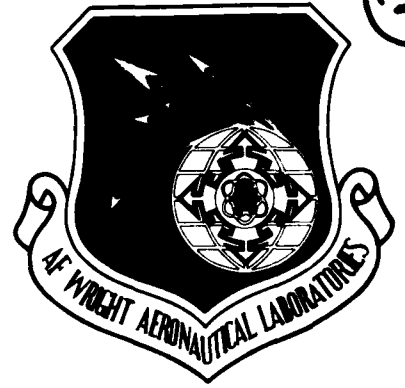


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DETERMINATION OF THE COEFFICIENT OF THERMAL EXPANSION OF JP-4 FUELS



Donovan S. Duvall, Michael D. Hale, Donald J. Lewis, and Arthur D. Snyder

MONSANTO COMPANY
DAYTON LABORATORY
DAYTON, OHIO 45407

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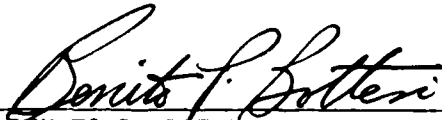
This technical report has been reviewed and is approved for publication.



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FOREWORD

This report was submitted by the Monsanto Company under Contract F33615-81-C-2035. This effort was sponsored by the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, as requested by the Defense Fuel Supply Center, Cameron Station, Alexandria, Virginia. Mr. Tim Dues was Contract Monitor, while Dr. Arthur D. Snyder of Monsanto served as Contract Monitor on the study which was performed during the period from April 1983 to July 1985.

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SECTION I
INTRODUCTION AND SUMMARY

1. BACKGROUND

The U.S. Department of Defense expends many billions of dollars annually in its acquisition of petroleum-based fuels.

Refined petroleum products are purchased in standard volumetric units, i.e., the U.S. gallon of 231 cubic inches at 60°F. In order to determine petroleum product volumes consistently with this criterion, it is generally necessary to convert apparent volumes observed at temperatures other than 60°F to volumes corrected to the 60°F standard. The process by which this objective is accomplished involves the use of volume correction factors which permit normalization of product volumes, observed within a wide range of temperatures and fuel densities, to volumes at 60°F. Issues of the petroleum measurement tables published prior to the current (1980) edition were based on technical evaluations of petroleum oils performed between 1912 and 1952.

Investigation of this body of technical data, executed by the American Petroleum Institute (API) in conjunction with the U.S. National Bureau of Standards (NBS), resulted in the publication of revised volume correction tables. These volume correction tables, designated as API standard 2540, ASTM D1250, IP-200, and ISO-91, are predicated upon the volumetric coefficients of thermal expansion, as experimentally determined by the NBS, for various categories of petroleum products, as well as a wide spectrum of crude oils. The current volume correction standard is typically used on a world-wide basis by both public and private sector entities, including the U.S. Department of Defense.

The petroleum volume correction tables are principally divided into four series, designated A through D, inclusively.

The tables termed "A" are devised for use with crude oils; "B" with refined products; "D" with lubricants. The "C" series tables are designed to accommodate experimental determination of the volumetric coefficient of thermal expansion for a specific petroleum oil batch or cargo.

2. PURPOSE OF STUDY

Subsequent to the publication of the current edition of the volume correction tables, the API published guidance concerning the application of the tables to several substances, including Aviation Turbine Fuel, Grade JP-4. Specifically, the guidance advocated the application of the volume correction series prepared for crude oils, viz, "A" for JP-4. In recognition of the fact that; (a) this recommendation was based upon the analysis of relatively few JP-4 samples, and (b) the compositional diversity of JP-4 is extensive, this study was initiated to evaluate the extent to which the use of the "A" series tables for JP-4 is applicable.

3. SUMMARY OF RESULTS

A program was carried out where density data were accurately measured at 10 different temperatures for 100 JP-4 jet fuels. Analytical instrumentation used in this work was a Mettler/Par Model ADS-55 density measuring system having a precision of 1×10^{-5} gm/cm³.

Statistical analysis of the density measurements was performed using a computerized nonlinear regression technique. Coefficient of thermal expansion (α) values were calculated for each fuel at 60°F.

A heavy majority of the JP-4 samples (88 out of 100) had α values more consistent with the "A" (crude group), than with the "B" (generalized products group). These findings are in agreement with the API's published guidance concerning the recommended use of table "A" for JP-4 jet fuels.

SECTION II
METHODOLOGY

1. PROCUREMENT/SOURCE OF FUEL SAMPLES

Fuel samples for this program were provided by the Air Force Contract Monitor. The 100 JP-4 samples were selected to represent a significant proportion of that fuel currently being used by the Air Force. The sources of all the fuels used in this program are listed in Appendix A.

2. DENSITY MEASUREMENTS

The scope of the test plan included the determination of density values on approximately 100 JP-4 fuel samples at the following temperatures: 30, 45, 55, 60, 65, 75, 85, 95, 105, and 120°F. Density measurements were conducted with a Mettler/Par Model ADS-55 density measuring system. This consisted of a Model DMA-55 vibrating tube density meter with an auto-sampler and a constant temperature bath controlling to $\pm 0.005^{\circ}\text{C}$ over the temperature range from -10 to $+60^{\circ}\text{C}$. The temperature of the sample tube was measured using a precision, hermetically glass-encapsulated thermometer which had been calibrated over the -10 to $+60^{\circ}\text{C}$ temperature range at 0.05°C intervals. Temperatures were recorded to the nearest 0.01°C . The precision of the ADS-55 system is $1 \times 10^{-5} \text{ g/cm}^3$. The analytical protocol and test plan were intended to insure that proper calibration and cleanliness were maintained during the entire measurement sequence. The goal was to make sure that measurements at any temperature could be reproduced to within $\pm 3 \times 10^{-5} \text{ g/cm}^3$ or better.

An early problem with density measurement was experienced when some of the fuels "bubbled" at the higher temperatures, i.e., 105° and 120°F. Since the density couldn't be accurately measured when boiling had been initiated, a change in technique was required. A successful alteration of the technique involved the elevation of the initial boiling point of the fuel by subjecting it to a small positive pressure. (This could be done since liquid fuels have insignificant compressibilities.) The pressurizing of the cell with 5 psi of N₂ was easily accomplished using a Teflon 3-way rotary valve.

3. DATA ANALYSIS PROCEDURES

History

The American Society for Testing and Materials (ASTM) published the Petroleum Measurement Tables in 1980 in 10 volumes. Most of the following information is taken from Volume X - Background, Development, and Program Documentation. This document, ASTM D 1250-80, also contains theoretical development which is valuable for evaluating these tables.

The original Petroleum Measurement Tables were developed in the late 1940's. In 1972, Downer and Inkley demonstrated that those tables did not provide a satisfactory representation of many petroleum fluids of current interest. As a result, API and the NBS initiated a research program in 1974. This study was funded by the API. The purpose was to "provide the solid scientific base for the development of more accurate, consequently more equitable, measurement tables."

Precise density data were collected on 349 different fluids, "representing a wide variety of refined products and 66.8 percent of the world crude production in 1974." The study was completed

in March 1979 and cost \$500,000. A working group was formed to study the results and produce the tables mentioned previously. That work is described by Hankinson et al. (1979).

Unfortunately, the JP-4 type fuels were not very well represented by the API study. Only four such samples were included. The present work was undertaken to better characterize this group and to determine whether the JP-4's properly belonged with the "A" table group (generalized crude oils) or with the "B" table group (generalized products).

Theory

The definition for the coefficient of thermal expansion is

$$\alpha = \frac{1}{V} \frac{dV}{dt} \quad (1)$$

where: α = coefficient of thermal expansion
 V = volume at any temperature, and
 t = temperature.

The working group chose to use the representation:

$$VCF = \frac{V_T}{V} = \frac{\rho}{\rho_T} = \text{EXP} -\alpha_T \Delta t [1 + \alpha_T \Delta t (k/2)] \quad (2)$$

where: VCF = volume correction factor
 t = any temperature
 T = base temperature
 α_T = α at the base temperature
 Δt = $t - T$
 ρ = density at t
 ρ_T = density at T
 V = volume at t
 V_T = volume at T

and k is an empirically derived constant, determined by the committee to be 1.6 to best represent the data. Throughout this study, the base temperature, T , was taken to be 60°F.

Further, the group determined that the coefficients of thermal expansion at the base temperature for each group were related to the densities at the base temperature by:

$$\alpha_T = \frac{K_0 + K_1 \rho_T}{(\rho_T)^2} \quad (3)$$

The data were also examined for internal consistency by computing a percent standard deviation and a maximum percent error. The percent standard deviation is defined by:

$$\sigma = 100 \sqrt{\frac{n_0}{\sum_{i=1}^{n_0} [(\rho_i - \rho_c) / \rho_i]^2 / (np - 1)}} \quad (4)$$

where: σ = percent standard deviation
 ρ_i = measured density
 ρ_c = calculated density (regression fit)
 np = number of points
 n_0 = total number of observations in a group.

The maximum percent error is given by:

$$\max_i \left| (\rho_i - \rho_c) / \rho_i \right| / \sigma \quad (5)$$

Analysis of Density Data

The density data for the 100 JP-4 fuel samples were entered into a data base on Monsanto's IBM mainframe computer in St. Louis, Missouri. These data were analyzed using the Statistical Analysis System (SAS), a programming language/statistical analysis package.

Nonlinear regression was used to estimate the parameters in equation 2. The logarithmic form was used, i.e., the model used was:

$$\log(\rho) = \log(\rho_T) - \alpha_T \Delta t [1 + \alpha_T \Delta t (k/2)] + e_i \quad (6)$$

where e_i is a random variation term. In general, the data fit the assumed model very well. The estimates for the parameters had very small standard deviations except for k . This parameter had very little impact on the regression, and it was determined that using the previously assumed value of 1.6 for k did not perceptibly degrade the regression fit. The estimates for α_T and ρ_T are given in tables 1, 2, and 3, sorted by sample number, alpha-t (α_T), and base density (ρ_T), respectively.

Included in each table is the API gravity, given by the equation:

$$^\circ\text{API} = (141.5 \times 999.012 / \text{base density}) - 131.5 \quad (7)$$

Also included are the percent standard deviation and the maximum percent error, as shown in equations 4 and 5. A comparison of these values with the appendix to Table 6C, 11.1.6.7.1, shows that the Monsanto data compare very favorably. No statistical tests were performed to determine whether the appendix data and the Monsanto data differ, however. Such tests would not appear appropriate because the Monsanto data cover a much narrower density range. The appendix data also cover varying temperature ranges.

Nonlinear regression was then applied to determine values for K_0 and K_1 , using the α_T and ρ_T values shown in the tables to fit equation 3. The nonlinear regression uses an iterative procedure, requiring starting values for the parameters. The values $K_0 = 190$ and $K_1 = 0.3$ were used as starting points, since those are the values used at the low end of the gasoline group, and they have similar API values. The procedure converged quickly to give values

of $K_0 = 300 \pm 59$ and $K_1 = 0.05 \pm 0.08$. Since the K_1 term was non-significant, the nonlinear regression was reapplied, setting K_1 to zero. That regression yielded $K_0 = 341.0 \pm 0.5$. The much smaller standard deviation for K_0 is a result of removing K_1 , which was highly correlated with K_0 . Based on these observations, K_0 was calculated for each sample as:

$$K_0 = \alpha_T (\rho_T)^2 \quad (8)$$

The right-most column in the three tables lists either 'JET' or 'CRUDE'. This determination was made based on whether the α_T value was closer to the α_T value determined from equation 3 above using the 'JET' coefficients or the 'CRUDE' coefficients. The 'JET' coefficients are $K_0 = 330.301$ and $K_1 = 0$. The 'CRUDE' coefficients are $K_0 = 341.0957$ and $K_1 = 0$.

TABLE 1. CALCULATED VALUES SORTED BY SAMPLE NUMBER

Sample No.	Alpha $\times 10^6$ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
541	583 757	760 394	54 4039	337 528	0 0092872	0 022652	CRUDE
585	588 734	763 937	53 5417	343 585	0 0065365	-0 01794	CRUDE
588	562 605	772 659	51 4529	335 876	0 0026834	-0 01882	CRUDE
589	598 096	760 916	54 2764	346 293	0 0034705	-0 015651	CRUDE
590	615 538	752 991	56 2316	349 007	0 0034969	-0 017306	CRUDE
591	585 201	760 259	54 4369	338 243	0 0053033	0 023479	CRUDE
592	583 451	761 772	54 0676	338 575	0 0034801	0 014054	CRUDE
594	574 962	763 858	53 5608	335 478	0 0068791	-0 021578	JET
595	604 953	757 654	55 0762	347 267	0 0031484	0 015481	CRUDE
596	581 223	764 468	53 4132	339 673	0 0014175	-0 014584	CRUDE
597	593 574	766 078	53 0245	348 354	0 0037204	0 019682	CRUDE
598	596 013	758 814	54 791	343 184	0 0039638	0 017863	CRUDE
599	607 348	756 772	55 2936	347 831	0 0036042	0 0171	CRUDE
600	590 813	758 068	54 9743	339 521	0 0036983	-0 016921	CRUDE
601	591 473	769 191	52 2778	349 948	0 0029975	0 013027	CRUDE
602	607 254	752 711	56 3014	344 054	0 0033419	0 016486	CRUDE
603	580 262	762 208	53 9614	337 11	0 004234	-0 017754	CRUDE
604	571 501	764 339	53 4444	333 879	0 003342	0 015522	JET
605	577 965	754 893	55 7586	329 361	0 0015975	-0 014985	JET
608	599 345	759 381	54 6519	345 618	0 0045526	-0 017738	CRUDE
609	585 362	772 715	51 4396	349 513	0 0023455	-0 015108	CRUDE
610	600 342	755 616	55 5794	342 769	0 0030678	0 01493	CRUDE
611	595 527	756 254	55 4216	340 594	0 0029107	-0 018391	CRUDE
612	579 312	764 431	53 4221	338 524	0 0017838	0 015486	CRUDE
613	574 05	769 266	52 2598	339 706	0 0023722	0 019833	CRUDE
614	567 878	771 436	51 7429	337 952	0 0043604	-0 018738	CRUDE
615	593 62	750 708	56 8025	334 542	0 0040095	-0 016136	JET
616	597 029	753 316	56 1506	338 805	0 0045995	-0 016308	CRUDE
617	601 405	752 126	56 4475	340 211	0 0044769	-0 017306	CRUDE
618	595 278	757 726	55 0585	341 778	0 0039377	-0 017219	CRUDE
624	589 087	763 366	53 6801	343 277	0 0043622	-0 017963	CRUDE
625	590 206	757 232	55 1802	338 424	0 0064584	-0 019015	CRUDE
626	593 483	752 631	56 3214	336 18	0 0053988	-0 018465	CRUDE
627	603 207	763 162	53 7296	351 318	0 0043162	-0 017844	CRUDE
628	596 502	753 596	56 0809	338 758	0 0035775	0 020787	CRUDE
629	569 905	771 756	51 667	339 44	0 0135503	0 023324	CRUDE
636	569 182	776 69	50 5034	343 358	0 0043464	0 015334	CRUDE
637	586 634	760 007	54 4985	338 846	0 0195866	-0 023701	CRUDE
638	613 289	752 708	56 3022	347 471	0 0112538	0 022379	CRUDE
639	585 527	767 145	52 7679	344 589	0 0107066	0 022607	CRUDE
643	600 151	754 051	55 9677	341 242	0 0097446	0 023231	CRUDE
644	597 611	760 534	54 3697	345 665	0 0099067	0 02316	CRUDE
914	608 807	756 008	55 4824	347 962	0 0055208	0 020128	CRUDE
915	571 281	779 398	49 871	347 031	0 0041162	-0 017647	CRUDE
916	579 312	763 241	53 7104	337 471	0 0019546	-0 016	CRUDE
917	577 57	762 081	53 9924	335 434	0 0108805	-0 017763	JET
918	594 005	752 906	56 2528	336 722	0 0017513	0 017245	CRUDE
919	594 116	752 328	56 397	336 268	0 0030684	0 016515	CRUDE
920	571 549	780 325	49 6555	348 02	0 0047596	0 017572	CRUDE
921	577 101	769 343	52 2414	341 58	0 0022566	0 01999	CRUDE

TABLE 1 (continued)

Sample No.	Alpha x 10 ⁶ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
922	573 835	763 667	53 6071	334 653	0 0038613	0 019461	JET
923	580 925	765 46	53 1735	340 381	0 0046753	-0 021039	CRUDE
924	583 025	758 271	54 9244	335 225	0 0043259	-0 016294	JET
925	563 948	772 9	51 3958	336 888	0 0057848	0 021449	CRUDE
926	572 015	766 861	52 8361	336 388	0 0197222	0 02227	CRUDE
927	589 643	759 14	54 711	339 807	0 0044831	-0 016435	CRUDE
928	575 157	767 151	52 7665	338 492	0 0066835	-0 015676	CRUDE
929	579 646	765 697	53 1164	339 842	0 0040857	-0 016849	CRUDE
930	572 244	769 01	52 321	338 412	0 0088048	0 023206	CRUDE
931	578 046	764 943	53 2983	338 237	0 0085534	0 022642	CRUDE
932	557 008	774 292	51 067	333 942	0 0080875	0 020282	JET
933	589 484	757 707	55 0631	338 434	0 0076505	0 018399	CRUDE
934	575 677	766 462	52 9321	338 19	0 0055272	0 022409	CRUDE
935	591 324	773 492	51 2559	353 783	0 0051233	0 01623	CRUDE
936	577 56	765 499	53 1641	338 444	0 0074283	0 019122	CRUDE
937	576 069	777 575	50 2962	348 304	0 0042289	0 018656	CRUDE
938	608 479	754 176	55 9366	346 092	0 0042614	0 018523	CRUDE
939	596 37	756 061	55 4693	340 902	0 0042212	0 017746	CRUDE
940	597 579	764 411	53 427	349 18	0 0079464	0 017269	CRUDE
941	592 74	756 971	55 2445	339 643	0 0069301	0 020606	CRUDE
997	590 478	752 252	56 416	334 142	0 0043057	-0 02004	JET
999	587 699	757 682	55 0693	337 387	0 0034414	-0 019471	CRUDE
1001	583 511	764 74	53 3474	341 253	0 0020502	-0 015637	CRUDE
1019	602 864	756 379	55 3907	344 904	0 0040695	-0 018105	CRUDE
1021	571 679	765 429	53 181	334 936	0 0694174	-0 028105	JET
1087	606 037	760 09	54 4782	350 13	0 0154985	-0 014262	CRUDE
1088	606 037	760 09	54 4782	350 13	0 0063159	-0 020438	CRUDE
1089	584 783	761 356	54 169	338 977	0 0027566	0 019661	CRUDE
1091	592 877	761 874	54 0428	344 137	0 0032064	-0 016656	CRUDE
1093	586 29	755 939	55 4995	335 032	0 0054399	0 013974	JET
1095	589 104	763 599	53 6236	343 497	0 0026258	-0 016592	CRUDE
1096	587 692	763 575	53 6294	342 652	0 0045801	-0 021483	CRUDE
1097	614 811	753 283	56 1588	348 865	0 0031644	0 016485	CRUDE
1157	579 866	761 16	54 2168	335 954	0 0029622	-0 024625	CRUDE
1181	581 682	761 362	54 1675	337 185	0 0027931	0 014941	CRUDE
1283	571 081	768 502	52 4425	337 278	0 0022525	-0 017732	CRUDE
1793	618 307	751 25	56 6667	348 958	0 0031916	-0 019234	CRUDE
1794	583 408	761 152	54 2187	337 999	0 0063782	-0 021453	CRUDE
1795	619 501	756 18	55 4399	354 236	0 0028004	0 019395	CRUDE
1796	589 625	763 362	53 6811	343 587	0 0338125	-0 022537	CRUDE
1954	577 798	762 777	53 8231	336 179	0 0031501	-0 020127	CRUDE
1955	577 431	762 953	53 7803	336 121	0 0034839	0 021313	CRUDE
1956	579 057	762 589	53 8688	336 746	0 0038383	-0 017272	CRUDE
1957	581 515	763 305	53 6949	338 811	0 0028993	0 019533	CRUDE
1958	588 463	760 573	54 3601	340 409	0 0138739	0 024269	CRUDE
1959	582 234	758 211	54 9391	334 717	0 012848	0 023968	JET
1960	610 364	751 451	56 6163	344 659	0 0129409	0 023683	CRUDE
1961	599 391	755 153	55 6941	341 806	0 0022506	0 016022	CRUDE
1962	593 399	753 269	56 1623	336 703	0 0021075	-0 016778	CRUDE
1963	579 99	768 308	52 489	342 366	0 0025856	-0 013189	CRUDE

TABLE 2. CALCULATED VALUES SORTED BY ALPHA

Sample No.	Alpha x 10 ⁶ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
932	557.008	774.292	51.067	333.942	0.0080875	0.020282	JET
588	562.605	772.659	51.4529	335.876	0.0026834	-0.01882	CRUDE
925	563.948	772.9	51.3958	336.888	0.0057848	0.021449	CRUDE
614	567.878	771.436	51.7429	337.952	0.0043604	-0.018738	CRUDE
636	569.182	776.69	50.5034	343.358	0.0043464	0.015334	CRUDE
629	569.905	771.756	51.667	339.44	0.0135503	0.023324	CRUDE
1283	571.081	768.502	52.4425	337.278	0.0022525	-0.017732	CRUDE
915	571.281	779.398	49.871	347.031	0.0041162	-0.017647	CRUDE
604	571.501	764.339	53.4444	333.879	0.003342	0.015522	JET
920	571.549	780.325	49.6555	348.02	0.0047596	0.017572	CRUDE
1021	571.679	765.429	53.181	334.936	0.0694174	-0.028105	JET
926	572.015	766.861	52.8361	336.388	0.0197222	0.02227	CRUDE
930	572.244	769.01	52.321	338.412	0.0088048	0.023206	CRUDE
922	573.835	763.667	53.6071	334.653	0.0038613	0.019461	JET
613	574.05	769.266	52.2598	339.706	0.0023722	0.019833	CRUDE
594	574.962	763.858	53.5608	335.478	0.0068791	-0.021578	JET
928	575.157	767.151	52.7665	338.492	0.0066835	-0.015676	CRUDE
934	575.677	766.462	52.9321	338.19	0.0055272	0.022409	CRUDE
937	576.069	777.575	50.2962	348.304	0.0042289	0.018656	CRUDE
921	577.101	769.343	52.2414	341.58	0.0022566	0.01999	CRUDE
1955	577.431	762.953	53.7803	336.121	0.0034839	0.021313	CRUDE
936	577.56	765.499	53.1641	338.444	0.0074283	0.019122	CRUDE
917	577.57	762.081	53.9924	335.434	0.0108805	-0.017763	JET
1954	577.798	762.777	53.8231	336.179	0.0031501	-0.020127	CRUDE
605	577.965	754.893	55.7586	329.361	0.0015975	-0.014985	JET
931	578.046	764.943	53.2983	338.237	0.0085534	0.022642	CRUDE
1956	579.057	762.589	53.8688	336.746	0.0038383	-0.017272	CRUDE
916	579.312	763.241	53.7104	337.471	0.0019546	-0.016	CRUDE
612	579.312	764.431	53.4221	338.524	0.0017838	0.015486	CRUDE
929	579.646	765.697	53.1164	339.842	0.0040857	-0.016849	CRUDE
1157	579.866	761.16	54.2168	335.954	0.0029622	-0.024625	CRUDE
1963	579.99	768.308	52.489	342.366	0.0025856	-0.013189	CRUDE
603	580.262	762.208	53.9614	337.11	0.004234	-0.017754	CRUDE
923	580.925	765.46	53.1735	340.381	0.0046753	-0.021039	CRUDE
596	581.223	764.468	53.4132	339.673	0.0014175	-0.014584	CRUDE
1957	581.515	763.305	53.6949	338.811	0.0028993	0.019533	CRUDE
1181	581.682	761.362	54.1675	337.185	0.0027931	0.014941	CRUDE
1959	582.234	758.211	54.9391	334.717	0.012848	0.023968	JET
924	583.025	758.271	54.9244	335.225	0.0043259	-0.016294	JET
1794	583.408	761.152	54.2187	337.999	0.0063782	-0.021453	CRUDE
592	583.451	761.772	54.0676	338.575	0.0034801	0.014054	CRUDE
1001	583.511	764.74	53.3474	341.253	0.0020502	-0.015637	CRUDE
541	583.757	760.394	54.4039	337.528	0.0092872	0.022652	CRUDE
1089	584.783	761.356	54.169	338.977	0.0027566	0.019661	CRUDE
591	585.201	760.259	54.4369	338.243	0.0053033	0.023479	CRUDE
609	585.362	772.715	51.4396	349.513	0.0023455	-0.015108	CRUDE
639	585.527	767.145	52.7679	344.589	0.0107066	0.022607	CRUDE
1093	586.29	755.939	55.4995	335.032	0.0054399	0.013974	JET
637	586.634	760.007	54.4985	338.846	0.0195866	-0.023701	CRUDE
1096	587.692	763.575	53.6294	342.652	0.0045801	-0.021483	CRUDE

TABLE 2 (continued)

Sample No.	Alpha $\times 10^6$ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
999	587 699	757 682	55 0693	337 387	0 0034414	-0 019471	CRUDE
1958	588 463	760 573	54 3601	340 409	0 0138739	0 024269	CRUDE
585	588 734	763 937	53 5417	343 585	0 0065365	-0 01794	CRUDE
624	589 087	763 366	53 6801	343 277	0 0043622	-0 017963	CRUDE
1095	589 104	763 599	53 6236	343 497	0 0026258	-0 016592	CRUDE
933	589 484	757 707	55 0631	338 434	0 0076505	0 018399	CRUDE
1796	589 625	763 362	53 6811	343 587	0 0338125	-0 022537	CRUDE
927	589 643	759 14	54 711	339 807	0 0044831	-0 016435	CRUDE
625	590 206	757 232	55 1802	338 424	0 0064584	-0 019015	CRUDE
997	590 478	752 252	56 416	334 142	0 0043057	-0 02004	JET
600	590 813	758 068	54 9743	339 521	0 0036983	-0 016921	CRUDE
935	591 324	773 492	51 2559	353 783	0 0051233	0 01623	CRUDE
601	591 473	769 191	52 2778	349 948	0 0029975	0 013027	CRUDE
941	592 74	756 971	55 2445	339 643	0 0069301	0 020606	CRUDE
1091	592 877	761 874	54 0428	344 137	0 0032064	-0 016656	CRUDE
1962	593 399	753 269	56 1623	336 703	0 0021075	-0 016778	CRUDE
626	593 483	752 631	56 3214	336 18	0 0053988	-0 018465	CRUDE
597	593 574	766 078	53 0245	348 354	0 0037204	0 019882	CRUDE
615	593 62	750 708	56 8025	334 542	0 0040095	-0 016136	JET
918	594 005	752 906	56 2528	336 722	0 0017513	0 017245	CRUDE
919	594 116	752 328	56 397	336 268	0 0030684	0 016515	CRUDE
618	595 278	757 726	55 0585	341 778	0 0039377	-0 017219	CRUDE
611	595 527	756 254	55 4216	340 594	0 0029107	-0 018391	CRUDE
598	596 013	758 814	54 791	343 184	0 0039638	0 017863	CRUDE
939	596 37	756 061	55 4693	340 902	0 0042212	0 017746	CRUDE
628	596 502	753 596	56 0809	338 758	0 0035775	0 020787	CRUDE
616	597 029	753 316	56 1506	338 805	0 0045995	-0 016308	CRUDE
940	597 579	764 411	53 427	349 18	0 0079464	0 017269	CRUDE
644	597 611	760 534	54 3697	345 665	0 0099067	0 02316	CRUDE
589	598 096	760 916	54 2764	346 293	0 0034705	-0 015651	CRUDE
608	599 345	759 381	54 6519	345 618	0 0045526	-0 017738	CRUDE
1961	599 391	755 153	55 6941	341 806	0 0022506	0 016022	CRUDE
643	600 151	754 051	55 9677	341 242	0 0097446	0 023231	CRUDE
610	600 342	755 616	55 5794	342 769	0 0030678	0 01493	CRUDE
617	601 405	752 126	56 4475	340 211	0 0044769	-0 017306	CRUDE
1019	602 864	756 379	55 3907	344 904	0 0040695	-0 018105	CRUDE
627	603 207	763 162	53 7296	351 318	0 0043162	-0 017844	CRUDE
595	604 953	757 654	55 0762	347 267	0 0031484	0 015481	CRUDE
1087	606 037	760 09	54 4782	350 13	0 0154985	-0 014262	CRUDE
1088	606 037	760 09	54 4782	350 13	0 0063159	-0 020438	CRUDE
602	607 254	752 711	56 3014	344 054	0 0033419	0 016486	CRUDE
599	607 348	756 772	55 2936	347 831	0 0036042	0 0171	CRUDE
938	608 479	754 176	55 9366	346 092	0 0042614	0 018523	CRUDE
914	608 807	756 008	55 4824	347 962	0 0055208	0 020128	CRUDE
1960	610 364	751 451	56 6163	344 659	0 0129409	0 023683	CRUDE
638	613 289	752 708	56 3022	347 471	0 0112538	0 022379	CRUDE
1097	614 811	753 283	56 1588	348 865	0 0031644	0 016485	CRUDE
590	615 538	752 991	56 2316	349 007	0 0034969	-0 017306	CRUDE
1793	618 307	751 25	56 6667	348 958	0 0031916	-0 019234	CRUDE
1795	619 501	756 18	55 4399	354 236	0 0028004	0 019395	CRUDE

TABLE 3. CALCULATED VALUES SORTED BY DENSITY

Sample No.	Alpha $\times 10^6$ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
615	593.62	750.708	56.8025	334.542	0.0040095	-0.016136	JET
1793	618.307	751.25	56.6667	348.958	0.0031916	-0.019234	CRUDE
1960	610.364	751.451	56.6163	344.659	0.0129409	0.023683	CRUDE
617	601.405	752.126	56.4475	340.211	0.0044769	-0.017306	CRUDE
997	590.478	752.252	56.416	334.142	0.0043057	-0.02004	JET
919	594.116	752.328	56.397	336.268	0.0030684	0.016515	CRUDE
626	593.483	752.631	56.3214	336.18	0.0053988	-0.018465	CRUDE
638	613.289	752.708	56.3022	347.471	0.0112538	0.022379	CRUDE
602	607.254	752.711	56.3014	344.054	0.0033419	0.016486	CRUDE
918	594.005	752.906	56.2528	336.722	0.0017513	0.017245	CRUDE
590	615.538	752.991	56.2316	349.007	0.0034969	-0.017306	CRUDE
1962	593.399	753.269	56.1623	336.703	0.0021075	-0.016778	CRUDE
1097	614.811	753.283	56.1588	348.865	0.0031644	0.016485	CRUDE
616	597.029	753.316	56.1506	338.805	0.0045995	-0.016308	CRUDE
628	596.502	753.596	56.0809	338.758	0.0035775	0.020787	CRUDE
643	600.151	754.051	55.9677	341.242	0.0097446	0.023231	CRUDE
938	608.479	754.176	55.9366	346.092	0.0042614	0.018523	CRUDE
605	577.965	754.893	55.7586	329.361	0.0015975	-0.014985	JET
1961	599.391	755.153	55.6941	341.806	0.0022506	0.016022	CRUDE
610	600.342	755.616	55.5794	342.769	0.0030678	0.01493	CRUDE
1093	586.29	755.939	55.4995	335.032	0.0054399	0.013974	JET
914	608.807	756.008	55.4824	347.962	0.0055208	0.020128	CRUDE
939	596.37	756.061	55.4693	340.902	0.0042212	0.017746	CRUDE
1795	619.501	756.18	55.4399	354.236	0.0028004	0.019395	CRUDE
611	595.527	756.254	55.4216	340.594	0.0029107	-0.018391	CRUDE
1019	602.864	756.379	55.3907	344.904	0.0040695	-0.018105	CRUDE
599	607.348	756.772	55.2936	347.831	0.0036042	0.0171	CRUDE
941	592.74	756.971	55.2445	339.643	0.0069301	0.020606	CRUDE
625	590.206	757.232	55.1802	338.424	0.0064584	-0.019015	CRUDE
595	604.953	757.654	55.0762	347.267	0.0031484	0.015481	CRUDE
999	587.699	757.682	55.0693	337.387	0.0034414	-0.019471	CRUDE
933	589.484	757.707	55.0631	338.434	0.0076505	0.018399	CRUDE
618	595.276	757.726	55.0585	341.778	0.0039377	-0.017219	CRUDE
600	590.813	758.068	54.9743	339.521	0.0036983	-0.016921	CRUDE
1959	582.234	758.211	54.9391	334.717	0.012848	0.023968	JET
924	583.025	758.271	54.9244	335.225	0.0043259	-0.016294	JET
598	596.013	758.814	54.791	343.184	0.0039638	0.017863	CRUDE
927	589.643	759.14	54.711	339.807	0.0044831	-0.016435	CRUDE
608	599.345	759.381	54.6519	345.618	0.0045526	-0.017738	CRUDE
637	586.634	760.007	54.4985	338.846	0.0195866	-0.023701	CRUDE
1087	606.037	760.09	54.4782	350.13	0.0154985	-0.014262	CRUDE
1088	606.037	760.09	54.4782	350.13	0.0063159	-0.020438	CRUDE
591	585.201	760.259	54.4369	338.243	0.0053033	0.023479	CRUDE
541	583.757	760.394	54.4039	337.528	0.0092872	0.022652	CRUDE
644	597.611	760.534	54.3697	345.665	0.0099067	0.02316	CRUDE
1958	588.463	760.573	54.3601	340.409	0.0138739	0.024269	CRUDE
589	598.096	760.916	54.2764	346.293	0.0034705	-0.015651	CRUDE
1794	583.408	761.152	54.2187	337.999	0.0063782	-0.021453	CRUDE
1157	579.866	761.16	54.2168	335.954	0.0029622	-0.024625	CRUDE
1089	584.783	761.356	54.169	338.977	0.0027566	0.019661	CRUDE

TABLE 3 (continued)

Sample No.	Alpha $\times 10^6$ at 60°F	Density (kg/m ³)	°API	K ₀	Percent standard deviation	Maximum percent error	Nearest Group
1181	581 682	761 362	54 1675	337 185	0 0027931	0 014941	CRUDE
592	583 451	761 772	54 0676	338 575	0 0034801	0 014054	CRUDE
1091	592 877	761 874	54 0428	344 137	0 0032064	-0 016656	CRUDE
917	577 57	762 081	53 9924	335 434	0 0108805	-0 017763	JET
603	580 262	762 208	53 9614	337 11	0 004234	-0 017754	CRUDE
1956	579 057	762 589	53 8688	336 746	0 0038383	-0 017272	CRUDE
1954	577 798	762 777	53 8231	336 179	0 0031501	-0 020127	CRUDE
1955	577 431	762 953	53 7803	336 121	0 0034839	0 021313	CRUDE
627	603 207	763 162	53 7296	351 318	0 0043162	-0 017844	CRUDE
916	579 312	763 241	53 7104	337 471	0 0019546	-0 016	CRUDE
1957	581 515	763 305	53 6949	338 811	0 0028993	0 019533	CRUDE
1796	589 625	763 362	53 6811	343 587	0 0338125	-0 022537	CRUDE
624	589 087	763 366	53 6801	343 277	0 0043622	-0 017963	CRUDE
1096	587 692	763 575	53 6294	342 652	0 0045801	-0 021483	CRUDE
1095	589 104	763 599	53 6236	343 497	0 0026258	-0 016592	CRUDE
922	573 835	763 667	53 6071	334 653	0 0038613	0 019461	JET
594	574 962	763 858	53 5608	335 478	0 0068791	-0 021578	JET
585	588 734	763 937	53 5417	343 585	0 0065365	-0 01794	CRUDE
604	571 501	764 339	53 4444	333 879	0 003342	0 015522	JET
940	597 579	764 411	53 427	349 18	0 0079464	0 017269	CRUDE
612	579 312	764 431	53 4221	338 524	0 0017838	0 015486	CRUDE
596	581 223	764 468	53 4132	339 673	0 0014175	-0 014584	CRUDE
1001	583 511	764 74	53 3474	341 253	0 0020502	-0 015637	CRUDE
931	578 046	764 943	53 2983	338 237	0 0085534	0 022642	CRUDE
1021	571 679	765 429	53 181	334 936	0 0694174	-0 028105	JET
923	580 925	765 46	53 1735	340 381	0 0046753	-0 021039	CRUDE
936	577 56	765 499	53 1641	338 444	0 0074283	0 019122	CRUDE
929	579 646	765 697	53 1164	339 842	0 0040857	-0 016849	CRUDE
597	593 574	766 078	53 0245	348 354	0 0037204	0 019882	CRUDE
934	575 677	766 462	52 9321	338 19	0 0055272	0 022409	CRUDE
926	572 015	766 861	52 8361	336 388	0 0197222	0 02227	CRUDE
639	585 527	767 145	52 7679	344 589	0 0107066	0 022607	CRUDE
928	575 157	767 151	52 7665	338 492	0 0066835	-0 015676	CRUDE
1963	579 99	768 308	52 489	342 366	0 0025856	-0 013189	CRUDE
1283	571 081	768 502	52 4425	337 278	0 0022525	-0 017732	CRUDE
930	572 244	769 01	52 321	338 412	0 0088048	0 023206	CRUDE
601	591 473	769 191	52 2778	349 948	0 0029975	0 013027	CRUDE
613	574 05	769 266	52 2598	339 706	0 0023722	0 019833	CRUDE
921	577 101	769 343	52 2414	341 58	0 0022566	0 01999	CRUDE
614	567 878	771 436	51 7429	337 952	0 0043604	-0 018738	CRUDE
629	569 905	771 756	51 667	339 44	0 0135503	0 023324	CRUDE
588	562 605	772 659	51 4529	335 876	0 0026834	-0 01882	CRUDE
609	585 362	772 715	51 4396	349 513	0 0023455	-0 015108	CRUDE
925	563 948	772 9	51 3958	336 888	0 0057848	0 021449	CRUDE
935	591 324	773 492	51 2559	353 783	0 0051233	0 01623	CRUDE
932	557 008	774 292	51 067	333 942	0 0080875	0 020282	JET
636	569 182	776 69	50 5034	343 358	0 0043464	0 015334	CRUDE
937	576 069	777 575	50 2962	348 304	0 0042289	0 018656	CRUDE
915	571 281	779 398	49 871	347 031	0 0041162	-0 017647	CRUDE
920	571 549	780 325	49 6555	348 02	0 0047596	0 017572	CRUDE

SECTION III
RESULTS AND DISCUSSION

1. DENSITY OF FUELS

Density measurements were made at 10 temperatures for each of 104 JP-4 samples. (There were four sets of blind duplicates, so data were assessed on 100 JP-4 fuels.) The temperature ranged from about 30°F to about 120°F.

Density measurements on JP-4 fuel made during this program are compiled in Appendix B. For each fuel sample the following information is given: (1) fuel number designation; (2) the correlation coefficient for a linear least squares fit of the data; (3) the density value at 60°F calculated from the least squares equation; and (4) the density values for 10 temperatures ranging from ~30°F to ~120°F. It can be observed that the linear correlations of these data are excellent with most values being -0.9999, or better.

An additional set of 24 miscellaneous fuels were submitted for analysis. Density measurements made on them are compiled in Appendix C. Coefficient of thermal expansion values were calculated at 60°F and are listed in Appendix D.

Problems were encountered with some of the samples. A shale crude sample, 82-POSF-0325, was so viscous that it was not possible for an aliquot to be drawn up into the instrument for analysis. Two gasoline samples, 84-POSF-2078 and 84-POSF-2079, were so volatile that density measurements could not be made because of "bubbling" even at low temperatures. A third gasoline, 84-POSF-2080, behaved very strangely. Vaporization was observed

at ~60 and 65°F, and then again at ~105 and 120°F. Density measurements were made at the other 6 temperatures. A reasonably good correlation coefficient was obtained from these results, and a density at 60°F was calculated.

2. COEFFICIENT OF THERMAL EXPANSION

As is evident from examining either Table 1, 2, or 3, most of the samples have α_T values more consistent with the 'CRUDE' group (88 to 12 for JP-4 jet fuels). Referring back to equation 3, Section II, this is equivalent to saying that K_0 values, for the most part, lie nearer to 341.0957 than to 330.301.

Figures 1 and 2 are "stem and leaf" plots for the α_T and K_0 values, respectively, which show a graphical representation of the frequency distribution of the α_T and K_0 values for the 100 JP-4 samples.

Figure 3 is a plot of the coefficient of expansion (α_T) versus density (ρ_T) at 60°F. A careful examination of the plot reveals that although the plot is reasonably linear, there is some grouping of points by geographical location (number in parentheses in plot indicates geographical district as defined in Table 4). An example of this is that most of the District 5 samples have a higher ρ_T/α_T ratio than most of the other fuel samples.

Stem	Leaf ^a
62	0
61	568
61	03
60	5667789
60	00133
59	56667788899
59	000011133334444
58	555667888999
58	00001122233344
57	5566778888899
57	0112222244
56	89
56	34
55	7

^aMultiply STEM LEAF by
10.

Note: Each digit in the leaf section represents an alpha data point. [For example, the 56 Stem and Leaf 3, 4, 8, 9 represent 4 data points: 1 between 562.5 and 563.5; 1 between 563.5 and 564.5; 1 between 567.5 and 568.5; and 1 between 568.5 and 569.5]

Figure 1. Stem and Leaf plot of alpha values at 60°F.

Stem	Leaf ^a
354	2
353	8
352	
351	3
350	11
349	00259
348	00349
347	0358
346	13
345	67
344	11679
343	234566
342	478
341	23688
340	24469
339	04567788
338	0022244445568888
337	123455
336	0122347779
335	02459
334	15779
333	99
332	
331	
330	
329	4

Note: Each digit in the leaf section represents a K_0 data point.
 [For example, the 342 Stem, and Leaf 4, 7, 8 represent
 3 data points: 1 between 342.35 and 342.45; 1 between
 342.65 and 342.75; and 1 between 342.75 and 342.85]

Figure 2. Stem and leaf plot of K_0 values.

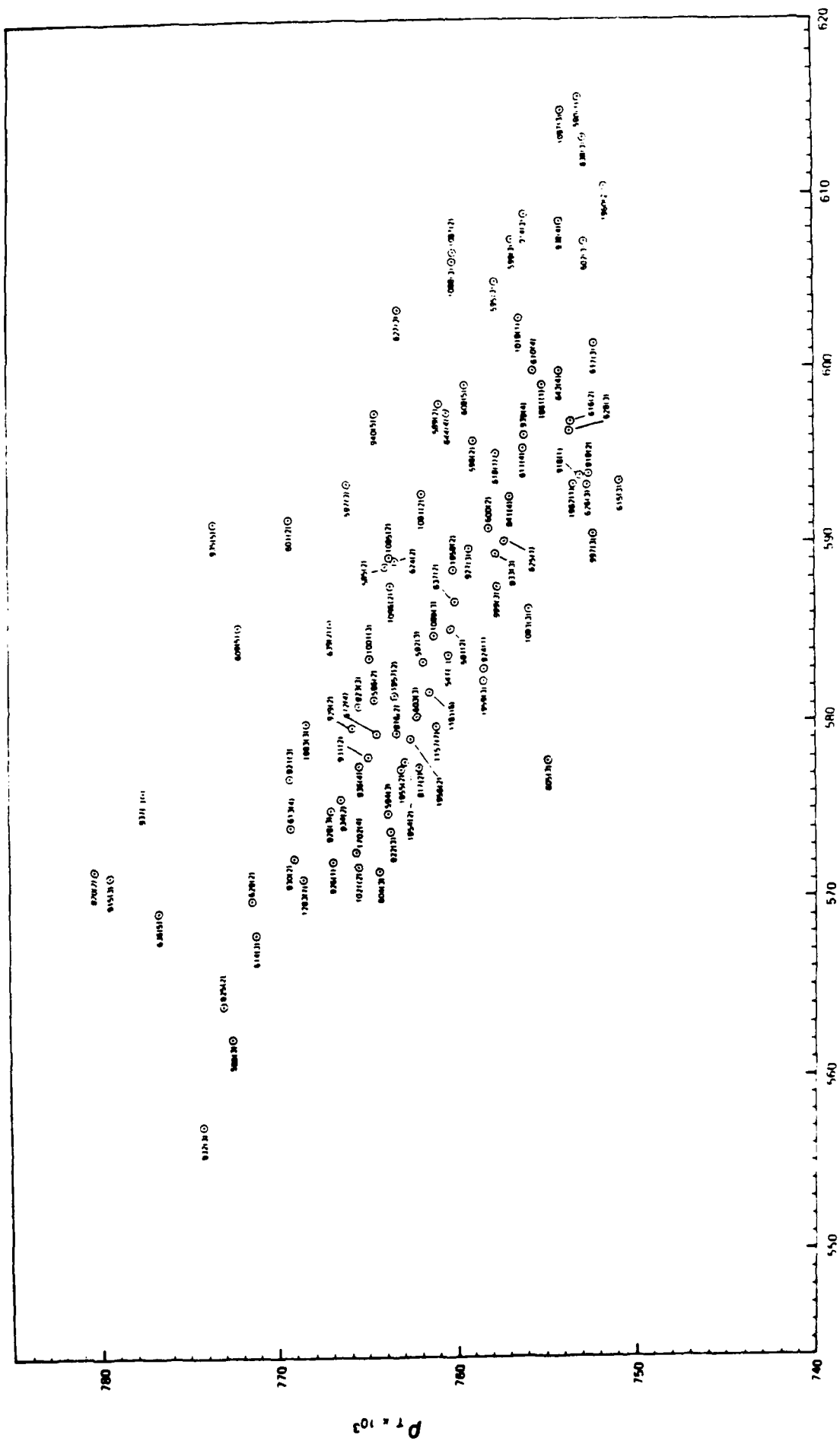


Figure 3. Plot of coefficient of expansion versus density at 60°F.

TABLE 4. GEOGRAPHICAL DISTRICTS

District 1 East Coast	District 2 Midwest	District 3 South	Rocky Mountain	District 5 Pacific	District 6 Far East	District 7	District 8
Connecticut	Illinois	Alabama	Colorado	Arizona	Guam	Europe	South America
Delaware	Indiana	Arkansas	Idaho	California	Singapore	Near East	West Indies
District of Col.	Iowa	Louisiana	Montana	Nevada	Japan	Africa	Canada
Florida	Kansas	Mississippi	Utah	Oregon			Virgin Islands
Georgia	Kentucky	New Mexico	Wyoming	Washington			
Maine	Michigan	Texas		Alaska			
Maryland	Minnesota			Hawaii			
Massachusetts	Missouri						
New Hampshire	Nebraska						
New Jersey	North Dakota						
New York	Ohio						
North Carolina	Oklahoma						
Pennsylvania	South Dakota						
Rhode Island	Tennessee						
South Carolina	Wisconsin						
Vermont							
West Virginia							
Virginia							

SECTION IV

CONCLUSIONS

The data for the 100 JP-4 fuel samples showed good consistency, both internally and with previous work. The samples by a count of 88 to 12 agree more closely with the generalized crude oil tables ("A" series tables) than with the generalized product tables ("B" series tables). The data also show that base density alone is not enough to determine the "correct" thermal expansion coefficient.

SECTION V

REFERENCES

1. Downer, L. and F. A. Inkley, Oil and Gas Journal, 70, No. 25, p. 52-55, June 19, 1972.
2. Hankinson, R. W., R. G. Segers, T. K. Buck, and F. P. Gielzecki, Oil and Gas Journal, 77, No. 52, p. 66-70, December 24, 1979.

APPENDIX A
SOURCE OF FUEL SAMPLES

82-POSF-0541
JP-4, GEFC-1A
J79 Low Smoke

MRC-585
JP-4
Indiana Fuel & Asphalt, Hammond, IN

MRC-588
JP-4
Amber Refining Inc. Refining Co.
Winston, Fort Worth, TX

MRC-589
JP-4
Amoco, Whiting, IN

MRC-590
JP-4
Cibro Petroleum Products, Inc.
Port of Albany, NY

MRC-591
JP-4
Ashland Petroleum Co.
St. Paul Park, MN

MRC-592
JP-4
Pride Refining Co., Abilene, TX

MRC-594
JP-4
Mobil Oil, Beaumont TX

MRC-595
JP-4
Chevron USA, El Paso, TX

MRC-596
JP-4
Allied Materials Corp., Shoud, OK

MRC-597
JP-4
Navajo, Artesia, NM

MRC-598
JP-4
Delta, Memphis, TN

MRC-599
JP-4
Cities Service, Inc.,
Lake Charles, LA

MRC-600
JP-4
Conoco, Inc., Ponca City, OK

MRC-601
JP-4
Conoco, Inc., Ponca City, OK

MRC-602
JP-4
Calcasien Refining Co., CPI
Lake Charles, LA

MRC-603
JP-4
Berry Refining Co., Stevens, AR

MRC-604
JP-4
Atlas Processing Co., Shreveport, LA

MRC-605
JP-4
Southland Oil Co., Sonderville, MS

MRC-608
JP-4
Golden Eagle, Carson City, CA

MRC-609
JP-4
Arco, Los Angeles, CA

MRC-610
JP-4
Amoco, Salt Lake City, UT

MRC-611
JP-4
Amoco, Boise, ID

MRC-612
JP-4
Simons Oil Co., Black Eagle, MT

MRC-613
JP-4
Exxon Company, USA Refining Dept.
Billings, MT

MRC-614
JP-4
Coastal States Ret. Chem.,
Corpus Christie, TX

MRC-615
JP-4
Koch Refining, Corpus Christie, TX

MRC-616
JP-4
Lakeshore Terminal Co.,
Harrisville, MI

MRC-617
JP-4
Chevron USA, Inc., Pascagoula, MS

MRC-618
JP-4
Getty, Delaware City, DE

MRC-624
JP-4
Laketon Asphalt, Inc., Laketon, IN

MRC-625
JP-4
Delaware Storage & Pipeline,
Dover, DE

MRC-626
JP-4
Hunt Oil, Tuscaloosa, AL

MRC-627
JP-4
Howell Hydrocarbons, San Antonia, TX

MRC-628
JP-4
Exxon, Baton Rouge, LA

MRC-629
JP-4
Crystal Refining Co.,
Carson City, MI

MRC-636
JP-4
Mobil Torrence Refining,
Norwalk, CA

MRC-637
JP-4
McConnel AFB, KS

MRC-638
JP-4
Pioneer Refining Ltd., Nixon, TX

MRC-639
JP-4
Amoco Oil Co., Des Moines, IA

MRC-643
JP-4
Chevron USA, Salt Lake Refining,
Salt Lake City, UT

MRC-644
JP-4
Phillips Petroleum Co.,
Wood Crossing, UT

83-POSF-0914
JP-4
Chevron, El Paso, TX

83-POSF-0915
JP-4
Copano, Corpus Christie, TX

83-POSF-0916
JP-4
Allied, Oklahoma City, OK

83-POSF-0917
JP-4
Industrial Fuel & Asphalt, Whiting, IN

83-POSF-0918 JP-4 Getty, Delaware City, DE	83-POSF-0930 JP-4 Oklahoma Ref., Oklahoma City, OK
83-POSF-0919 JP-4 Gladieux, Fort Wayne, IN	83-POSF-0931 JP-4 Tonkawa Ref., Oklahoma City, OK
83-POSF-0920 JP-4 Contractor unknown, Milwaukee, WI	83-POSF-0932 JP-4 Berry, Shreveport, LA
83-POSF-0921 JP-4 Hunt Pan Am, Corpus Christie, TX	83-POSF-0933 JP-4 Winson Ref., Fort Worth, TX
83-POSF-0922 JP-4 Sun, Corpus Christie, TX	83-POSF-0934 JP-4 Allied, Oklahoma City, OK
83-POSF-0923 JP-4 Pioneer, San Antonio, TX	83-POSF-0935 JP-4 Hawaiian Ind. Ewa Beach, Hawaii
83-POSF-0924 JP-4 Sun Petroleum, Marcus Hook, PA	83-POSF-0936 JP-4 Amoco, Salt Lake City, UT
83-POSF-0925 JP-4 Peerless, Grand Rapids, MI	83-POSF-0937 JP-4 Arco-Watson Refinery
83-POSF-0926 JP-4 Ashland, Buffalo, NY	83-POSF-0938 JP-4 Phillips, Wood Cross, UT
83-POSF-0927 JP-4 Aviall, Fort Worth, TX	83-POSF-0939 JP-4 Wyoming Ref., Newcastle, WY
83-POSF-0928 JP-4 Exxon, Baton Rouge, LA	83-POSF-0940 JP-4 Exxon, Benicia, CA
83-POSF-0929 JP-4 Ashland, Louisville, KY	83-POSF-0941 JP-4 Conoco, Commerce City, CO

83-POSF-0997
JP-4
Koch, Corpus Christie, TX

83-POSF-0999
JP-4
Coastal States, Corpus Christie, TX

83-POSF-1001
JP-4
Exxon, Baton Rouge, LA

83-POSF-1019
JP-4
Getty, Delaware City, DE

83-POSF-1021
JP-4
Oklahoma Ref., Oklahoma City, OK

83-POSF-1087
WPAFB, Dayton, OH

83-POSF-1088
JP-4
Howell, San Antonio, TX

83-POSF-1089
JP-4
Amarillo ACFT, Amarillo, TX
aka: 83-POSF-1090

83-POSF-1090
JP-4
Amarillo, ACFT, Amarillo, TX
aka: 83-POSF-1089

83-POSF-1091
JP-4
Amoco, Whiting, IN
aka: 83-POSF-1092

83-POSF-1092
JP-4
Amoco, Whiting, IN

83-POSF-1093
JP-4
Pioneer, Nixon, TX
aka: 83-POSF-1094

83-POSF-1094
JP-4
Pioneer, Nixon, TX

83-POSF-1095
JP-4
WPAFB, Dayton, OH

83-POSF-1096
JP-4
Laketon, Laketon, IN

83-POSF-1097
JP-4
Amerada Hess, Houston, TX
aka: 83-POSF-1098 Duplicate (2)

83-POSF-1098
JP-4
Amerada Hess, Houston, TX

84-POSF-1157
JP-4
Hahn AFB, Germany

83-POSF-1181
JP-4
Osan AFB, Korea

83-POSF-1283
JP-4
Camp New Amsterdam, The Netherlands

83-POSF-1793
JP-4
Amoco, Whiting, IN

83-POSF-1794
JP-4
Mobil, Beaumont, TX

84-POSF-1795
JP-4
Howell, San Antonio, TX

84-POSF-1796
JP-4
Continental, Laurel, DE

84-POSF-1954
JP-4
Continental Services, Escanaba, MI

84-POSF-1955
JP-4
Continental Services, Escanaba, MI

83-POSF-1956
JP-4
Continental Services, Escanaba, MI

84-POSF-1957
JP-4
Oklahoma Ref., Oklahoma City, OK

84-POSF-1958
JP-4
Triangle Ref., St. Louis, MO

84-POSF-1959
JP-4
S. T. Services, Elmendorf, TX

84-POSF-1960
JP-4
Gladieux Ref., Ft. Wayne, IN

84-POSF-1961
JP-4
Getty, Delaware City, DE

84-POSF-1962
JP-4
Sun Ref., Marcus Hook, PA

84-POSF-1963
JP-4
Giant Ref., Gallup, NM

APPENDIX B
TEMPERATURE-DENSITY DATA ON 100 JP-4 FUEL SAMPLES

82-POSF-0541		585 ^a		588 ^a		589 ^a	
Calculated at 60°F = 0.76036 Correlation = -0.999986		Calculated at 60°F = 0.76390 Correlation = -0.999994		Calculated at 60°F = 0.77263 Correlation = -0.999989		Calculated at 60°F = 0.76088 Correlation = -0.999992	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.87	0.77254	32.89	0.77612	32.89	0.78439	32.89	0.77321
45.19	0.76685	44.88	0.77077	44.91	0.77922	44.91	0.76780
54.76	0.76265	55.24	0.76602	55.24	0.77471	55.24	0.76305
59.90	0.76043	60.23	0.76384	60.23	0.77252	60.23	0.76077
65.09	0.75809	64.39	0.76194	64.39	0.77075	64.38	0.75890
74.90	0.75376	74.82	0.75721	74.82	0.76622	74.82	0.75419
85.02	0.74923	84.64	0.75272	84.64	0.76191	84.64	0.74964
95.20	0.74471	95.47	0.74792	95.43	0.75719	95.47	0.74468
105.11	0.74026	104.39	0.74387	104.39	0.75324	104.39	0.74057
119.60	0.73368	119.54	0.73692	119.54	0.74651	119.55	0.73355

590 ^a		591 ^a		592 ^a		594 ^a	
Calculated at 60°F = 0.75296 Correlation = -0.999986		Calculated at 60°F = 0.76023 Correlation = -0.999994		Calculated at 60°F = 0.76174 Correlation = -0.999983		Calculated at 60°F = 0.76383 Correlation = -0.999978	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.10	0.76536	32.89	0.77224	32.89	0.77373	32.90	0.77565
45.13	0.75987	44.91	0.76705	44.91	0.76845	44.91	0.77049
54.75	0.75542	55.24	0.76233	55.24	0.76388	55.24	0.76594
60.20	0.75290	60.23	0.76016	60.23	0.76170	60.23	0.76380
65.25	0.75055	64.38	0.75827	64.38	0.75984	64.38	0.76199
75.10	0.74599	74.82	0.75365	74.82	0.75520	74.82	0.75734
84.77	0.74149	84.64	0.74922	84.64	0.75075	84.64	0.75288
94.59	0.73690	95.47	0.74439	95.47	0.74595	95.76	0.74808
105.07	0.73193	104.39	0.74039	104.39	0.74189	104.39	0.74427
119.88	0.72491	119.55	0.73351	119.55	0.73502	119.55	0.73743

^aThese samples were also used in Contract F08635-85-C-0067, "Distillate Fuel Variability".

(continued)

595 ^a		596 ^a		597 ^a		598 ^a	
Calculated at 60°F = 0.76444 Correlation = -0.999985		Calculated at 60°F = 0.75762 Correlation = -0.999991		Calculated at 60°F = 0.76604 Correlation = -0.999985		Calculated at 60°F = 0.75878 Correlation = -0.999982	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.90	0.76999	32.90	0.77645	32.34	0.77860	32.34	0.77126
44.91	0.76458	44.91	0.77117	45.07	0.77283	45.07	0.76552
55.24	0.75981	55.24	0.76657	55.27	0.76822	55.27	0.76095
60.23	0.75753	60.23	0.76435	59.70	0.76618	59.70	0.75893
64.38	0.75565	64.38	0.76252	65.11	0.76374	65.11	0.75649
74.82	0.75088	74.82	0.75788	74.99	0.75930	74.99	0.75207
84.64	0.74630	84.64	0.75348	84.84	0.75476	84.84	0.74755
95.47	0.74132	95.39	0.74864	94.94	0.75012	94.94	0.74296
104.39	0.73716	104.39	0.74461	104.20	0.74581	104.20	0.73866
119.55	0.73006	119.55	0.73775	120.09	0.73846	120.09	0.73133

599 ^a		600 ^a		601 ^a		602 ^a	
Calculated at 60°F = 0.75673 Correlation = -0.999985		Calculated at 60°F = 0.75804 Correlation = -0.999985		Calculated at 60°F = 0.76916 Correlation = -0.999987		Calculated at 60°F = 0.75268 Correlation = -0.999985	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.34	0.76941	32.34	0.77041	32.34	0.78173	33.10	0.76491
45.07	0.76359	45.07	0.76472	45.07	0.77594	45.13	0.75951
55.27	0.75893	55.27	0.76019	55.27	0.77132	54.75	0.75515
59.70	0.75688	59.70	0.75819	59.70	0.76930	60.20	0.75260
65.11	0.75440	65.29	0.75573	65.29	0.76681	65.25	0.75030
74.99	0.74991	74.99	0.75137	74.99	0.76237	75.10	0.74577
84.84	0.74531	84.84	0.74690	84.84	0.75785	84.77	0.74135
94.94	0.74064	94.94	0.74237	94.94	0.75323	94.59	0.73683
104.20	0.73631	104.20	0.73813	104.20	0.74893	105.07	0.73196
120.09	0.72885	120.09	0.73086	120.09	0.74156	119.88	0.72504

(continued)

603 ^a		604 ^a		605 ^a		608 ^a	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76218		60°F = 0.76431		60°F = 0.75486		60°F = 0.75935	
Correlation = -0.999985		Correlation = -0.999986		Correlation = -0.999992		Correlation = -0.999978	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.10	0.77403	33.10	0.77600	33.10	0.76658	32.34	0.77189
45.13	0.76878	45.13	0.77082	45.13	0.76137	45.07	0.76613
54.75	0.76456	54.75	0.76667	54.75	0.75719	55.27	0.76152
60.20	0.76211	60.20	0.76427	60.20	0.75480	59.70	0.75949
65.25	0.75988	65.25	0.76203	65.25	0.75259	65.29	0.75701
75.10	0.75550	75.10	0.75770	75.10	0.74827	74.99	0.75258
84.77	0.75122	84.77	0.75347	84.77	0.74403	84.84	0.74805
94.59	0.74686	94.59	0.74918	94.59	0.73973	94.94	0.74342
105.07	0.74216	105.07	0.74451	105.07	0.73510	104.20	0.73912
119.88	0.73543	119.88	0.73791	119.88	0.72851	120.09	0.73170

609 ^a		610 ^a		611 ^a		612 ^a	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.77268		60°F = 0.75558		60°F = 0.75622		60°F = 0.76440	
Correlation = -0.999988		Correlation = -0.999984		Correlation = -0.999984		Correlation = -0.999989	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.10	0.78482	33.10	0.76773	33.10	0.76829	33.10	0.77629
45.17	0.77940	45.17	0.76230	45.17	0.76289	45.17	0.77096
54.75	0.77511	54.75	0.75803	54.75	0.75863	54.75	0.76677
60.20	0.77260	60.20	0.75555	60.20	0.75617	60.20	0.76434
65.25	0.77033	65.26	0.75322	65.26	0.75389	65.26	0.76209
75.10	0.76586	75.13	0.74874	75.13	0.74944	75.13	0.75772
84.77	0.76148	84.76	0.74433	84.76	0.74505	84.76	0.75342
94.59	0.75700	94.58	0.73985	94.58	0.74062	94.58	0.74905
105.07	0.75219	105.07	0.73503	105.07	0.73581	105.07	0.74433
119.88	0.74534	119.88	0.72815	119.88	0.72898	119.88	0.73764

(continued)

613 ^a		614 ^a		615 ^a		616 ^a	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76923		60°F = 0.77141		60°F = 0.75068		60°F = 0.75328	
Correlation = -0.999987		Correlation = -0.999986		Correlation = -0.999982		Correlation = -0.999978	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.34	0.78142	32.34	0.78353	33.10	0.76262	32.34	0.76565
45.08	0.77582	45.08	0.77793	45.17	0.75725	45.08	0.76001
55.28	0.77136	55.28	0.77349	54.75	0.75309	55.28	0.75547
59.71	0.76938	59.71	0.77150	60.20	0.75061	59.71	0.75343
64.98	0.76705	64.98	0.76926	65.26	0.74836	64.98	0.75105
74.98	0.76267	74.98	0.76488	75.13	0.74399	74.98	0.74660
84.81	0.75828	84.81	0.76055	84.76	0.73963	84.81	0.74213
94.92	0.75377	94.92	0.75609	94.58	0.73523	94.92	0.73756
104.20	0.74960	104.20	0.75194	105.07	0.73046	104.20	0.73329
120.04	0.74248	120.04	0.74485	119.88	0.72373	120.04	0.72599

617 ^a		618 ^a		624 ^a		625 ^a	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.75209		60°F = 0.75769		60°F = 0.76333		60°F = 0.75720	
Correlation = -0.999978		Correlation = -0.999979		Correlation = -0.999978		Correlation = -0.999970	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.34	0.76453	33.10	0.76976	32.97	0.77542	32.97	0.76918
45.08	0.75885	45.47	0.76423	45.20	0.76997	45.20	0.76382
55.28	0.75428	54.75	0.76012	54.71	0.76576	54.71	0.75959
59.71	0.75227	60.20	0.75766	59.91	0.76343	59.91	0.75733
64.98	0.74985	65.26	0.75535	65.09	0.76108	65.09	0.75496
74.98	0.74538	75.13	0.75090	74.90	0.75669	74.90	0.75058
84.81	0.74085	84.76	0.74654	85.02	0.75208	85.02	0.74601
94.92	0.73627	94.58	0.74205	95.20	0.74747	95.20	0.74146
104.20	0.73200	105.07	0.73725	105.12	0.74293	105.12	0.73594
120.04	0.72464	119.88	0.73040	119.59	0.73625	119.59	0.73025

(continued)

626 ^a		627 ^a		628 ^a		629 ^a	
Calculated at 60°F = 0.75260		Calculated at 60°F = 0.76313		Calculated at 60°F = 0.75356		Calculated at 60°F = 0.77167	
Correlation = -0.999975		Correlation = -0.999978		Correlation = -0.999984		Correlation = -0.999988	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.97	0.76460	32.97	0.77549	32.34	0.76597	32.34	0.78380
45.20	0.75921	45.20	0.76995	45.08	0.76027	45.08	0.77820
54.71	0.75497	54.71	0.76559	55.28	0.75570	55.28	0.77376
59.91	0.75273	59.91	0.76325	59.71	0.75371	59.71	0.77179
65.09	0.75035	65.09	0.76083	64.98	0.75134	64.98	0.76946
74.90	0.74597	74.90	0.75630	74.98	0.74690	74.98	0.76516
85.02	0.74143	85.02	0.75160	84.81	0.74240	84.81	0.76080
95.20	0.73686	95.20	0.74687	94.92	0.73783	94.92	0.75635
105.12	0.73234	105.12	0.74226	104.20	0.73359	104.20	0.75222
119.59	0.72568	119.59	0.73540	120.04	0.72630	120.04	0.74512

636 ^a		637 ^a		638 ^a		639 ^a	
Calculated at 60°F = 0.77666		Calculated at 60°F = 0.76001		Calculated at 60°F = 0.75267		Calculated at 60°F = 0.76711	
Correlation = -0.999981		Correlation = -0.999985		Correlation = -0.999981		Correlation = -0.999983	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.97	0.78856	32.87	0.77228	32.87	0.76536	32.87	0.77946
45.20	0.78318	45.20	0.76651	45.19	0.75939	45.19	0.77365
54.71	0.77902	54.71	0.76232	54.76	0.75505	54.76	0.76943
59.91	0.77678	59.91	0.76007	59.90	0.75274	59.90	0.76719
65.09	0.77446	65.09	0.75774	65.09	0.75032	65.09	0.76480
74.90	0.77007	74.90	0.75336	74.90	0.74581	74.90	0.76043
85.02	0.76559	85.02	0.74885	85.02	0.74110	85.02	0.75586
95.20	0.76109	95.20	0.74426	95.20	0.73640	95.20	0.75128
105.12	0.75660	105.11	0.73980	105.11	0.73176	105.11	0.74674
119.59	0.75005	119.59	0.73325	119.60	0.72491	119.60	0.74013

(continued)

643 ^a		644 ^a		83-POSF-0914		83-POSF-0915	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.75402		60°F = 0.76050		60°F = 0.75597		60°F = 0.77937	
Correlation = -0.999986		Correlation = -0.999987		Correlation = -0.999991		Correlation = -0.999984	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.95	0.76644	32.87	0.77298	32.95	0.76840	32.95	0.79138
45.19	0.76062	45.19	0.76715	44.51	0.76312	44.51	0.78626
54.76	0.75636	54.76	0.76285	55.26	0.75824	55.26	0.78153
59.90	0.75408	59.90	0.76056	59.58	0.75619	59.58	0.77958
65.09	0.75171	65.09	0.75816	65.03	0.75368	65.03	0.77710
74.90	0.74728	74.90	0.75373	74.19	0.74945	74.19	0.77310
85.02	0.74269	85.02	0.74912	84.40	0.74472	84.40	0.76852
95.20	0.73805	95.20	0.74445	95.77	0.73940	95.77	0.76338
105.11	0.73349	105.11	0.73993	105.08	0.73504	105.08	0.75921
119.60	0.72683	119.60	0.73318	119.39	0.72848	120.76	0.75204

83-POSF-0916		83-POSF-0917		83-POSF-0918		83-POSF-0919	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76321		60°F = 0.76205		60°F = 0.75287		60°F = 0.75230	
Correlation = -0.999986		Correlation = -0.999962		Correlation = -0.999989		Correlation = -0.999985	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.95	0.77512	32.95	0.77378	32.95	0.76495	32.95	0.76434
44.51	0.77007	44.51	0.76897	44.51	0.75981	44.51	0.75923
55.26	0.76535	55.26	0.76425	55.26	0.75501	55.26	0.75442
59.58	0.76343	59.58	0.76230	59.58	0.75308	59.58	0.75255
65.03	0.76101	65.03	0.75988	65.03	0.75065	65.03	0.75008
74.19	0.75696	74.19	0.75584	74.19	0.74656	74.19	0.74596
84.40	0.75243	84.40	0.65130	84.40	0.74197	84.43	0.74140
95.77	0.74733	95.77	0.74617	95.77	0.73682	95.84	0.73623
105.08	0.74317	105.08	0.74199	105.08	0.73259	105.04	0.73203
120.76	0.73609	119.39	0.73577	119.39	0.72607	119.39	0.72550

(continued)

83-POSF-0920		83-POSF-0921		83-POSF-0922		83-POSF-0923	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.78029		60°F = 0.76931		60°F = 0.76367		60°F = 0.76543	
Correlation = -0.999994		Correlation = -0.999988		Correlation = -0.999984		Correlation = -0.999992	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.95	0.79236	32.95	0.78129	32.95	0.77545	32.95	0.77743
44.51	0.78724	44.51	0.77621	44.51	0.77041	44.51	0.77236
55.26	0.78242	55.26	0.77145	55.26	0.76580	55.26	0.76757
59.58	0.78048	59.58	0.76952	59.58	0.76384	59.58	0.76563
65.03	0.77808	65.03	0.76709	65.03	0.76144	65.03	0.76322
74.19	0.77397	74.19	0.76302	74.19	0.75742	74.19	0.75913
84.43	0.76942	84.43	0.75847	84.43	0.75295	84.43	0.75456
95.84	0.76420	95.84	0.75337	95.84	0.74790	95.84	0.74942
105.04	0.76005	105.04	0.74920	105.04	0.74377	105.04	0.74521
119.39	0.75365	120.76	0.74208	120.76	0.73676	119.99	0.73859

83-POSF-0924		83-POSF-0925		83-POSF-0926		83-POSF-0927	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.75824		60°F = 0.77287		60°F = 0.76683		60°F = 0.75911	
Correlation = -0.999994		Correlation = -0.999992		Correlation = -0.999954		Correlation = -0.999987	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.89	0.77024	32.89	0.78464	33.08	0.77871	33.08	0.77111
44.88	0.76495	44.88	0.77957	44.56	0.77370	44.56	0.76607
55.24	0.76032	55.24	0.77497	54.52	0.76929	54.52	0.76159
60.23	0.75818	60.23	0.77278	59.81	0.76696	59.81	0.75927
64.39	0.75633	64.39	0.77097	65.21	0.76449	65.21	0.75675
74.82	0.75168	74.82	0.76641	74.88	0.76022	74.88	0.75242
84.64	0.74729	84.64	0.76207	85.62	0.75553	85.62	0.74766
95.43	0.74251	95.43	0.75732	95.88	0.75090	95.88	0.74299
104.39	0.73855	104.39	0.75344	105.46	0.74658	105.46	0.73863
119.54	0.73170	119.54	0.74675	119.99	0.74062	120.81	0.73165

(continued)

83-POSF-0928		83-POSF-0929		83-POSF-0930		83-POSF-0931	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76712		60°F = 0.76566		60°F = 0.76898		60°F = 0.76491	
Correlation = -0.999993		Correlation = -0.999988		Correlation = -0.999992		Correlation = -0.999992	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.08	0.77899	33.08	0.77757	33.01	0.78099	33.01	0.77697
44.56	0.77400	44.56	0.77255	44.56	0.77572	44.56	0.77168
54.52	0.76958	54.52	0.76817	54.70	0.77127	54.70	0.76723
59.81	0.76726	59.81	0.76578	59.75	0.76908	59.75	0.76500
65.21	0.76477	65.21	0.76333	65.32	0.76667	65.32	0.76260
74.88	0.76050	74.88	0.75904	74.33	0.76267	74.33	0.75858
85.62	0.75582	85.62	0.75432	84.13	0.75834	84.13	0.75423
95.88	0.75120	95.88	0.74968	95.48	0.75329	95.48	0.74914
105.46	0.74691	105.46	0.74538	105.40	0.74887	105.40	0.74470
120.06	0.74047	120.81	0.73843	120.36	0.74226	120.36	0.73806

83-POSF-0932		83-POSF-0933		83-POSF-0934		83-POSF-0935	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.77426		60°F = 0.75768		60°F = 0.76643		60°F = 0.77346	
Correlation = -0.999992		Correlation = -0.999993		Correlation = -0.999995		Correlation = -0.999993	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.01	0.78596	33.01	0.76979	33.01	0.77841	33.01	0.78583
44.56	0.78091	44.56	0.76456	44.56	0.77321	44.56	0.78050
54.70	0.77655	54.70	0.76004	54.70	0.76878	54.70	0.77591
59.75	0.77439	59.75	0.75778	59.75	0.76654	59.75	0.77357
65.32	0.77203	65.32	0.75537	65.32	0.76412	65.32	0.77108
74.33	0.76807	74.35	0.75127	74.35	0.76008	74.35	0.76692
84.13	0.76382	84.13	0.74687	84.13	0.75578	84.13	0.76242
95.48	0.75886	95.48	0.74171	95.48	0.75069	95.48	0.75713
105.40	0.75449	105.40	0.73722	105.40	0.74629	105.40	0.75252
120.06	0.74827	120.06	0.73072	120.36	0.73961	119.98	0.74585

(continued)

83-POSF-0936		83-POSF-0937		83-POSF-0938		83-POSF-0939	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76547		60°F = 0.77754		60°F = 0.75414		60°F = 0.75603	
Correlation = -0.999996		Correlation = -0.999995		Correlation = -0.999991		Correlation = -0.999988	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.01	0.77747	33.03	0.78966	33.03	0.76655	33.03	0.76819
44.56	0.77229	44.55	0.78446	44.55	0.76120	44.55	0.76297
54.70	0.76784	54.69	0.77995	54.69	0.75658	54.69	0.75842
59.75	0.76556	59.75	0.77764	59.75	0.75427	59.75	0.75616
65.29	0.76314	65.29	0.77519	65.29	0.75177	65.29	0.75373
74.35	0.75912	74.35	0.77114	74.35	0.74759	74.35	0.74957
84.13	0.75478	84.11	0.76672	84.11	0.74307	84.11	0.74518
95.51	0.74967	95.51	0.76159	95.51	0.73777	95.51	0.73994
105.40	0.74522	105.39	0.75706	105.39	0.73316	105.39	0.73541
119.98	0.73883	119.98	0.75049	119.98	0.72640	119.98	0.72876

83-POSF-0940		83-POSF-0941		83-POSF-0997		83-POSF-0999	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76438		60°F = 0.75694		60°F = 0.75222		60°F = 0.75765	
Correlation = -0.999991		Correlation = -0.999993		Correlation = -0.999987		Correlation = -0.99987	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.03	0.77677	33.03	0.76907	32.47	0.76445	32.47	0.76990
44.55	0.77141	44.55	0.76388	44.98	0.75891	44.98	0.76434
54.69	0.76680	54.69	0.75933	54.72	0.75453	54.72	0.75998
59.75	0.76451	59.75	0.75706	60.36	0.75209	60.36	0.75753
65.29	0.76200	65.29	0.75462	65.21	0.74991	65.21	0.75536
74.35	0.75782	74.35	0.75051	74.96	0.74561	74.96	0.75102
84.11	0.75331	84.11	0.74609	84.86	0.74119	84.86	0.74657
95.51	0.74801	95.51	0.74091	94.65	0.73681	94.65	0.74220
105.39	0.74362	105.39	0.73637	104.52	0.73233	104.52	0.73772
120.04	0.73673	120.04	0.72987	119.96	0.72533	119.96	0.73069

(continued)

83-POSF-1001		83-POSF-1019		83-POSF-1021		83-POSF-1087	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76471		60°F = 0.75634		60°F = 0.76561		60°F = 0.75995	
Correlation = -0.999989		Correlation = -0.999982		Correlation = -0.999991		Correlation = -0.999984	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.47	0.77698	32.47	0.76886	32.47	0.77773	32.47	0.77261
44.98	0.77141	44.98	0.76318	44.98	0.77223	44.98	0.76686
54.72	0.76708	54.72	0.75880	54.72	0.76796	54.71	0.76241
60.36	0.76457	60.36	0.75621	60.36	0.76548	60.36	0.75982
65.21	0.76241	65.21	0.75397	65.11	0.76341	65.11	0.75767
74.96	0.75806	74.96	0.74957	74.96	0.75903	74.97	0.75308
84.86	0.75360	84.86	0.74503	84.86	0.75464	84.86	0.74848
94.65	0.74920	94.62	0.74051	94.65	0.75028	94.65	0.74392
104.52	0.74475	104.52	0.73594	104.52	0.74589	104.51	0.73934
119.96	0.73770	119.96	0.72871	119.96	0.73896	119.96	0.73203

83-POSF-1088		83-POSF-1089		83-POSF-1090		83-POSF-1091	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76006		60°F = 0.76132		60°F = 0.76148		60°F = 0.76184	
Correlation = -0.999983		Correlation = -0.999986		Correlation = -0.999989		Correlation = -0.999987	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.08	0.77240	32.47	0.77355	33.08	0.77340	32.47	0.77427
44.56	0.76723	45.00	0.76799	44.56	0.76839	45.00	0.76859
54.52	0.76263	54.71	0.76370	54.52	0.76394	54.71	0.76424
59.81	0.76021	60.36	0.76119	59.81	0.76161	60.36	0.76172
65.21	0.75759	65.11	0.75912	65.21	0.75909	65.08	0.75958
74.88	0.75318	74.97	0.75468	74.88	0.75483	74.97	0.75511
85.62	0.74830	84.86	0.75024	85.62	0.75012	84.86	0.75061
95.88	0.74347	94.65	0.74585	95.88	0.74548	94.65	0.74613
105.46	0.73900	104.51	0.74141	105.49	0.74132	104.51	0.74165
120.04	0.73213	119.96	0.73437	120.05	0.73468	119.96	0.73449

(continued)

83-POSF-1092		83-POSF-1093		83-POSF-1094		83-POSF-1095	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76189		60°F = 0.75591		60°F = 0.75594		60°F = 0.76357	
Correlation = -0.999990		Correlation = -0.999995		Correlation = -0.999988		Correlation = -0.999984	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.12	0.77400	32.89	0.76794	33.12	0.76779	32.47	0.77594
44.64	0.76892	44.88	0.76268	44.64	0.76280	45.00	0.77031
54.57	0.76438	54.73	0.75823	54.57	0.75842	54.71	0.76597
59.74	0.76201	60.23	0.75581	59.74	0.75606	60.36	0.76342
65.21	0.75948	64.39	0.75394	65.21	0.75355	65.08	0.76131
74.88	0.75516	74.82	0.74937	74.88	0.74933	74.97	0.75685
85.62	0.75033	84.64	0.74493	85.62	0.74466	84.86	0.75237
95.88	0.74565	95.76	0.73998	95.85	0.74001	94.65	0.74795
105.48	0.74123	104.39	0.73616	105.49	0.73581	104.51	0.74346
120.05	0.73456	119.54	0.72932	120.05	0.72924	119.96	0.73633

83-POSF-1096		83-POSF-1097		83-POSF-1098		83-POSF-1157	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76354		60°F = 0.75325		60°F = 0.75332		60°F = 0.76113	
Correlation = -0.999990		Correlation = -0.999986		Correlation = -0.999987		Correlation = -0.999992	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.12	0.77557	32.89	0.76576	33.12	0.76574	33.31	0.77290
44.64	0.77051	44.88	0.76027	44.64	0.76052	44.58	0.76794
54.57	0.76603	55.24	0.75549	54.57	0.75592	54.81	0.76343
59.74	0.76367	60.23	0.75315	59.74	0.75347	59.77	0.76127
65.21	0.76116	64.39	0.75126	65.21	0.75085	65.49	0.75896
74.88	0.75687	74.82	0.74644	74.88	0.74641	75.04	0.75452
85.62	0.75204	84.64	0.74181	85.62	0.74140	85.10	0.74998
95.85	0.74741	95.76	0.73659	95.85	0.73662	94.59	0.74582
105.48	0.74301	104.39	0.73260	105.49	0.73209	104.48	0.74140
120.05	0.73637	119.54	0.72541	120.05	0.72518	119.27	0.73475

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83-POSF-1181		83-POSF-1283		84-POSF-1793		84-POSF-1794	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76133		60°F = 0.76054		60°F = 0.75121		60°F = 0.76112	
Correlation = -0.999991		Correlation = -0.999980		Correlation = -0.999983		Correlation = -0.999992	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.31	0.77315	33.31	0.78018	32.16	0.76410	32.16	0.77348
44.58	0.76816	44.58	0.77524	45.12	0.75814	45.12	0.76779
54.81	0.76363	54.81	0.77076	54.89	0.75363	54.89	0.76344
59.77	0.76145	59.77	0.76861	60.28	0.75111	60.28	0.76097
65.31	0.76094	65.49	0.76610	65.18	0.74882	65.18	0.75883
75.04	0.75468	75.04	0.76188	74.96	0.74429	74.98	0.75448
85.10	0.75018	85.10	0.75741	84.89	0.73966	84.89	0.74995
94.59	0.74598	94.59	0.75326	94.70	0.73507	94.70	0.74568
104.48	0.74153	104.48	0.74885	104.61	0.73038	104.61	0.74124
119.27	0.73485	119.27	0.74224	120.02	0.72304	120.11	0.73422

84-POSF-1795		84-POSF-1796		84-POSF-1954		84-POSF-1955	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.75614		60°F = 0.76333		60°F = 0.76275		60°F = 0.76292	
Correlation = -0.999987		Correlation = -0.999993		Correlation = -0.999994		Correlation = -0.999994	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.18	0.76914	32.18	0.77565	33.11	0.77461	33.11	0.77480
45.14	0.76313	45.14	0.76994	45.23	0.76927	45.23	0.76943
54.89	0.75858	54.89	0.76566	54.93	0.76501	54.93	0.76517
60.31	0.75601	60.31	0.76320	59.77	0.76283	59.77	0.76301
65.19	0.75373	65.19	0.76102	65.31	0.76043	65.31	0.76060
74.98	0.74914	74.98	0.75668	75.04	0.75612	75.04	0.75630
84.89	0.74447	84.89	0.75230	85.10	0.75167	85.10	0.75185
94.71	0.73986	94.71	0.74790	95.06	0.74723	95.06	0.74743
104.64	0.73512	104.64	0.74345	105.16	0.74276	105.16	0.74293
120.11	0.72770	120.11	0.73548	119.92	0.73611	119.93	0.73354

(continued)

84-POSF-1956		84-POSF-1957		84-POSF-1958		84-POSF-1959	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.76256		60°F = 0.76327		60°F = 0.76054		60°F = 0.75818	
Correlation = -0.999991		Correlation = -0.999993		Correlation = -0.999980		Correlation = -0.999982	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
33.08	0.77446	33.08	0.77524	32.77	0.77296	32.77	0.77041
45.23	0.76909	45.23	0.76983	45.28	0.76705	45.28	0.76461
54.93	0.76481	54.93	0.76553	54.93	0.76276	54.93	0.76037
59.77	0.76264	59.77	0.76339	59.78	0.76957	59.78	0.75821
65.31	0.76025	65.31	0.76094	65.31	0.75814	65.31	0.75581
75.04	0.75591	75.04	0.75659	75.04	0.75379	75.04	0.75154
85.10	0.75146	85.10	0.75212	85.10	0.74928	85.10	0.74707
95.06	0.74705	95.06	0.74766	95.06	0.74482	95.06	0.74269
105.16	0.74253	105.16	0.74314	105.16	0.74024	105.28	0.73808
119.92	0.73585	119.92	0.73644	119.93	0.73354	119.93	0.73354

84-POSF-1960		84-POSF-1961		84-POSF-1962		84-POSF-1963	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.75142		60°F = 0.75818		60°F = 0.75142		60°F = 0.76828	
Correlation = -0.999982		Correlation = -0.999982		Correlation = -0.999982		Correlation = -0.999988	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.77	0.76411	33.31	0.76718	33.31	0.76515	33.31	0.78014
45.28	0.75809	44.58	0.76209	44.58	0.76014	44.58	0.77515
54.93	0.75369	54.81	0.75750	54.81	0.75556	54.81	0.77060
59.78	0.75148	59.77	0.75526	59.77	0.75337	59.77	0.76843
65.31	0.74898	65.49	0.75269	65.49	0.75083	65.49	0.76588
75.04	0.74447	75.04	0.74832	75.04	0.74653	75.04	0.76159
85.10	0.73988	85.10	0.74372	85.10	0.74199	85.10	0.75705
95.06	0.73533	94.59	0.73943	94.59	0.73774	94.59	0.75283
105.28	0.73056	104.48	0.73487	104.48	0.73325	104.48	0.74836
119.93	0.72371	119.27	0.72805	119.27	0.72650	119.27	0.74162

APPENDIX C

TEMPERATURE-DENSITY DATA ON 24 FUEL SAMPLES

JP-7 82-POSF-026		JP-5 82-POSF-0155		JP-4 82-POSF-0159		DF-Marine 82-POSF-0184	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.79933		60°F = 0.81828		60°F = 0.75993		60°F = 0.84530	
Correlation = -0.999972		Correlation = -0.999997		Correlation = -0.999977		Correlation = -0.999984	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.63	0.81020	32.60	0.82935	32.60	0.77205	32.63	0.85610
44.98	0.80535	44.92	0.82438	44.92	0.76660	44.98	0.85126
54.75	0.80141	54.79	0.82039	54.79	0.76230	54.75	0.84737
59.68	0.79948	59.69	0.81844	59.69	0.76012	59.68	0.84544
65.20	0.79727	65.16	0.81620	65.16	0.75769	65.20	0.84325
74.64	0.79351	74.41	0.81246	74.41	0.75359	74.64	0.83952
84.44	0.78960	84.77	0.80825	84.77	0.74886	84.44	0.83565
94.67	0.78551	94.93	0.80416	94.93	0.74437	94.67	0.83160
105.08	0.78131	105.06	0.79999	105.06	0.73975	105.08	0.82742
120.13	0.77504	119.90	0.79395	119.90	0.73302	120.13	0.82128

JP-5 82-POSF-0314		JP-4 82-POSF-0323		Shale Crude 82-POSF-0325		JP-5 82-POSF-0443	
Calculated at		Calculated at		Sample too		Calculated at	
60°F = 0.82361		60°F = 0.77997		viscous for		60°F = 0.81261	
Correlation = -0.999974		Correlation = -0.999982		measurement		Correlation = -0.999988	
°F	ρ	°F	ρ			°F	ρ
32.63	0.83462	32.61	0.79217			32.63	0.82360
44.98	0.82965	44.92	0.78668			44.98	0.81864
54.75	0.82574	54.79	0.78234			54.75	0.81471
59.68	0.82375	59.69	0.78014			59.68	0.81275
65.20	0.82153	65.16	0.77772			65.20	0.81054
74.64	0.81773	74.41	0.77360			74.64	0.80675
84.44	0.81377	84.77	0.76885			84.44	0.80280
94.67	0.80964	94.93	0.76434			94.67	0.79868
105.08	0.80535	105.06	0.75972			105.08	0.79440
120.13	0.79905	119.90	0.75295			120.13	0.78812

(continued)

Shale JP-8		Jet A		DF-2		Jet A	
82-POSF-0562		83-POSF-0709		83-POSF-1051		83-POSF-1254	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.80322		60°F = 0.81167		60°F = 0.84178		60°F = 0.81005	
Correlation = -0.999967		Correlation = -0.999978		Correlation = -0.999992		Correlation = -0.999980	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.63	0.81444	32.63	0.82269	32.63	0.85232	32.60	0.82116
44.98	0.80937	44.98	0.81773	44.91	0.84757	44.91	0.81619
54.75	0.80537	54.75	0.81378	54.75	0.84379	54.75	0.81220
59.68	0.80336	59.68	0.81180	59.70	0.84190	59.70	0.81022
65.20	0.80111	65.20	0.80958	65.20	0.83979	65.20	0.80797
74.64	0.79724	74.64	0.80578	74.64	0.83618	74.64	0.80413
84.44	0.79320	84.44	0.80183	84.20	0.83242	84.20	0.80017
94.67	0.78900	94.67	0.79771	94.66	0.82847	94.66	0.79599
105.08	0.78462	105.08	0.79341	105.01	0.82440	105.01	0.79168
120.20	0.77814	120.20	0.78710	120.20	0.81846	120.13	0.78534

Shale JP-8		Jet A		DF-2		Jet A	
83-POSF-1257		83-POSF-1260		83-POSF-1530		83-POSF-1723	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.81004		60°F = 0.81345		60°F = 0.79597		60°F = 0.81277	
Correlation = -0.999996		Correlation = -0.999997		Correlation = -0.999976		Correlation = -0.999997	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.61	0.82114	32.61	0.82446	32.60	0.80729	32.61	0.82389
44.92	0.81614	44.92	0.81952	44.91	0.80221	44.96	0.81889
54.79	0.81216	54.79	0.81557	54.75	0.79816	54.79	0.81491
59.69	0.81019	59.69	0.81360	59.70	0.79613	59.69	0.81292
65.16	0.80796	65.27	0.81131	65.20	0.79386	65.27	0.81064
74.41	0.80422	74.41	0.80767	74.64	0.78996	74.41	0.80693
84.77	0.79999	84.77	0.80349	84.20	0.78591	84.77	0.80269
94.93	0.79587	94.93	0.79940	94.66	0.78165	94.93	0.79856
105.06	0.79174	105.06	0.79530	105.01	0.77725	105.06	0.79443
119.90	0.78563	119.90	0.78925	120.13	0.77078	119.90	0.78831

(continued)

JP-7		JP-8		JP-8		JP-5	
84-POSF-2003		84-POSF-2035		84-POSF-2038		84-POSF-2071	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.79754		60°F = 0.79871		60°F = 0.80155		60°F = 0.80593	
Correlation = -0.999997		Correlation = -0.999981		Correlation = -0.999986		Correlation = -0.999997	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.61	0.80841	32.60	0.80990	32.60	0.81290	32.61	0.81694
44.96	0.80351	44.91	0.80488	44.92	0.80782	44.96	0.81198
54.78	0.79963	54.75	0.80087	54.75	0.80373	54.78	0.80804
59.68	0.79769	59.70	0.79886	59.70	0.80170	59.68	0.80608
65.27	0.79545	65.20	0.79662	65.20	0.79943	65.27	0.80381
74.41	0.79184	74.64	0.79277	74.64	0.79551	74.41	0.80015
84.80	0.78769	84.20	0.78876	84.20	0.79144	84.80	0.79594
94.92	0.78366	94.66	0.78457	94.66	0.78717	94.92	0.79185
105.06	0.77961	105.01	0.78022	105.01	0.78275	105.06	0.78775
119.89	0.77365	120.20	0.77383	120.00	0.77641	119.89	0.78171

JPTS		Gasoline		Gasoline		Gasoline	
84-POSF-2075		84-POSF-2078		84-POSF-2079		84-POSF-2080	
Calculated at		Calculated at		Calculated at		Calculated at	
60°F = 0.79483		60°F = 0.75056		60°F = 0.75056		60°F = 0.75056	
Correlation = -0.999987		This sample so volatile that density measurements could not be made, even at temperatures as low as 32°F.		This sample so volatile that density measurements could not be made even at temperatures as low as 32°F.		Correlation = -0.999098	
°F	ρ	°F	ρ	°F	ρ	°F	ρ
32.60	0.80605			32.62	0.76371	32.62	0.76371
44.92	0.80102			44.96	0.75749	44.96	0.75749
54.75	0.79700			54.78	0.75359	54.78	0.75359
59.70	0.79497			59.68	Bubbles	59.68	Bubbles
65.20	0.79272			65.27	Bubbles	65.27	Bubbles
74.64	0.78886			74.41	0.74423	74.41	0.74423
84.20	0.78484			84.80	0.73789	84.80	0.73789
94.66	0.78062			94.92	0.73363	94.92	0.73363
105.01	0.77625			105.06	Bubbles	105.06	Bubbles
120.00	0.76999			119.89	Bubbles	119.89	Bubbles

APPENDIX D

COEFFICIENT OF THERMAL EXPANSION AND DENSITY
VALUES FOR MISCELLANEOUS FUELS AT 60°F

<u>Sample No.</u>	<u>Alpha Value at 60°F</u>	<u>Density (kg/m³)</u>	<u>Type of fuel</u>	<u>Nearest Group</u>
26	499.32	799.35	JP-7	Jet
155	493.24	818.31	JP-5	Jet
159	585.32	759.96	JP-4	Crude
184	467.92	845.32	DF-Marine	Jet
314	490.20	823.63	JP-5	Jet
323	572.86	780.00	JP-4	Crude
443	495.45	812.63	JP-5	Jet
562	512.12	803.24	JP-8 (shale)	Jet
709	497.25	811.69	Jet A	Jet
1051	456.70	841.80	DF-2	Jet
1254	502.19	810.08	Jet A	Jet
1257	499.45	810.07	Jet A	Jet
1260	493.31	813.48	Jet A	Jet
1530	520.64	796.00	Jet A	Jet
1723	499.01	812.80	Jet A	Jet
2003	496.84	797.57	JP-7	Jet
2035	512.32	798.74	JP-8	Jet
2038	518.16	801.58	JP-8	Jet
2071	498.38	805.95	JP-5	Jet
2075	516.37	794.85	JPTS	Jet
2080	645.52	750.61	Gasoline	Crude

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