Designation: D1405/D1405M – 08

StandardTest Method for Estimation of Net Heat of Combustion of Aviation Fuels[1]

This standard is issued under the fixed designation D1405/D1405M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the estimation of the net heat of combustion at constant pressure in SI units (megajoules per kilogram) or inch-pound units [Btu per pound].

1.2 This test method is purely empirical and is applicable only to liquid hydrocarbon fuels derived by normal refining processes from conventional crude oil, which conform to the requirements of specifications for aviation gasolines, or aircraft turbine and jet engine fuels of limited boiling ranges and compositions as described in Note 1.

NOTE 1—The estimation of the net heat of combustion of a hydrocarbon fuel from aniline-gravity product is justifiable only when the fuel belongs to a well-defined class for which a relation between heat of combustion and aniline-gravity product has been derived from accurate experimental measurements on representative samples of that class. Even in this case, the possibility that the estimates may be in error by large amounts for individual fuels should be recognized. The classes of fuels used to establish the correlation presented in this test method are represented by the following specifications:

Fuel	Specification
Aviation gasoline fuels:	
Grades 80, 82, 100/130, and 115/145	Specification D910 Specification D6227 DEF STAN 91–90 NATO Code F-18
Aviation turbine fuels:	
JP-4,Avtag/FSII	MIL-DTL-5624 DEF STAN 91–88 NATO Code F-40
JP-5,Avcat/FSII	MIL-DTL-5624 DEF STAN 91–86 NATO Code F-44
Jet A, Jet A-1, Avtur	Specification D1655 DEF STAN 91–91 NATO Code F-35

1.3 This test method is not applicable to pure hydrocarbons. It is not intended as a substitute for experimental measurements of heat of combustion.

1.4 The heat of combustion may also be determined in SI units by Test Method D4529. Test Method D4529 requires calculation of a single equation for all aviation fuels with a precision equivalent to that of this test method.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)

D240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter

D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

D611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents

D910 Specification for Aviation Gasolines

D941 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Lipkin Bicapillary Pycnometer[3]

D1217 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Bingham Pycnometer

D1250 Guide for Use of the Petroleum Measurement Tables

D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.05 on Properties of Fuels, Petroleum Coke and Carbon Material.

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This test method has been approved by the sponsoring committee and accepted by the Cooperating Societies in accordance with established procedures. DOI: 10.1520/D1405_D1405M-08.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

D1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1655 Specification for Aviation Turbine Fuels
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4529 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D6227 Specification for Unleaded Aviation Gasoline Containing a Non-hydrocarbon Component

2.2 *U.S. Military Standards:*[4]

MIL-DTL-5624 Aviation Turbine Fuels, Grades JP-4, JP-5, and JP-5/JP-8 ST
MIL-T-83133 Aviation Turbine Fuel, Grade JP-8

2.3 *Directorate of Standardization, Ministry of Defence:*[5]

DEF STAN 91–86 Aviation Turbine Fuel, High Flash Kerosene Type with Fuel System Icing Inhibitor
DEF STAN 91–88 Aviation Turbine Fuel, Wide Cut Type with Fuel System Icing Inhibitor
DEF STAN 91–90 Aviation Gasoline 80 and 100LL
DEF STAN 91–91 Aviation Turbine Fuel, Kerosene Type, Jet A-1

2.4 *NATO Codes:*[5]

F-18 Aviation Gasoline
F-35 Aviation Turbine Fuel, Jet A Type
F-40 Aviation Turbine Fuel, Grade JP-4
F-44 Aviation Turbine Fuel, Grade JP-5

3. Summary of Test Method

3.1 Correlations[6,7] have been established between the net heat of combustion and the product of the aniline point and API gravity. These relations, assuming the sample to be sulfur free, are given by the following equations:

3.1.1 Where the net heat of combustion is required in SI units (Note 2) (megajoules per kilogram):

Type Fuel	Equation	
Aviation gasoline, Grades 100–130 and 115–145	$Qp\,(\text{net}) = 41.9557 + 0.00020543\,(A \times G)$	(1)
JP-4	$Qp\,(\text{net}) = 41.8145 + 0.00024563\,(A \times G)$	(2)
JP-5	$Qp\,(\text{net}) = 41.6680 + 0.00024563\,(A \times G)$	(3)
Kerosine Jet A or A-1	$Qp\,(\text{net}) = 41.6796 + 0.00025407\,(A \times G)$	(4)

where:
Q_p (net) = net heat of combustion, MJ/kg, on a sulfur-free basis,
A = aniline point, °F, and
G = gravity, °API.

NOTE 2—In SI, the unit of heat of combustion has the dimensions J/kg, but for practical use a multiple is more convenient. The megajoule per kilogram (MJ/kg) is 10^6 J/kg and is customarily used for the representation of heats of combustion of petroleum fuels, particularly for mixtures such as those covered in this International Standard.

3.1.2 Where the net heat of combustion is required in inch-pound units or British Thermal Units [Btu per pound].

Type Fuel	Equation	
Aviation gasoline, Grades 100–130 and 115–145	$Qp\,(\text{net}) = 18\,037.7 + 0.0883\,(A \times G)$	(5)
JP-4	$Qp\,(\text{net}) = 17\,977 + 0.1056\,(A \times G)$	(6)
JP-5	$Qp\,(\text{net}) = 17\,914 + 0.1056\ \ (A \times G)$	(7)
Kerosine Jet A or A-1	$Qp\,(\text{net}) = 17\,919 + 0.10923\ \ (A \times G)$	(8)

where:
Q_p (net) = net heat of combustion, Btu/lb, on a sulfur-free basis,
A = aniline point, °F, and
G = gravity, °API.

3.2 To correct for the effect of the sulfur content of the sample on the net heat of combustion, apply the following equation:

3.2.1 Where the net heat of combustion is required in SI units (megajoules per kilogram):

$$Q` = Qp(\text{net}) \times [1 - 0.01(S)] + 0.1016(S) \quad (9)$$

where:

$Q`$ = net heat of combustion, MJ/kg, of the sample containing S % sulfur,

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

[5] Available from Directorate of Standardization, Stan Ops I, Room 1138, Kentigern House, 65 Brown Street, Glasgow, G2 8EX, U.K.

[6] Cogliano, J. A., and Jessup, R. S., "Relation Between Net Heat of Combustion and Aniline-Gravity Product of Aircraft Fuels," *ASTM Bulletin*, ASTBA, No. 201, October 1954, p. 55 (TP 217); also the National Institute of Standards and Technology findings as reported by Armstrong , G. T., Jessup, R. S., and Mears, T. W., "Net Heat of Combustion of Aviation Gasoline and its Correlations with Other Properties," *Journal of Chemical and Engineering Data*, Vol 3, 1958, pp. 20–28.

[7] Armstrong, G. T., Fano, L., Jessup, R. S., Marantz, S., Mears, T. W., and Walker, J. A., "Net Heat of Combustion and Other Properties of Kerosene and Related Fuels," *Journal of Chemical and Engineering Data*, National Institute of Standards and Technology, Gaithersburg, MD. Vol 7, No. 1, January 1962, pp. 107–117.

S = sulfur content of the sample, mass, %, and
0.1016 = a constant based on the thermo-chemical data on sulfur compounds.

3.2.2 Where the net heat of combustion is required in inch-pound units or British Thermal Units [Btu per pound]:

$$Q` = Qp(\text{net}) \times [1 - 0.01(S)] + 43.7(S) \quad (10)$$

where:

$Q`$ = net heat of combustion, Btu/lb, of the sample containing S % sulfur,
S = sulfur content of the sample, mass %, and
43.7 = a constant based on the thermochemical data on sulfur compounds.

3.3 The empirical linear Eq 1-4 and Eq 5-9 for the estimated net heat of combustion were derived by the method of least squares from accurate data on fuels, most of which conformed at least approximately to specifications for aviation gasolines, or aircraft turbine and jet engine fuels of Types JP-4 and JP-5 and to Specification D1655, Jet A and A-1.

4. Significance and Use

4.1 This test method is intended for use as a guide in cases where an experimental determination of heat of combustion is not available and cannot be made conveniently, and where an estimate is considered satisfactory. It is not intended as a substitute for experimental measurements of heat of combustion.

NOTE 3—The procedure for the experimental determination of the net heat of combustion is described in Test Methods D240 and D4809.

5. Procedure

5.1 Determine the aniline points of the sample to the nearest 0.05°C [0.1°F] as described in Test Method D611.

5.2 Determine the API gravity of the sample to the nearest 0.1° API as described in Test Method D287. Alternatively, determine the relative density by Test Methods D941, D1217, and D4052 and correct the result to API gravity by Guide D1250.

5.3 Determine the sulfur content of the sample to the nearest 0.02 % sulfur as described in Test Methods D129, D1266, D2622, D3120, D4294, or D5453 depending upon the volatility of the sample.

6. Calculation

6.1 Calculate the product of the aniline point in degrees Fahrenheit and the gravity in degrees API; round off the value obtained to the nearest integer.

TABLE 1 Values of Q′ for Aviation Gasolines Calculated from Eq 1 and Eq 9 in MJ/kg

Aniline-Gravity Product	Net Heat of Combustion, MJ/kg				
	0% Sulfur	0.1% Sulfur	0.2% Sulfur	0.3% Sulfur	0.4% Sulfur
4 000	42.777	42.745	42.712	42.680	42.647
4 200	42.819	42.786	42.753	42.721	42.688
4 400	42.860	42.827	42.794	42.761	42.729
4 600	42.901	42.868	42.835	42.802	42.770
4 800	42.942	42.909	42.876	42.843	42.811
5 000	42.983	42.950	42.917	42.884	42.852
5 200	43.024	42.991	42.958	42.925	42.892
5 400	43.065	43.032	42.999	42.966	42.933
5 600	43.106	43.073	43.040	43.007	42.974
5 800	43.147	43.114	43.081	43.048	43.015
6 000	43.188	43.155	43.122	43.089	43.056
6 200	43.229	43.196	43.163	43.130	43.097
6 400	43.270	43.237	43.204	43.171	43.138
6 600	43.312	43.278	43.245	43.212	43.179
6 800	43.353	43.319	43.286	43.253	43.220
7 000	43.394	43.360	43.327	43.294	43.261
7 200	43.435	43.402	43.368	43.335	43.302
7 400	43.476	43.443	43.409	43.376	43.343
7 600	43.517	43.484	43.450	43.417	43.384
7 800	43.558	43.525	43.491	43.458	43.424
8 000	43.599	43.566	43.532	43.499	43.465
8 200	43.640	43.607	43.573	43.540	43.506
8 400	43.681	43.648	43.614	43.581	43.547
8 600	43.722	43.689	43.655	43.622	43.588
8 800	43.763	43.730	43.696	43.663	43.629
9 000	43.805	43.771	43.737	43.704	43.670
9 200	43.846	43.812	43.778	43.745	43.711
9 400	43.887	43.853	43.819	43.786	43.752
9 600	43.928	43.894	43.860	43.827	43.793
9 800	43.969	43.935	43.901	43.867	43.834
10 000	44.010	43.976	43.942	43.908	43.875
10 200	44.051	44.017	43.983	43.949	43.916
10 400	44.092	44.058	44.024	43.990	43.956
10 600	44.133	44.099	44.065	44.031	43.997
10 800	44.174	44.140	44.106	44.072	44.038
11 000	44.215	44.181	44.147	44.113	44.079
11 200	44.257	44.222	44.188	44.154	44.120
11 400	44.298	44.263	44.229	44.195	44.161
11 600	44.339	44.305	44.270	44.236	44.202
11 800	44.380	44.346	44.311	44.277	44.243
12 000	44.421	44.387	44.352	44.318	44.284

6.2 From Tables 1-8, make a linear interpolation between rows bracketing the aniline-gravity products and within columns bracketing the sulfur content of the sample. Use the table applicable to the type of product being tested. Thus, use Table 1 or Table 5 for Aviation Gasolines, Table 2 or Table 6 for JP-4 jet-type fuels; Table 3 or Table 7 for JP-5 jet type fuels, and Table 4 or Table 8 for kerosene-type aviation turbine fuels (Specification D1655, Jet A or A-1).

TABLE 2 Values of Q' for JP-4 Fuels Calculated from Eq 2 and Eq 9 in MJ/kg

Aniline-Gravity Product	Net Heat of Combustion, MJ/kg					
	0% Sulfur	0.2% Sulfur	0.4% Sulfur	0.6% Sulfur	0.8% Sulfur	1.0% Sulfur
5 200	43.092	43.026	42.960	42.894	42.828	42.762
5 400	43.141	43.075	43.009	42.943	42.877	42.811
5 600	43.190	43.124	43.058	42.992	42.926	42.860
5 800	43.239	43.173	43.107	43.041	42.975	42.908
6 000	43.288	43.222	43.156	43.090	43.023	42.957
6 200	43.337	43.271	43.205	43.138	43.072	43.006
6 400	43.387	43.320	43.254	43.187	43.121	43.054
6 600	43.436	43.369	43.303	43.236	43.169	43.103
6 800	43.485	43.418	43.351	43.285	43.218	43.152
7 000	43.534	43.467	43.400	43.334	43.267	43.200
7 200	43.583	43.516	43.449	43.383	43.316	43.249
7 400	43.632	43.565	43.498	43.431	43.364	43.297
7 600	43.681	43.614	43.547	43.480	43.413	43.346
7 800	43.730	43.663	43.596	43.529	43.462	43.395
8 000	43.780	43.712	43.645	43.578	43.511	43.443

TABLE 3 Values of Q′ for JP-5 Fuels Calculated from Eq 3 and Eq 9 in MJ/kg

Analine-Gravity Product	Net Heat of Combustion, MJ/kg					
	0% Sulfur	0.2% Sulfur	0.4% Sulfur	0.6% Sulfur	0.8% Sulfur	1.0% Sulfur
4 200	42.700	42.635	42.569	42.504	42.439	42.374
4 400	42.749	42.684	42.618	42.553	42.488	42.423
4 600	42.798	42.733	42.667	42.602	42.537	42.472
4 800	42.847	42.782	42.716	42.651	42.586	42.520
5 000	42.896	42.831	42.765	42.700	42.634	42.569
5 200	42.945	42.880	42.814	42.749	42.683	42.617
5 400	42.994	42.929	42.863	42.797	42.732	42.666
5 600	43.044	42.978	42.912	42.846	42.780	42.715
5 800	43.093	43.027	42.961	42.895	42.829	42.763
6 000	43.142	43.076	43.010	42.944	42.878	42.812
6 200	43.191	43.125	43.059	42.993	42.927	42.861
6 400	43.240	43.174	43.108	43.042	42.975	42.909
6 600	43.289	43.223	43.157	43.090	43.024	42.958
6 800	43.338	43.272	43.206	43.139	43.073	43.007
7 000	43.387	43.321	43.255	43.188	43.122	43.055

6.3 From the values obtained in 6.2, make a linear interpolation for the sulfur content within the row for the calculated aniline gravity constant.

6.3.1 *Example:*

Sample: JP-4 Fuel

6.3.1.1 *Determined Values:*

Aniline point, A = 137°F

Gravity, G = 54.8° API

Sulfur content = 0.10 mass %

6.3.1.2 *Calculated Value:*

A × G product = 7508

By interpolation from Table 2:

A × G	0 % Sulfur	0.1 % Sulfur	0.2 % Sulfur
7400	43.632		43.565
7508[A]	43.659[B]	43.625[C]	43.592[B]
7600	43.681		43.614

By interpolation from Table 6:

A × G	0.0 % Sulfur	0.1 % Sulfur	0.2 % Sulfur
7400	18 758		18 729
7508[A]	18 769[B]	18 755[C]	18 740[B]
7600	18 779		18 750

[A] Value calculated from determined values.

[B] First step interpolation between rows in columns bracketing the sulfur content.

[C] Second step interpolation within a row between columns.

6.3.1.3 *Estimated Net Heat of Combustion:*

43.625 MJ/kg

[18 755 Btu/lb]

7. Report

7.1 Report the result in megajoule per kilogram to the nearest 0.001 or [British thermal units per pound] to the nearest integer as estimated Net Heat of Combustion, D1405 or [D1405M].

8. Precision and Bias

8.1 *Repeatability*—The difference between successive test results obtained by the same operator with the apparatus under constant operating conditions on identical test material (using a second set of measured values for the aniline point temperature, the relative density, and the sulfur content determined by Test Methods D611, D1298, and D129, respectively) would in the long run, in the normal and correct operation of the test method, exceed the following value only in one case in twenty:

$$\text{Repeatability} = 0.012 \text{ MJ/kg or } [5 \text{ Btu/lb}] \quad (11)$$

8.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material (using the aniline point temperature, the relative density, and the sulfur content determined by Test Methods D611, D1298, and D129, respectively) would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

$$\text{Reproducibility} = 0.035 \text{ MJ/kg or } [15 \text{ Btu/lb}] \quad (12)$$

NOTE 4—Use of fuel property data obtained with greater or lesser precision than that of the methods indicated will have a like trend on the precision of the predicted heat of combustion.

8.3 *Bias*—No general statement is made on bias for the standard, since the data used to determine the correlation cannot be compared with accepted reference materials.

9. Keywords

9.1 aviation fuel; gross heat of combustion; heat energy; heat of combustion; heating tests; net heat of combustion