Compressed-Liquid Densities of Three "Reference" Turbine Fuels*

Stephanie L. Outcalt

National Institute of Standards and Technology, Materials Measurement Laboratory, Applied Chemicals and Materials Division, 325 Broadway, Mail Stop 647.07, Boulder, CO 80305-3337

KEYWORDS Aviation fuel; Compressed-liquid; Density; Vibrating-tube densimeter

ABSTRACT: Compressed-liquid densities of three aviation fuels have been measured with a vibrating-tube densimeter. These fuels were chosen through a deliberative, collaborative process to replace a previous "reference" fuel (Jet A 4658) and represent a larger range of operability than that individual fuel provided. Density measurements were made from 270 K to 470 K, and 0.5 MPa to 45 MPa and have an overall combined uncertainty of 0.81 kg·m^{-3}. The data from each of the three fuels have been correlated with a modified Tait equation and the parameters are reported. Densities of the fuels reported herein are compared with previously reported densities of Jet A 4658 and correlations for JP-5 and JP-8.

INTRODUCTION

The National Jet Fuels Combustion Program (a collaboration of multiple U.S. agencies under the auspices of the Federal Aviation Administration) was undertaken to address knowledge shortfalls identified during the evaluation of alternative jet fuels in recent years. The desired outcome of the program is to develop an improved rig evaluation process for ASTM D4054 (Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives[1]) to minimize full-scale engine testing and to develop improved and validated non-proprietary combustion models for combustor evaluation and design.[2]

Prior to the National Jet Fuels Combustion Program, Jet A 4658 was commonly used as a reference fuel for the evaluation of aviation processes and potential, new alternative aviation fuels. Jet A 4658 was formulated as a mixture (in approximately equal volume aliquots) of five available batches of Jet A. As such, it was considered to be representative of the variations possible amongst batches of Jet A. As part of the National Jet Fuels Combustion Program, it was decided to develop three reference fuels; one with properties (viscosity, flash point, and aromatics/hydrogen content) very near the average for the U.S., plus two fuels near the edges of property distribution for properties relevant to combustion while remaining within specification. [2] These are the fuels studied in this work.

The United States Department of Defense (DoD) is one of the largest single consumers of energy in the world. The Air Force consumes 48% of the DoD energy budget which accounts for approximately 50% of the total DoD energy costs.[3] Aviation fuel costs also greatly affect the private sector; in 2011, fuel costs averaged approximately 35 % of the total operating costs of commercial airlines.[4] As such, throughout the military and private industry there is a huge push to increase fuel efficiency and to develop alternative and renewable fuels in order to reduce costs.

The data reported here are part of a larger project at the National Institute of Standards and Technology (NIST) to characterize three aviation fuels which were developed as reference fuels for the National Jet Fuel Combustion Program. The NIST project included a detailed composition analysis of each of the fuels, composition explicit distillation curves [5] and in this work, compressed-liquid density measurements. The data measured at NIST on these fuels will be added to a growing collection of data for both traditional and alternative aviation fuels measured at NIST. This data collection provides knowledge to aid in the development of new aviation fuels to help both the military and private industry increase efficiency and decrease cost.

EXPERIMENTAL SECTION

Sample Fluids: Three sample fluids were obtained from the Fuels Branch of the Air Force Research Laboratory (AFRL, Wright Patterson Air Force Base). The fuels were given the designations JP-8-10264, Jet A-10325 and JP-5-10289 and will be referred to as such in the remainder of this work. The JP-8-10264 is a best case fuel, having the lowest viscosity, flash point and aromatics content of the three fuels. The Jet A-10325 represents an average Jet-A, and the JP-5-10289 a worst case fuel with the highest viscosity, flash point and aromatics content of the three fuels.

A detailed composition analysis of each of the fuels was completed at NIST and is reported in Lovestead et al.[5] The composition analysis included measurements of each sample with gas chromatography/tandem quadrupole time-of-flight-mass spectrometry (GC/QToF-MS) and NMR spectroscopy. The GC/QToF-MS analysis has the most relevance to the work reported here. The uncalibrated area percent of each compound relative to the total area for each multi-component fuel sample is presented in Table 2 of reference [5]. This table indicates that the JP-8-10264 has the greatest percentage of components (12.1 %) with gas chromatographic retention times below approximately 5.5 minutes. This is compared to 6.0 % for Jet A-10325 and 2.5 % for JP-5-10289. Retention times are typically indicative of a components boiling point; with shorter times indicating lower boiling points.

Lower boiling points are generally associated with relatively lower molecular weight and hence lower density components. The detailed composition analysis presented in Lovestead et al. [5] confirmed that these three fuels did in fact have approximately the desired flash points and aromatics content as prescribed by the National Jet Fuel Combustion Program. [2]

Because there is the potential for air being entrained in the samples, the samples were transferred to stainless steel cylinders and degassed through freezing the sample with liquid nitrogen and evacuating the vapor space. This procedure has been described in detail in Outcalt and Lemmon.[6] The process helps to insure that the samples are free of air and any other dissolved impurities.

Instrumentation: The densities of the compressed test liquids were measured with the automated densimeter of Outcalt and McLinden.[7] The instrument has been used to successfully measure densities of numerous existing and potential alternative aviation fuels.[3, 8, 9] The primary component of the apparatus is a commercial vibrating-tube densimeter. As the instrument and the calibration procedure have been previously described in detail[7], a brief description is given here as supporting information. The overall combined uncertainty (k=2, 95 % confidence level) in density is 0.81 $kg{\cdot}m^{-3}$, corresponding to a relative uncertainty in density of 0.09 % to 0.13 %. In this work, we measured isotherms from 270 K to 470 K in 20 K increments, over the range 0.5 MPa to 45 MPa for each of the fuel samples.

RESULTS

Tables 1 to 3 list measured values of compressed-liquid density from 270 K to 470 K at pressures to 45 MPa for JP-8-10264, JP-5-10289, and Jet A-10325, respectively. These data were extrapolated to ambient pressure (0.083 MPa) by a method described previously.[8] Figure 1 illustrates densities of the fuels studied in this work extrapolated to ambient pressure in comparison to a previously measured flight-line Jet A[9], the CRC World Survey correlations for JP-5 and JP-8 [10]. It can be seen in the figure that all of the fuels studied in this work meet the density specification (MIL-DTL-83133G) for military aviation fuels[11] which states that the fuel density at 288.15K must be within 775 kg·m^{-3} and 840 kg·m^{-3}. The figure also illustrates that with the exception of the JP-8-10264, the extrapolated densities of this work agree with previous density measurements and correlations. The JP-5-10289 was intended to be representative of a worst case JP-5 and is in close agreement with the CRC World Survey JP-5 correlation. The Jet A-10325 was to represent an average Jet A and has extrapolated density values similar to that of a previously measured flight-line Jet A[9] as well as the CRC World Survey JP-8 correlation. The JP-8-10264 has the lowest densities of the three fuels measured. It was formulated to represent a best case JP-8, but it's ambient pressure densities are 20 kg·m^{-3} to 25 kg·m^{-3} below that of the CRC World Survey correlation for JP-8.

CORRELATION OF DATA

The correlation of the data measured in this work was carried out in the same way it has been done previously for other fuels. [8] Simply, the extrapolated density values were correlated with a Rackett equation[12] and the results of that correlation were then used to represent the density at the reference pressure of 0.083 MPa in a Tait equation similar to that given in Dymond and Malhotra [13]. Details of the correlation procedure are given in supporting information. Correlation parameters for the Rackett equation are listed in Table 4. Differences between our extrapolated densities and the unpublished atmospheric pressure data [14] (provided by the Air Force) for each of the three fuels are shown in Figure 2. The baseline is the Rackett correlation for each of the fluids studied in this work. For the Jet A-10325 and JP-8-10264 samples, all but the highest temperature point (358 K) of the JP-8-10264 agree with our extrapolated data to within 0.1 %. The JP-5-10289 exhibits the greatest differences; 0.13 % to 0.19 %. Given that the high end of our relative uncertainty is 0.13 % and our atmospheric pressure data are an extrapolation, this agreement is quite good.

Tait equation parameters are given in Table 5 for each of the three fuels. Figures 3 to 5 show deviations of the measured compressed-liquid densities of JP-8-10264, JP-5-10289, and Jet A-10325 from their Tait correlations, as a function of pressure. All three fuel samples are fitted to within their experimental uncertainty of 0.81 kg·m^{-3} by their respective Tait equations.

CONCLUSIONS

The compressed-liquid densities of three aviation fuels that were chosen to serve as reference fuels for testing combustion rigs have been measured from 270 K to 470 K up to pressures of 45 MPa. All of the fuels meet the density specification for aviation fuels as dictated by the military.[11] As the density specification for aviation fuels in ASTM D 1655-16a[15] is identical to that of the military specification, the data presented here are applicable to the commercial aviation industry as well. The wide-range in temperature and pressure of the density data reported here make them valuable in developing predictive equations of state for the thermophysical properties of the fuels. Such equations then aid in understanding the results of performance testing done with these fuels as well as assessing the potential advantages and disadvantages of pursuing these fuel formulations for wide-spread use in military and commercial aviation.

ACKNOWLEDGMENT

We acknowledge Tim Edwards for suggestions that improved the manuscript.

REFERENCES

1. Outcalt, S. L.; McLinden, M. O. Industrial & Engineering Chemistry Research 46 (2007)
2. Colket, M. B.; Heyne, J.; Rumizen, M.; Edwards, J. T.; Gupta, M.; Roquemore, W. M.; Moder, J. P.; Tishkoff, J. M.; Li, C., "An Overview of the National Jet Fuels Combustion Program", 54th AIAA Aerospace Sciences Meeting, AIAA SciTech. 2016.
3. Outcalt, S. L.; Fortin, T. J. Journal of Chemical and Engineering Data 56 (2011)
4. Outcalt, S. L. Journal of Chemical and Engineering Data 56 (2011)
5. Lovestead, T. M.; Burger, J. L.; Schneider, N.; Bruno, T. J. Energy & Fuels (in press)
6. Outcalt, S. L.; Lemmon, E. W. J. Chem. Eng. Data 58 (2013)
7. Outcalt, S. L.; McLinden, M. O. Ind. Eng. Chem. Res. 46 (2007)

8. Outcalt, S. L.; Fortin, T. J. J. Chem. Eng. Data 57 (2012)
9. Outcalt, S. L.; Laesecke, A.; Freund, M. B. Energy & Fuels 23 (2009)
10. Hadaller, O. J.; Johnson, J. M., *World Fuel Sampling Program, CRC Report No. 647*. Coordination Research Council: Alpharetta, GA, 2006.
11. 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-83133G*; Department of Defense: 30 April 2010, 2010.
12. Rackett, H. G. J. Chem. Eng. Data 15 (1970)
13. Dymond, J. H.; Malhotra, R. Int. J. Thermophys. 9 (1988)
14. Edwards, J. T., Data provided by Fuels Branch of the Air Force Research Laboratory, AFRL, Wright Patterson Air Force Base. 2016.
15. Outcalt, S. L.; McLinden, M. O. International Journal of Thermophysics 16 (1995)

Table 1: Compressed-liquid densities of fuel JP-8-10264.

270.00 K		**290.00 K**		**310.00 K**		**330.00 K**		**350.00 K**		**370.00 K**	
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}
45.02	819.11	45.00	806.87	45.02	793.93	45.03	781.86	45.04	770.01	45.02	758.09
40.02	816.68	40.01	804.22	40.01	791.12	40.01	778.82	40.02	766.69	40.02	754.52
35.01	814.16	35.01	801.52	35.00	788.21	35.01	775.68	35.01	763.23	35.02	750.77
30.01	811.59	30.01	798.70	30.01	785.19	30.01	772.39	30.02	759.62	30.02	746.86
25.01	808.93	25.01	795.80	25.01	782.04	25.01	768.94	25.01	755.84	25.02	742.74
20.01	806.16	20.02	792.80	20.02	778.76	20.01	765.33	20.02	751.88	20.02	738.41
15.02	803.33	15.01	789.70	15.01	775.35	15.02	761.52	15.02	747.69	15.01	733.78
10.01	800.39	10.02	786.47	10.01	771.75	10.01	757.53	10.01	743.28	10.02	728.88
5.02	797.33	5.01	783.04	5.02	767.92	5.01	753.26	5.02	738.56	5.01	723.60
4.01	796.69	4.02	782.32	4.02	767.09	4.02	752.39	4.02	737.57	4.01	722.48
3.02	796.06	3.01	781.60	3.02	766.26	3.02	751.49	3.02	736.59	3.02	721.36
2.01	795.42	2.02	780.90	2.02	765.44	2.01	750.58	2.02	735.59	2.01	720.20
1.02	794.77	1.01	780.16	1.02	764.61	1.01	749.71	1.01	734.56	1.02	719.03
0.51	794.44	0.52	779.79	0.50	764.22	0.52	749.28	0.51	734.03	0.52	718.43
390.00 K		**410.00 K**		**430.00 K**		**450.00 K**		**470.00 K**			
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}		
45.02	746.04	45.03	734.40	45.02	722.77	45.02	711.38	44.99	700.26		
40.02	742.22	40.01	730.26	40.01	718.30	40.02	706.61	40.02	695.21		
35.02	738.20	35.01	725.90	35.01	713.57	35.01	701.54	35.02	689.72		
30.01	733.93	30.01	721.28	30.01	708.56	30.01	696.12	30.01	683.87		
25.01	729.44	25.01	716.36	25.01	703.22	25.01	690.27	25.02	677.54		
20.01	724.70	20.02	711.18	20.03	697.48	20.02	683.95	20.01	670.59		
15.01	719.62	15.01	705.50	15.02	691.26	15.01	677.01	15.01	662.90		
10.02	714.16	10.02	699.40	10.01	684.42	10.01	669.36	10.02	654.24		
5.01	708.22	5.01	692.66	5.01	676.81	5.02	660.72	5.03	644.30		
4.01	706.93	4.01	691.22	4.01	675.18	4.01	658.78	4.02	642.06		
3.01	705.62	3.02	689.77	3.01	673.48	3.01	656.83	2.00	637.32		
2.02	704.35	2.01	688.29	2.01	671.74	2.02	654.87	1.02	634.89		
1.02	703.01	1.02	686.76	1.02	669.99	1.01	652.67	0.51	633.56		
0.51	702.34	0.52	685.98	0.51	669.04	0.51	651.61				

The combined expanded uncertainties are $U_c(T)$ = 30 mK, $U_c(p)$ = 0.01 MPa, and $U_c(\rho)$ = 0.81 kg·m^{-3} (level of confidence = 0.95).

Table 2: Compressed-liquid densities of fuel JP-5-10289.

270.00 K		290.00 K		310.00 K		330.00 K		350.00 K		370.00 K	
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}
45.01	861.89	45.01	849.82	45.00	837.39	45.03	825.26	45.00	813.45	44.99	801.66
39.99	859.55	40.00	847.30	40.00	834.68	39.99	822.31	39.99	810.33	39.99	798.32
35.00	857.16	35.00	844.72	35.00	831.88	35.00	819.32	35.00	807.10	35.00	794.82
30.00	854.71	29.99	842.06	30.00	829.00	30.00	816.21	30.00	803.74	30.00	791.17
25.00	852.19	24.99	839.32	25.00	826.02	25.00	812.97	25.00	800.23	24.99	787.34
20.00	849.59	19.99	836.49	20.00	822.93	19.99	809.61	20.00	796.56	19.99	783.33
15.00	846.92	14.99	833.57	15.00	819.74	15.00	806.13	15.00	792.72	15.00	779.12
10.00	844.16	9.99	830.54	9.99	816.39	10.00	802.45	10.00	788.69	10.00	774.66
5.00	841.32	4.99	827.40	5.00	812.91	5.00	798.60	4.99	784.43	5.00	769.91
4.00	840.74	4.00	826.76	3.99	812.18	3.99	797.79	3.99	783.54	4.00	768.92
3.00	840.15	2.99	826.10	3.00	811.45	2.99	796.98	3.01	782.66	3.00	767.92
2.00	839.56	1.99	825.46	2.00	810.73	1.99	796.15	1.99	781.74	1.99	766.88
1.00	838.96	1.00	824.79	1.00	809.99	0.98	795.33	1.00	780.83	0.99	765.85
0.49	838.66	0.50	824.46	0.49	809.62	0.49	794.92	0.50	780.36	0.50	765.34
390.00 K		**410.00 K**		**430.00 K**		**450.00 K**		**470.00 K**			
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}		
44.98	789.75	45.01	778.09	44.99	766.49	44.99	754.99	45.00	743.78		
39.99	786.15	39.99	774.21	40.00	762.32	40.00	750.55	40.00	739.01		
34.99	782.38	34.99	770.15	35.00	757.92	34.99	745.83	35.01	733.95		
30.00	778.45	30.00	765.88	29.99	753.28	29.99	740.83	29.99	728.53		
24.99	774.30	24.99	761.36	24.99	748.35	25.00	735.50	24.98	722.72		
19.99	769.92	19.99	756.58	19.99	743.10	19.99	729.77	19.99	716.46		
14.99	765.29	15.00	751.48	15.00	737.48	14.99	723.56	14.99	709.60		
9.99	760.35	10.00	746.00	9.99	731.39	9.99	716.79	10.00	702.06		
5.00	755.05	4.99	740.07	5.00	724.71	4.99	709.28	4.99	693.55		
3.99	753.93	3.99	738.81	4.00	723.30	4.00	707.69	3.99	691.70		
3.00	752.82	3.00	737.54	3.00	721.86	2.98	706.01	3.00	689.79		
1.99	751.66	2.00	736.25	2.00	720.39	1.99	704.33	1.99	687.84		
0.99	750.49	1.00	734.93	0.99	718.86	1.00	702.60	1.00	685.81		
0.50	749.90	0.49	734.24	0.49	718.10	0.50	701.71	0.50	684.78		

The combined expanded uncertainties are $U_c(T)$ = 30 mK, $U_c(p)$ = 0.01 MPa, and $U_c(\rho)$ = 0.81 kg·m^{-3} (level of confidence = 0.95).

Table 3: Compressed-liquid densities of fuel Jet A-10325.

270.00 K		**290.00 K**		**310.00 K**		**330.00 K**		**350.00 K**		**370.00 K**	
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}
45.00	841.18	44.98	829.03	45.04	816.70	45.01	804.39	45.03	792.50	45.02	780.57
39.99	838.81	40.00	826.48	39.99	813.88	39.98	801.38	39.99	789.25	39.99	777.07
35.00	836.38	35.00	823.86	34.99	810.98	34.99	798.28	35.00	785.92	35.00	773.48
29.99	833.86	29.99	821.07	29.99	807.99	30.00	795.09	29.99	782.46	29.99	769.72
24.98	831.27	25.00	818.31	25.00	804.91	25.00	791.77	25.00	778.84	25.00	765.78
20.00	828.62	20.00	815.41	20.00	801.71	20.00	788.30	19.99	775.05	19.99	761.61
14.99	825.88	14.99	812.37	15.00	798.38	15.00	784.66	15.00	771.04	15.00	757.20
9.99	823.05	9.99	809.21	10.00	794.93	9.99	780.85	10.00	766.82	10.00	752.54
4.99	820.12	4.99	805.96	5.00	791.32	5.00	776.84	5.00	762.36	5.00	747.58
4.00	819.52	4.00	805.29	3.99	790.58	4.00	776.00	4.00	761.44	4.00	746.54
3.00	818.91	3.00	804.63	3.00	789.84	3.00	775.16	2.99	760.49	3.00	745.48
1.99	818.29	2.00	803.96	1.99	789.07	1.99	774.32	2.00	759.54	2.00	744.38
1.00	817.68	1.00	803.27	0.99	788.30	0.99	773.46	0.99	758.56	0.99	743.27
0.50	817.38	0.49	802.92	0.49	787.91	0.50	773.02	0.49	758.07	0.50	742.72
390.00 K		**410.00 K**		**430.00 K**		**450.00 K**		**470.00 K**			
p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}	p MPa	ρ kg·m^{-3}		
45.01	768.50	45.03	756.72	44.97	745.02	45.04	733.56	44.96	722.20		
39.98	764.76	39.98	752.68	40.00	740.74	39.99	728.89	40.00	717.30		
34.99	760.88	34.98	748.47	35.01	736.22	34.99	724.00	35.00	712.03		
29.99	756.81	29.99	744.07	30.00	731.40	29.99	718.79	30.01	706.40		
25.00	752.50	25.00	739.39	24.99	726.28	25.00	713.23	24.99	700.30		
19.99	747.94	19.99	734.39	19.99	720.80	19.99	707.22	19.99	693.71		
14.99	743.09	14.99	729.03	14.99	714.89	15.00	700.69	15.00	686.52		
9.99	737.91	9.99	723.26	10.00	708.46	9.99	693.50	10.00	678.47		
4.99	732.32	5.00	717.00	5.00	701.40	5.00	685.48	5.00	669.33		
3.99	731.14	4.00	715.65	3.99	699.86	4.00	683.73	4.00	667.51		
2.99	729.95	3.00	714.31	2.99	698.32	2.99	681.94	2.99	665.58		
2.00	728.72	2.00	712.92	2.00	696.74	1.99	680.10	1.99	663.44		
0.99	727.49	0.99	711.49	1.00	695.12	1.00	678.25	1.00	660.88		
0.50	726.85	0.50	710.76	0.49	694.27	0.50	677.26	0.50	659.75		

The combined expanded uncertainties are $U_c(T)$ = 30 mK, $U_c(p)$ = 0.01 MPa, and $U_c(\rho)$ = 0.81 kg·m^{-3} (level of confidence = 0.95).

Table 4. Rackett correlation parameters for the ambient pressure density of three reference fuels.

	JP-8-10264		JP-5-10289		Jet A-10325	
Parameter	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.
β_1 ($kg \cdot m^{-3}$)	148.5	0.1	143.9	0.1	150.43	0.01
β_2	0.3892	2×10^{-4}	0.3754	1×10^{-4}	0.3877	1×10^{-4}
β_3 (K)	623.50	0.08	670.68	0.06	641.3	0.1
β_4	0.4452	2×10^{-4}	0.4356	1×10^{-4}	0.4404	1×10^{-4}

Table 5. Tait correlation parameters for the density of three reference fuels at pressures to 45 MPa and temperatures from 270 K to 470 K.

	JP-8-10264		JP-5-10289		Jet A-10325	
Parameter	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.
C	0.08146	7×10^{-5}	0.0868	1×10^{-4}	0.08313	7×10^{-5}
β_5 (MPa)	320.9	0.3	391.9	0.7	343.1	0.4
β_6 (MPa)	-294.8	0.4	-354.7	0.7	-309.2	0.4
β_7 (MPa)	69.6	0.1	83.8	0.2	72.0	0.1

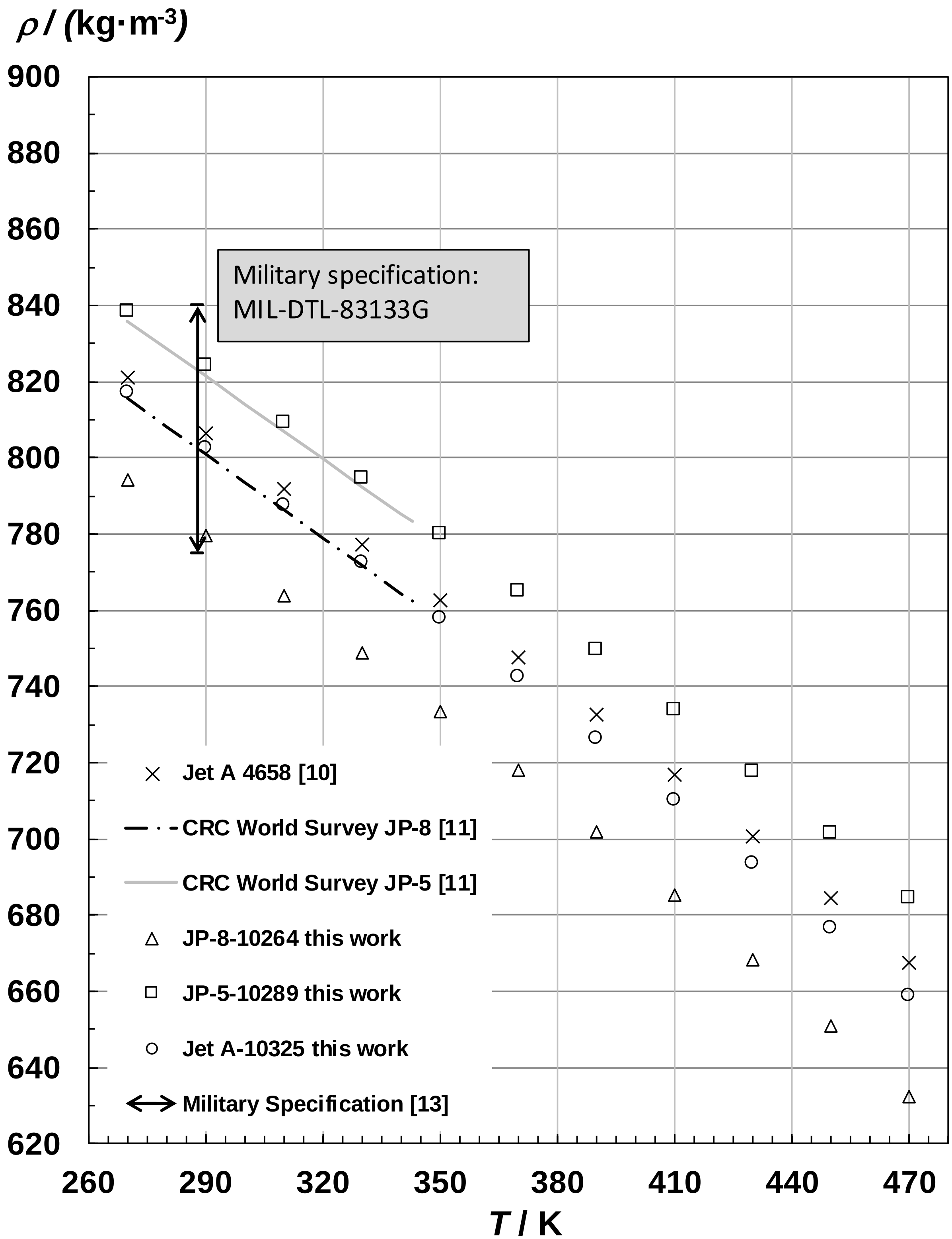

Figure 1. Ambient pressure densities of the three fuels studied in this work in comparison to a previously measured Jet A[9] and the correlations for JP-5 and JP-8 from the CRC World Fuel Sampling Program[10].

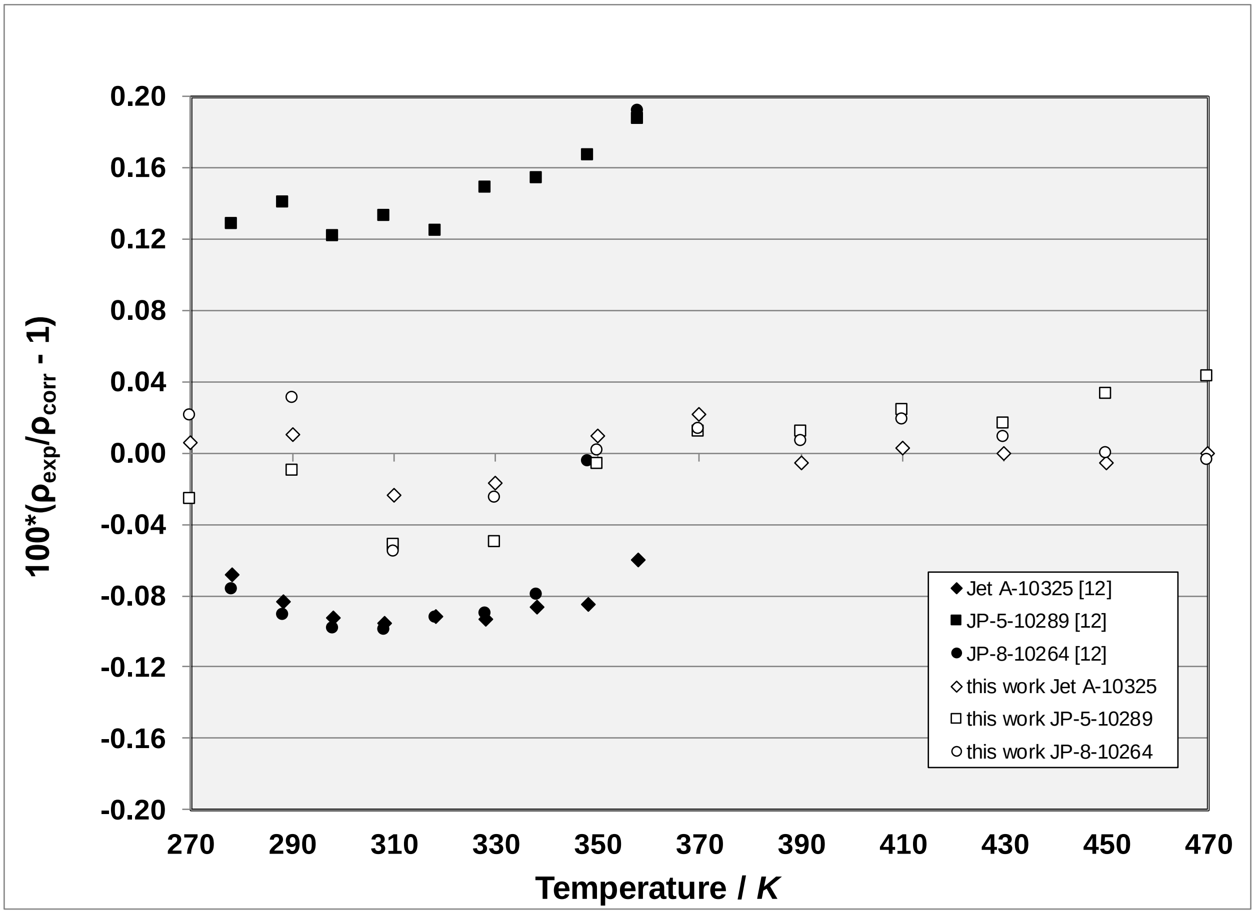

Figure 2. Deviations of atmospheric pressure densities (extrapolated) of this work and unpublished data provided by the Air Force [14] from the Rackett correlations for each of the three fuels.

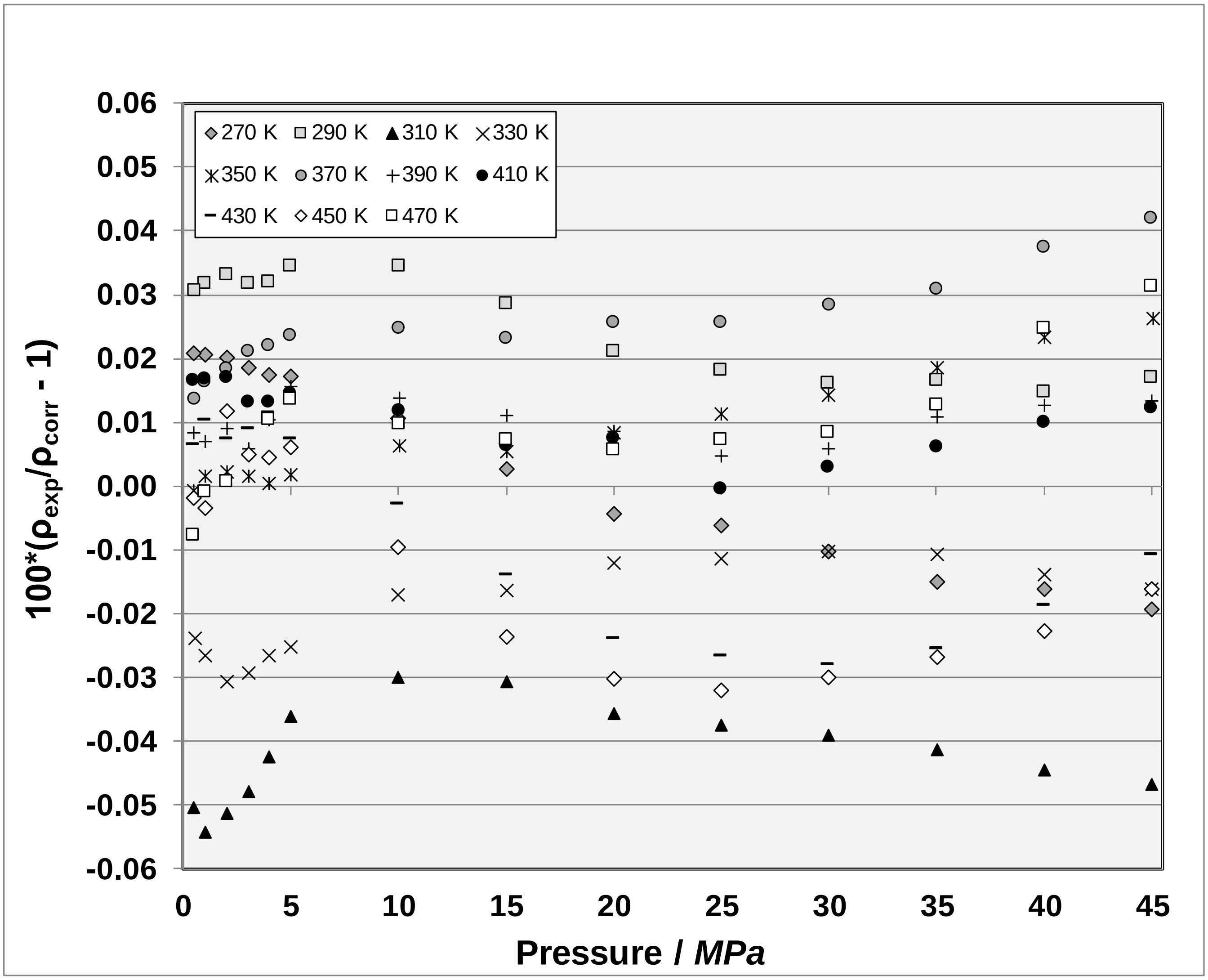

Figure 3. Deviations of compressed-liquid density data from the Tait correlation for JP-8-10264.

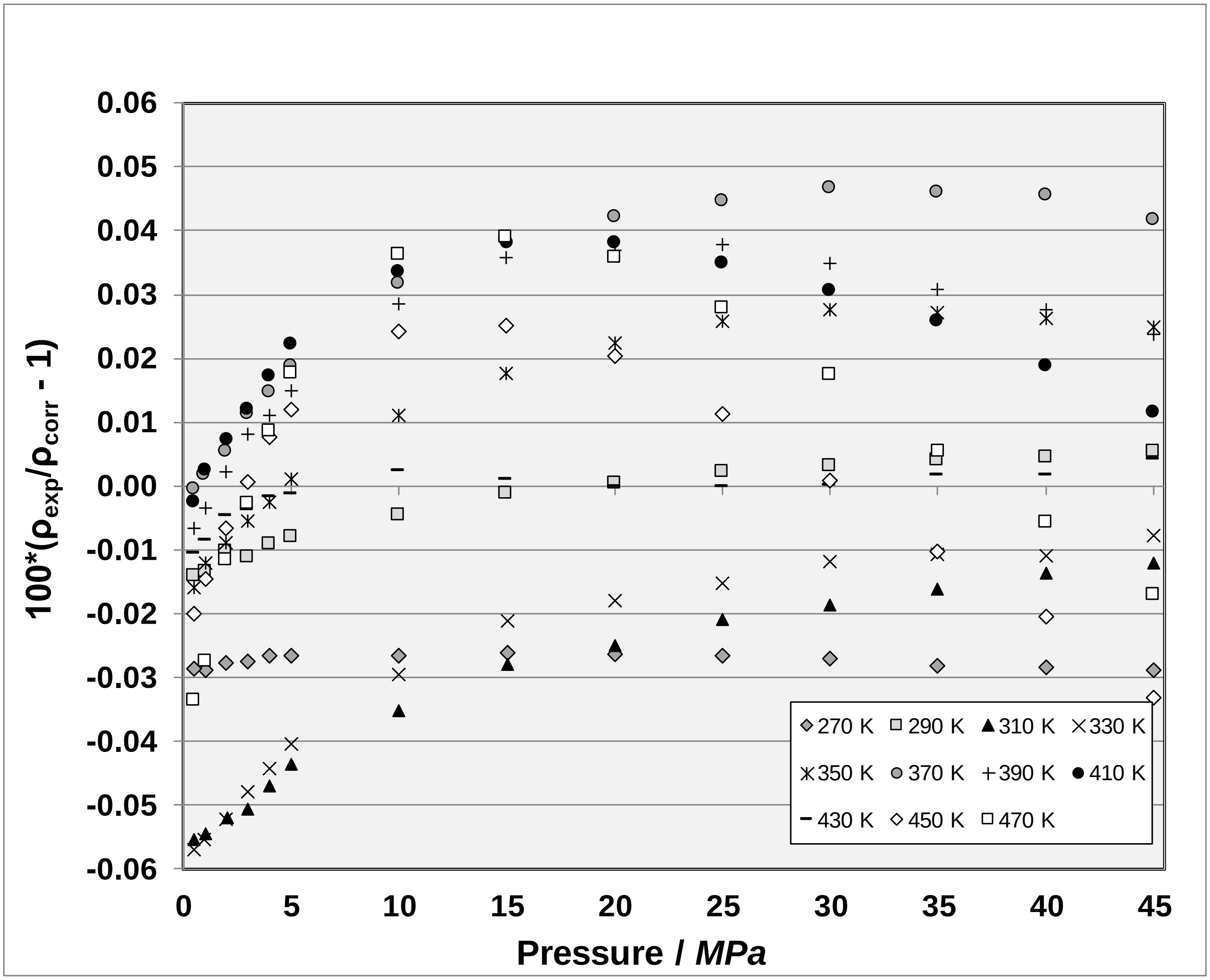

Figure 4. Deviations of compressed-liquid density data from the Tait correlation for JP-5-10289.

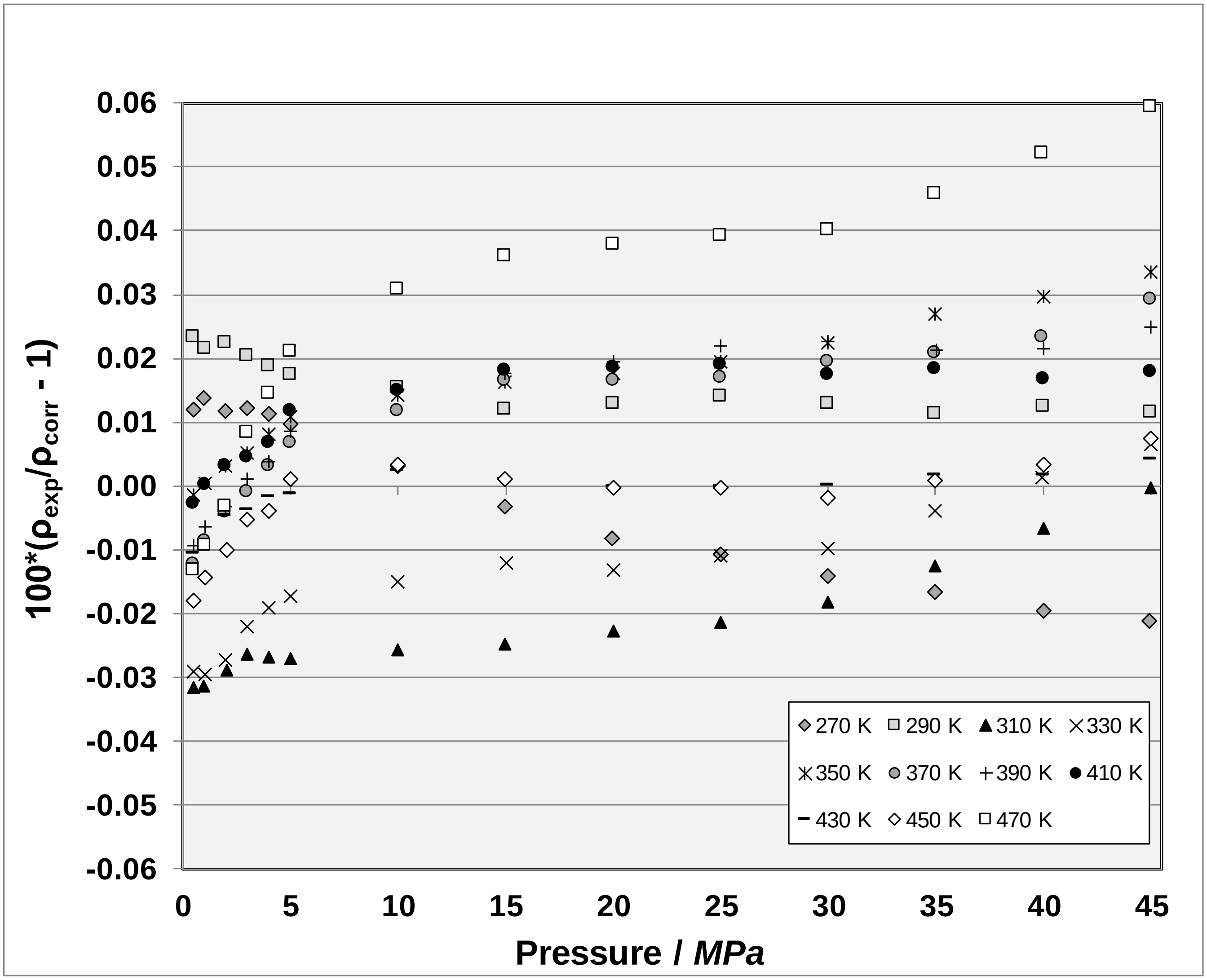

Figure 5. Deviations of compressed-liquid density data from the Tait correlation for Jet A-10325.