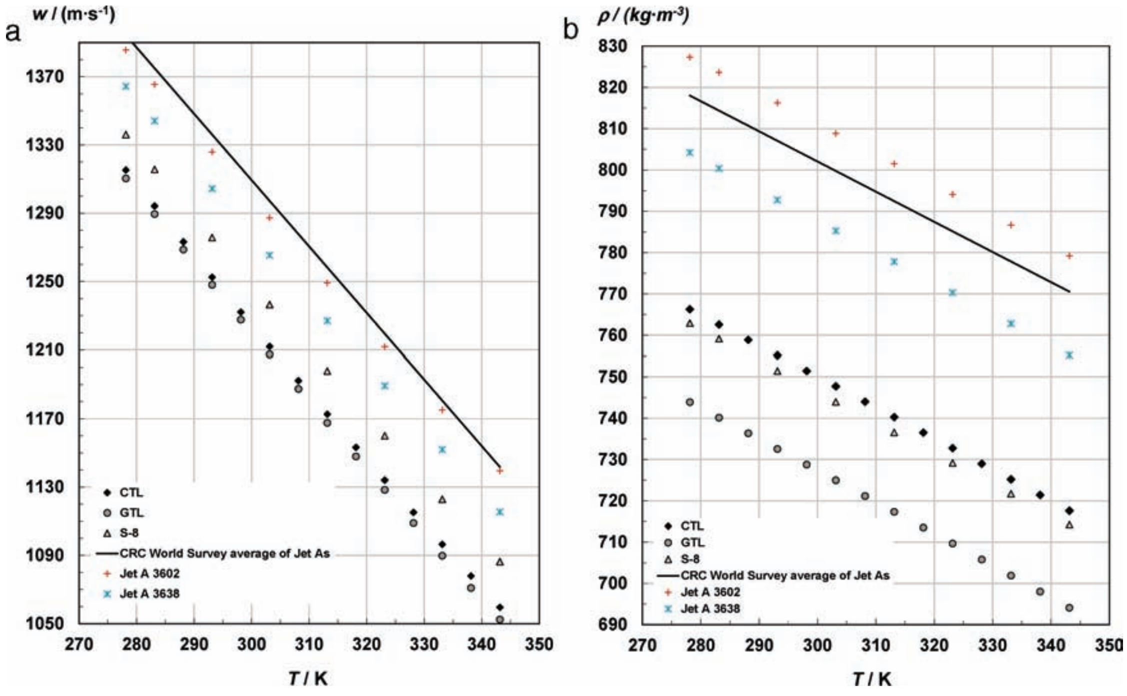

Figure 1. Measured (a) speed of sound data and (b) density data of the CTL and GTL samples, S-8, and two Jet As as a function of temperature at an ambient pressure of 0.083 MPa.

sibility) is a common property used in engineering calculations and thus has also been derived from the ambient pressure speed of sound and density measurements and is reported. Data for compressed liquid density have been extrapolated to 0.083 MPa and combined with ambient pressure density data to correlate a Rackett equation for density. Additionally, the compressed-liquid density data have been correlated with a Tait equation. Parameters for all of the correlations are reported. The newly presented data are compared with previously measured data on petroleum-derived Jet As and S-8,[7] which is perhaps the best known synthetic aviation fuel.[8−10] Data reported here greatly extend the amount of available data on synthetic aviation fuels. These data are critical for the development of accurate equations of state and provide information for basic engineering calculations.

Table 3. Compressed Liquid Densities of the GTL Sample Measured in the High-Pressure Vibrating-Tube Densimeter along Isotherms from (310 to 470) K[a]

270 K		290 K		310 K		330 K		350 K		370 K	
pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ
MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}
50.04	778.2	50.00	765.9	50.02	753.9	49.99	742.1	50.03	730.5	50.02	718.9
40.01	773.2	40.01	760.5	40.00	748.1	40.01	735.8	40.01	723.7	40.00	711.6
30.01	767.9	30.01	754.7	30.01	741.8	30.01	729.0	30.00	716.3	30.01	703.6
20.00	762.3	20.01	748.5	20.01	735.0	20.00	721.5	20.01	708.1	20.00	694.6
10.00	756.2	10.00	741.8	10.00	727.5	10.01	713.3	10.01	698.9	10.00	684.4
5.00	753.0	5.00	738.2	5.00	723.5	5.00	708.8	5.00	693.9	5.01	678.7
4.01	752.3	4.00	737.5	4.01	722.7	4.00	707.8	4.00	692.8	4.01	677.5
3.00	751.6	3.01	736.7	3.01	721.8	3.01	706.9	3.01	691.7	3.00	676.2
2.00	751.0	2.01	735.9	2.00	721.0	2.00	705.9	2.01	690.6	2.01	675.0
1.00	750.3	1.00	735.2	1.00	720.1	1.00	704.9	1.00	689.5	1.00	673.7
0.50	749.9	0.50	734.8	0.50	719.7	0.50	704.4	0.50	688.9	0.50	673.0
0.083	*749.7*	*0.083*	*734.4*	*0.083*	*719.3*	*0.083*	*704.0*	*0.083*	*688.4*	*0.083*	*688.4*

390 K		410 K		430 K		450 K		470 K	
pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ
MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}	MPa	kg·m^{-3}
50.01	707.4	50.02	696.0	50.01	684.8	50.01	673.6	50.03	662.8
40.01	699.5	40.01	687.5	40.00	675.7	40.01	663.9	40.01	652.3
30.00	690.8	30.00	678.0	30.00	665.5	30.00	652.7	30.00	640.2
20.01	681.0	20.00	667.2	20.00	653.6	20.00	639.7	19.99	625.8
10.01	669.6	10.01	654.5	10.01	639.3	10.00	623.6	10.01	607.8
5.00	663.0	5.00	647.0	5.01	630.8	5.01	613.8	5.00	596.4
4.00	661.7	4.01	645.4	4.00	628.9	4.00	611.6	3.99	593.8
3.00	660.2	3.00	643.8	3.00	627.0	3.00	609.3	3.00	591.1
2.01	658.8	2.01	642.1	2.01	625.1	2.00	607.0	2.01	588.3
1.00	657.3	1.00	640.4	1.00	623.0	1.01	604.6	1.00	585.3
0.50	656.5	0.50	639.5	0.50	621.9	0.50	603.3	0.50	583.7
0.083	*655.9*	*0.083*	*638.7*	*0.083*	*621.1*	*0.083*	*602.3*	*0.083*	*582.5*

[a] Values extrapolated to 0.083 MPa are indicated in *italics*.

2. SAMPLE LIQUIDS

The two samples measured in this work were provided by the Propulsion Directorate of the Air Force Research Laboratory, Wright-Patterson AFB, Ohio. A detailed discussion of composition and distillation curves for each of the samples is described in Bruno et al.[11] The two samples were designated as CTL (coal to liquid) and GTL (gas to liquid) and will be referred to as such from here forward. In general, CTL SPKs are typically predominantly iso-paraffins while GTL SPKs have much greater amounts of normal paraffins.[3] The samples measured in this work, were analyzed by gas chromatography (30 m capillary column of 5 % phenyl−95 % dimethyl polysiloxane having a thickness of 1 μm, flame ionization detection and mass spectrometric detection). Table 1 lists the four major components (by area %) that were detected for the GTL and CTL samples, as well as for a previously studied S-8 sample.[7,8,11] The GTL sample had as its four major components (by area percent): *n*-decane, 2-methyl nonane, *n*-nonane, and 2-methyl decane. These four components made up 45.4 % of the total peak area and are either straight chain hydrocarbons or straight chains with one methyl branch. The CTL sample exhibited a distribution of the primary components very different from GTL. By area percent, 2,5,6-trimethyl octane, *x*-methyl decane, 2,3-dimethyl octane, and 3,7-dimethyl nonane were the four major components, but combined, they account for only 14.2 % of the total peak area of the sample.[11] Only one of these components is a straight-chain hydrocarbon, while the rest are branched with at least two methyl side groups. For comparison, the previously studied S-8 sample had *n*-decane, 4-methyl octane, *n*-undecane, and *n*-decane as its four major components, and these four components made up just 9.6 % of the total peak area.[8] These fuels are thus complex mixtures and are not only the result of the starting materials used to produce them, but also production variables (i.e., catalyst type and process temperatures).

3. EXPERIMENTAL SECTION

A commercial density and sound speed analyzer was used to measure these properties at ambient pressure (0.083 MPa). Details of the instrument and experimental procedures have been reported in Laesecke et al.,[12] and thus only a brief descrip-

Table 4. Compressed Liquid Densities of the CTL Sample Measured in the High-Pressure Vibrating-Tube Densimeter along Isotherms from (310 to 470) K[a]

270 K		290 K		310 K		330 K		350 K		370 K	
pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ
MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$
50.05	800.6	50.01	788.6	50.01	777.1	50.00	765.4	50.00	753.8	50.01	742.5
40.01	795.7	40.00	783.3	40.01	771.4	40.00	759.3	40.01	747.2	40.01	735.3
30.01	790.5	30.01	777.6	30.00	765.2	30.00	752.6	30.01	739.9	30.01	727.5
20.00	784.9	20.00	771.5	19.99	758.5	20.00	745.3	20.00	732.0	20.00	718.8
10.00	779.0	10.01	764.9	10.00	751.3	10.00	737.2	10.01	723.0	10.00	708.8
5.00	775.8	5.00	761.3	5.00	747.3	5.01	732.8	5.00	718.1	5.01	703.3
4.01	775.2	4.00	760.6	4.01	746.5	4.00	731.9	4.00	717.0	4.00	702.1
3.01	774.5	3.00	759.9	3.01	745.7	3.00	731.0	3.00	716.0	3.01	701.0
2.00	773.8	2.00	759.1	2.00	744.8	2.00	730.0	2.02	714.9	2.01	699.7
1.00	773.2	1.00	758.4	1.01	744.0	1.00	729.1	1.00	713.8	1.00	698.5
0.51	772.8	0.50	758.0	0.50	743.6	0.51	728.6	0.50	713.3	0.50	697.8
0.083	*772.5*	*0.083*	*757.7*	*0.083*	*743.2*	*0.083*	*728.2*	*0.083*	*712.8*	*0.083*	*697.3*

390 K		410 K		430 K		450 K		470 K	
pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ	pressure p	density ρ
MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$	MPa	$kg\cdot m^{-3}$
50.01	731.3	50.00	720.1	49.99	709.2	50.01	698.4	50.02	687.7
40.00	723.6	40.00	711.9	40.00	700.3	40.00	688.9	40.00	677.5
30.02	715.2	30.01	702.7	30.00	690.3	30.00	678.1	30.01	665.8
20.01	705.6	20.00	692.2	19.99	678.8	20.00	665.4	20.00	652.0
10.01	694.6	10.00	679.9	10.01	665.1	9.99	650.0	10.01	634.7
5.00	688.3	5.01	672.8	5.00	656.9	5.00	640.7	5.01	623.9
4.00	686.9	4.00	671.2	4.01	655.2	4.01	638.7	4.00	621.5
3.00	685.5	3.01	669.6	3.00	653.3	3.01	636.5	3.01	619.0
2.00	684.1	2.00	668.0	2.01	651.5	2.00	634.3	2.00	616.4
1.01	682.7	1.00	666.4	1.00	649.5	1.00	632.0	1.01	613.6
0.50	682.0	0.50	665.5	0.50	648.5	0.50	630.8	0.50	612.2
0.083	*681.3*	*0.083*	*664.8*	*0.083*	*647.7*	*0.083*	*629.8*	*0.083*	*611.0*

[a] Values extrapolated to 0.083 MPa are indicated in *italics*.

Table 5. Rackett Correlation Parameters for the Density of the CTL and GTL Samples at an Ambient Pressure of 0.083 MPa and Temperatures from (270 to 470) K

	CTL		GTL	
parameter	value	std. dev.	value	std. dev.
$\beta_1/kg\cdot m^{-3}$	263.846	0.045	250.281	0.026
β_2	0.524 308	$4.3\cdot 10^{-5}$	0.515 106	$2.6\cdot 10^{-5}$
β_3/K	542.366	0.026	530.023	0.015
β_4	0.596 694	$6.9\cdot 10^{-5}$	0.596 018	$4.4\cdot 10^{-5}$

tion will be given here. The instrument contains a sound speed cell and a vibrating quartz tube densimeter in series. The temperature is measured with an integrated Pt-100 thermometer with an estimated uncertainty of 0.01 K. The instrument was calibrated with deionized water and toluene over the entire temperature range. During measurements temperature scans were programmed from (343 to 278) K in decrements of 5 K. Fresh samples of test liquids were injected for each temperature scan instead of performing repetitive measurements on the same sample. At least four temperature scans were performed for each test liquid. For measurements reported here, the expanded relative uncertainty ($k\sim 2$) is ± 0.01 % for density and ranges from ± 0.04 % to ± 0.1 % for speed of sound.

The densities of the compressed test liquids were measured with the automated densimeter of Outcalt and McLinden.[13] Central to the apparatus is a commercial vibrating-tube densimeter. Several physical and procedural improvements have been implemented beyond that of the commercial instrument operated in a stand-alone mode to minimize the uncertainty in the measurements. Some of these improvements include more accurate measurements of temperature and pressure, better temperature control, and complete automation of the instrument control and data acquisition. The temperature range of the instrument is (270 to 470) K with pressures up to 50 MPa. In this work, we measured 11 isotherms over the range (0.5 to 50) MPa for each of the samples. The

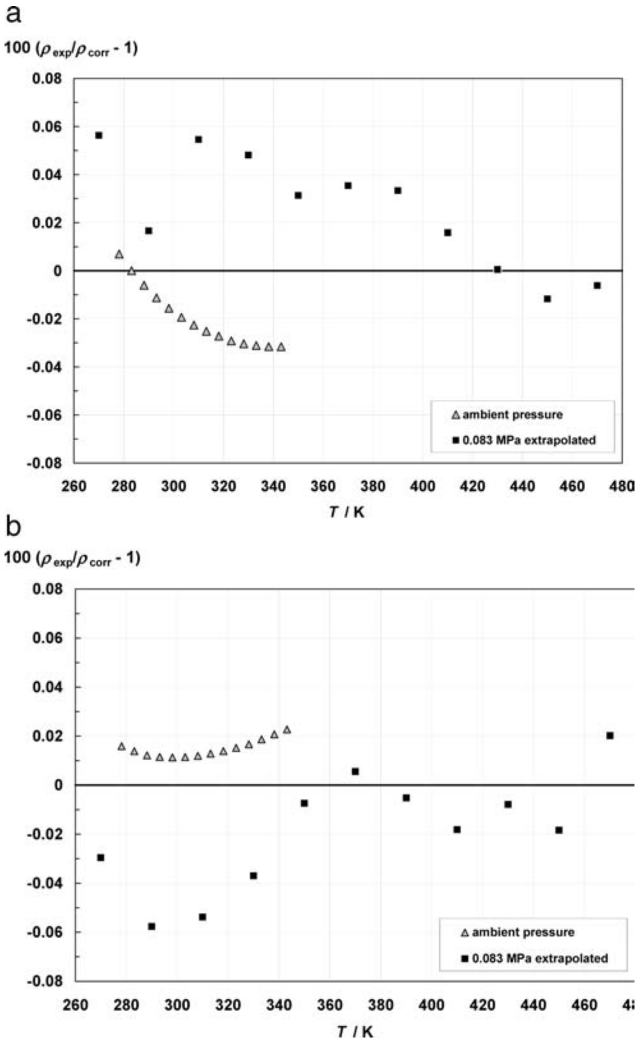

Figure 2. Deviations of measured and extrapolated ambient pressure density data of the (a) CTL sample and (b) GTL sample from the Rackett correlation.

Table 6. Tait Correlation Parameters for the Density of the CTL and GTL Samples in Terms of Temperature and Pressure

	CTL		GTL	
parameter	value	std. dev.	value	std. dev.
C	$80.473 \cdot 10^{-3}$	8.7×10^{-5}	$84.305 \cdot 10^{-3}$	$9.4 \cdot 10^{-5}$
$\beta 5$	288.90	0.46	313.63	0.50
$\beta 6$	−264.69	0.51	−295.12	0.57
$\beta 7$	61.90	0.16	70.83	0.17

instrument was calibrated with propane and toluene over the entire temperature and pressure range. The overall uncertainty ($k = 2$) in density is at most 0.81 $\text{kg} \cdot \text{m}^{-3}$ corresponding to a relative uncertainty in density of 0.14 %.

4. RESULTS

Table 2 lists values of density, speed of sound, and derived adiabatic compressibilities for the GTL and CTL samples at ambient pressure from (278.15 to 343.15) K. Adiabatic compressibilities were calculated from the measured densities and speeds of sound via the thermodynamic relation

$$\kappa_S = -(\partial V/\partial p)_S/V = 1/(\rho w^2) \tag{1}$$

where V denotes volume, p is pressure, ρ is the density, and w the speed of sound. The subscript S indicates "at constant entropy". The bulk modulus of a fluid is the inverse of the adiabatic compressability. Bulk modulus values are often found in engineering applications and thus are also listed in Table 2. The data for the speed of sound and ambient density are depicted graphically in Figure 1 parts a and b, respectively. In both figures, the height of the symbols is approximately representative of the uncertainty in the measurement of density. The values for S-8 and two other petroleum-derived Jet As as reported in Outcalt et al.[7] are shown for comparison as well as the CRC World Survey[14] average of Jet As. It can be seen in Figure 1a,b that the speeds of sound of the CTL and GTL at ambient pressure are quite similar (differing by 0.4 % to 0.7 %, or 0.5 % on average), while the densities at atmospheric pressure differ by approximately 3 %. Figure 1b shows that the CTL and S-8 densities are

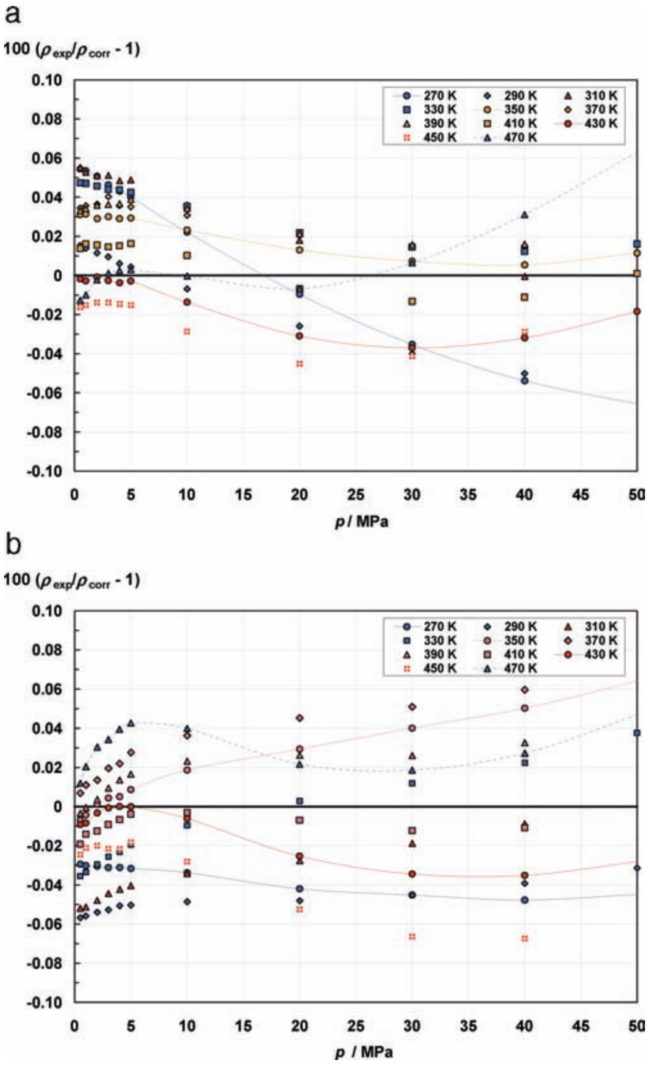

Figure 3. Deviations of density data of compressed liquid (a) CTL and (b) GTL from the Tait correlation as a function of pressure.

similar (within 0.5 %) while the GTL densities are lower. The densities of all three fuels are within the SPK density range (730 $kg \cdot m^{-3}$ to 770 $kg \cdot m^{-3}$) that is required for aviation turbine fuels at 288.15 K according to the specification standard ASTM D7566.[15] Figure 1 both parts a and b shows the large difference between the properties of the synthetic fuels and the petroleum-derived aviation fuels.

Listed in Tables 3 and 4 are measured values of compressed liquid density from (270 to 470) K with pressures to 50 MPa for the GTL and CTL samples, respectively. Also listed are density values extrapolated to 0.083 MPa (this is the approximate atmospheric pressure in Boulder, CO) for each temperature. These were obtained by fitting a second-order polynomial to the isothermal data at pressures less than or equal to 10 MPa and extrapolating to 0.083 MPa. This extrapolation was performed to examine the consistency of the compressed liquid data with the measurement results at ambient pressure from the density and sound speed analyzer.

5. CORRELATION OF DATA

Density measurements at ambient pressure and values extrapolated to 0.083 MPa from measured compressed liquid data were correlated with the Rackett equation to check the repeatability of the instruments and the consistency of our data in the combined temperature range (270 to 470) K. The Rackett equation is written as

$$\rho = \beta_1 \cdot \beta_2^{-\left(1 + \left(1 - \frac{T}{\beta_3}\right)^{\beta_4}\right)} \qquad (2)$$

Table 5 lists the Rackett correlation parameters for the CTL and GTL measurements. In Figure 2a,b for CTL and GTL, respectively, the correlations serve as the baseline to compare the ambient pressure and extrapolated values.

To make the present results immediately usable for engineering and design purposes, the compressed liquid density data were correlated with a Tait equation similar to that of Dymond and Malhotra.[16] The temperature dependence of the parameter C was omitted because it was not needed to fit the data within their experimental uncertainty. The equation used to fit the compressed liquid density data reads

$$\rho(T,p) = \frac{\rho_{\mathrm{ref}}(T, p_{\mathrm{ref}})}{1 - C \ln[(p + B(T))/(p_{\mathrm{ref}} + B(T))]} \qquad (3)$$

where $\rho_{\mathrm{ref}}(T)$ is the temperature-dependent density at the reference pressure $p_{\mathrm{ref}} = 0.083$ MPa from eq 2. The temperature dependence of the Tait parameter $B(T)$ was expressed by a quadratic polynomial

$$B(T) = \beta_5 + \beta_6 T_{\mathrm{r}} + \beta_7 T_{\mathrm{r}}^2 \qquad (4)$$

where T_{r} is the absolute temperature T divided by 273.15 K. Parameters for the Tait correlations are given in Table 6. Figure 3 parts a and b shows deviations of the measured data for compressed liquid density from the Tait correlations for the CTL and GTL samples, respectively. The correlations for CTL and GTL represent our data with an AAD of 0.02 % and 0.03 %, respectively. These deviations are well within the stated uncertainty.

6. CONCLUSIONS

Density and speed of sound at ambient pressure and compressed liquid densities of two synthetic aviation fuels were measured over a temperature range of (270 to 470) K with pressures to 50 MPa. The data reported here greatly extend the range of available data for CTL and GTL SPK fuels. The density data have been correlated with a modified Tait equation within their experimental uncertainty of 0.1 %. The general composition of each of the samples has been described, and it can be seen that the properties of density and speed of sound reported here are relatively similar (within 3 % in density and 0.5 % in speed of sound). A comparison of the ambient pressure density and speed of sound data reported here to that of previously reported data for S-8 showed that, of the two fuels in this study, the CTL had values closer to those of S-8 than the GTL sample. This result is interesting, as the GTL, like the S-8, sample was derived from natural gas, and therefore it might be expected that these two fuels would have more similar properties; however, as these fuels are complex mixtures, it is difficult to predict their thermophysical properties based solely on the types of chemical species present in the product or the feedstock.

AUTHOR INFORMATION

Corresponding Author

*Phone: 1-303-497-5786. Fax: 1-303-497-5224. E-mail: outcalt@boulder.nist.gov.

Funding Sources

We acknowledge the financial support of the Air Force Research Laboratory (MIPR F4FBEY5102G001) and of the Air Force Office of Scientific Research (MIPR F1ATA06004G004).

REFERENCES

(1) Leckel, D. Diesel Production from Fischer−Tropsch: The Past, the Present, and New Concepts. *Energy Fuels* **2009**, *23* (5), 2342–2358.

(2) *The Synthesis of hydrocarbons and chemicals from CO and H2*; U.S. Naval Technical Mission in Europe Technical Report No. 248−45; U.S. Department of Defense: Washington, DC, 1945; p 8.

(3) Moses, C. A. *Comparative Evaluation of Semi-Synthetic Jet Fuels*; final report for Project AV-2-04a: Coordinating Research Council: Alpharetta, GA, September 2008.

(4) Rahmes, T. F.; Kinder, J. D.; Henry, M.; Crenfeldt, G.; LeDuc, G. F.; Zombanakis, G. P.; Abe, Y.; Lambert, D. M.; Lewis, C.; Juenger, J. A.; Andac, M. G.; Reilly, K. R.; Holmgren, J.; McCall, M. J.; Bozzano, A. G. In *Sustainable bio-derived synthetic paraffinic kerosene (bio-SPK) jet fuel flight tests and engine program results*, Aviation Technology, Integration and Operations Conference (ATIO), Hilton Head, SC, 2009; American Institute for Aeronautics and Astronautics: Hilton Head, SC, 2009; pp 1−19.

(5) Outcalt, S. L.; Laesecke, A.; Brumback, K. J. Thermophysical Properties Measurements of Rocket Propellants RP-1 and RP-2. *J. Propul. Power* **2009**, *25* (5), 1032–1040.

(6) NATO. *Detail Specification Turbine Fuel, Aviation, Kerosene Type JP-8 (NATO F-34, NATO F-35, and JP-8 + 100 (NATO F-37), MIL-DTL-83133F*; U.S. Department of Defense: Washington, DC, April 11, 2008.

(7) Outcalt, S.; Laesecke, A.; Freund, M. B. Density and Speed of Sound Measurements of Jet A and S-8 Aviation Turbine Fuels. *Energy Fuels* **2009**, *23*, 1626–1633.

(8) Smith, B. L.; Bruno, T. J. Application of a Composition-Explicit Distillation Curve Metrology to Mixtures of Jet-A and S-8. *J. Propul. Power* **2008**, *24* (3), 618–623.

(9) Bruno, T. J.; Laesecke, A.; Outcalt, S. L.; Seelig, H. D.; Smith, B. L. *Properties of a 50/50 Mixture of Jet-A + S-8*; U.S. Department of Commerce: Washington, DC, 2007; p 32.

(10) Huber, M. L.; Smith, B. L.; Ott, L. S.; Bruno, T. J. Surrogate Mixture Model for the Thermophysical Properties of Synthetic Aviation Fuel S-8: Explicit Application of the Advanced Distillation Curve. *Energy Fuels* **2008**, *22* (2), 1104–1114.

(11) Bruno, T. J.; Baibourine, E.; Lovestead, T. M. Comparison of Synthetic Isoparaffinic Kerosene Turbine Fuels with the Composition-Explicit Distillation Curve Method. *Energy Fuels* **2010**, *24*, 3049–3059.

(12) Laesecke, A.; Outcalt, S. L.; Brumback, K. J. Density and Speed of Sound Measurements of Methyl- and Propylcyclohexane. *Energy Fuels* **2008**, *22*, 2629–2636.

(13) Outcalt, S. L.; McLinden, M. O. Automated Densimeter for the Rapid Characterization of Industrial Fluids. *Ind. Eng. Chem. Res.* **2007**, *46*, 8264–8269.

(14) Hadaller, O. J.; Johnson, J. M. *World Fuel Sampling Program, CRC Report No. 647*; Coordination Research Council: Alpharetta, GA, 2006.

(15) ASTM. *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*; ASTM: West Conshohocken, PA, September 2009; p 18.

(16) Dymond, J. H.; Malhotra, R. The Tait equation: 100 years on. *Int. J. Thermophys.* **1988**, *9* (6), 941–951.