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

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1. Scope

1.1 This test method covers the estimation of the net heat of combustion at constant pressure in metric (SI) units, megajoules per kilogram.

1.2 This test method is purely empirical, and it 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 its aniline point temperature and density is justifiable only when the fuel belongs to a well-defined class for which a relationship between these quantities has been derived from accurate experimental measurements on representative samples of that class. Even in this class, the possibility that the estimates can be in error by large amounts for individual fuels should be recognized. The JP-8 fuel, although not experimentally tested, has properties similar to JP-5 and Jet A fuels and can be considered in the same class. The classes of fuels used to establish the correlation presented in this test method are represented by the following applications:

Fuel	Specification
Aviation gasoline fuels: Grades 80, 82, 100/130, and 115/145	Specification D 910 Specification D 6227 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
JP-8, Avtur/FSII	MIL-DTL-83133 DEF STAN 91–87 NATO Code F-34
Jet A, Jet A-1, Avtur	Specification D 1655 DEF STAN 91–91 NATO Code F-35

1.3 The net heat of combustion can also be estimated by Test Method D 1405. Test Method D 1405 requires calculation of one of four equations dependent on the fuel type with the precision equivalent to that of this test method.

1.4 The values stated in acceptable metric units are to be regarded as the standard.

1.5 *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:*

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[2]

D 240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter[2]

D 611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents[2]

D 910 Specification for Aviation Gasolines[2]

D 941 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Lipkin Bicapillary Pycnometer[2]

D 1217 Test Method for Density and Relative Density (Specific Gravity) of Liquids by Bingham Pycnometer[2]

D 1250 Guide for Petroleum Measurement Tables[2]

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[2]

D 1298 Test Method for Density, Relative Density (Specific Gravity) or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[2]

D 1405 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels[2]

[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 Petroleum, Coke, and Carbon Materials.

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[2] *Annual Book of ASTM Standards,* Vol 05.01.

D 1655 Specification for Aviation Turbine Fuels[2]
D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[3]
D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry[3]
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[3]
D 4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectrometry[3]
D 4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)[3]
D 5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence[4]
D 6227 Specification for Grade 82 Unleaded Aviation Gasoline[5]

2.2 *U.S. Military Standards:*[6]
MIL-DTL-5624 Aviation Turbine Fuels, Grades JP-4, JP-5, and JP-5/JP-8 ST
MIL-DTL-83133 Aviation Turbine Fuel, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8+100

2.3 *Directorate of Standardization, Ministry of Defence:*[7]
DEF STAN 91–86 Aviation Turbine Fuel, High Flash Kerosene Type with Fuel System Icing Inhibitor
DEF STAN 91–87 Aviation Turbine Fuel, 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
DEF STAN 91–91 Aviation Turbine Fuel, Kerosene Type, Jet A-1

2.4 *NATO Codes:*[7]
F-18 Aviation Gasoline
F-34 Aviation Turbine Fuel, Grade JP-8
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 The aniline point, density, and sulfur content of the sample are determined by experimental test methods and the net heat of combustion is calculated using the values obtained by these test methods based on reported correlations.[8,9,10]

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 2).

NOTE 2—The procedures for the experimental determination of the gross and net heats of combustion are described in Test Methods D 240 and D 4809.

4.2 The net heat of combustion is a factor in the performance of all aviation fuels. Because the exhaust of aircraft engines contains uncondensed water vapors, the energy released by fuel in vaporizing water cannot be recovered and must be subtracted from gross heat of combustion determinations to calculate net heat of combustion. For high performance weight-limited aircraft, the net heat of combustion per unit mass and the mass of fuel loaded determine the total safe range. The proper operation of the aircraft engine also requires a certain minimum net energy of combustion per unit volume of fuel delivered.

4.3 Because the heat of combustion of hydrocarbon fuel-mixtures are slowly varying functions of the physical properties of the mixtures, the heat of combustion of the mixtures can often be estimated with adequate accuracy from simple field tests of density and aniline point temperature, without the elaborate apparatus needed for calorimetry.

4.4 The empirical quadratic equation for the net heat of combustion of a sulfur-free fuel was derived by the method of least squares from accurate measurements on fuels, most of which conformed to specifications for fuels found in Note 1 and were chosen to cover a range of values of properties. Those fuels not meeting specifications were chosen to extend the range of densities and aniline-point temperatures above and below the specification limits to avoid end effects. The sulfur correction was found by a simultaneous least-squares regression analysis of sulfur-containing fuels among those tested.

5. Procedure

5.1 Determine the aniline point temperature of the sample to the nearest 0.05°C as described in Test Methods D 611.

5.2 Determine the density at 15°C of the sample to the nearest 0.5 kg/m^3 as described in Test Methods D 941, D 1217, D 1298, or D 4052 or Guide D 1250.

5.3 Determine the sulfur content of the sample to the nearest 0.02 mass % sulfur as described in Test Methods D 129, D 1266, D 2622, D 3120, D 4294, or D 5453.

6. Calculation

6.1 Calculate the net heat of combustion using either Procedure A or B.

[3] *Annual Book of ASTM Standards*, Vol 05.02.
[4] *Annual Book of ASTM Standards*, Vol 05.03.
[5] *Annual Book of ASTM Standards*, Vol 05.04.
[6] Available from Department of Defense Single Stock Point, 700 Robbins Ave., Building 4D, Philadelphia, PA 19111-5098.
[7] Available from Directorate of Standardization, Stan Ops 1, Room 1138, Kentigern House, 65 Brown Street, Glasgow, G2 8EX, U.K.
[8] Armstrong, G. T., Fano, L., Jessup, R. S. Maraatz, S., Mears, T. W., and Walker, J. A., "Net Heat of Combustion and Other Properties of Kerosine and Related Fuels," *Journal of Chemical and Engineering Data*, National Institute for Standards and Technology, Washington, DC, Vol 7, No. 1, January 1962, pp. 107–117.
[9] Cogliance, 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 for 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 Correlation with Other Properties," *Journal of Chemical and Engineering Data*, Vol 3, 1958, pp. 20–28.
[10] Nuttall, R. L., and Armstrong, G. T., "Estimation of Net Enthalpies of Some Aviation Fuels Expressed in the International System of Units (SI)," NIST Technical Note 937, April 1977.

6.1.1 *Procedure A* (*By Equation*)—Insert the measured values in (Eq 1) and calculate *Qp*, the net heat of combustion at constant pressure on a sulfur-free basis (Note 3).

$$Qp = 22.9596 - 0.0126587\,A + 26\,640.9\,(1/\rho) + 32.622\,(A/\rho) - 6.69030 \times 10^{-5}(A)^2 - 9\ 217\ 760\,(1/\rho)^2 \quad (1)$$

where:
ρ = density at 15°C, kg/m^3,
A = aniline point temperature, °C, and
Qp = net heat of combustion on sulfur-free basis, MJ kg^{-1}.

NOTE 3—In SI units the heat of combustion has the unit J kg^{-1}, but for practical purposes a multiple is more convenient. The megajoule per kilogram (MJ kg^{-1}) is 10^6 J kg^{-1} 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.

6.1.2 *Procedure B* (*See Table 1*)—Make a linear interpolation between rows bracketing the density and within columns bracketing the aniline point of the sample. Then make a linear interpolation for the aniline point within the row for the calculated density to obtain *Qp*.

6.2 Calculate the net heat of combustion, $Q'p$, corrected for sulfur content in accordance with the following equation:

$$Q'p = Qp - 0.1163\,S \quad (2)$$

where:
S = sulfur content, mass %.

6.3 Calculate the volumetric net heat of combustion in accordance with the following equation:

$$q_p = Q_p\rho \times 10^{-3} \quad (3)$$

where:
q_p = volumetric heat of combustion, MJ L^{-1}.

7. Report

7.1 Report the following information:

7.1.1 Report the result for the net heat of combustion in MJ kg^{-1} to the nearest 0.001.

7.1.2 Report the result for the volumetric net heat of combustion q_p in MJ L^{-1} to the nearest 0.001, if required.

8. Precision and Bias [11]

8.1 *Precision*—The following criteria shall be used for judging the acceptability of estimated heat of combustion results (95 % confidence) when using data on the aniline point temperature, the density, and the sulfur content of a fuel determined by Test Methods D 611, D 1298, and D 129, respectively (Note 4):

8.1.1 *Repeatability*— The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, 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:

Repeatability	0.012 MJ/kg or 5 BTU/lb

8.1.2 *Reproducibility*— The difference between two single

[11] The precision is based on the conversion of data in Test Method D 1405 to SI units and the calculations using this test method.

TABLE 1 Net Heat of Combustion

Fuel, ρ kg/m^3 × 10^{-3}	Q_p, MJ/kg						
	A, °C						
	20	30	40	50	60	70	80
0.6500	42.8522	43.1941	43.5225	43.8376	44.1393	44.4276	44.7026
0.6600	42.8721	43.2064	43.5272	43.8347	44.1288	44.4095	44.6768
0.6700	42.8819	43.2087	43.5222	43.8223	44.1090	44.3824	44.6423
0.6800	42.8823	43.2020	43.5083	43.8013	44.0808	44.3470	44.5998
0.6900	42.8743	43.1870	43.4864	43.7723	44.0449	44.3042	44.5500
0.7000	42.8584	43.1644	43.4570	43.7362	44.0021	44.2545	44.4936
0.7100	42.8354	43.1348	43.4209	43.6935	43.9528	44.1987	44.4313
0.7200	42.8059	43.0990	43.3786	43.6449	43.8973	44.1373	44.3635
0.7300	42.7704	43.0573	43.3307	43.5908	43.8375	44.0708	44.2908
0.7400	42.7295	43.0103	43.2778	43.5318	43.7725	43.9997	44.2136
0.7500	42.6837	42.9586	43.2201	43.4683	43.7031	43.9245	44.1325
0.7600	42.6332	42.9024	43.1582	43.4007	43.6297	43.8454	44.0477
0.7700	42.5787	42.8423	43.0925	43.3294	43.5529	43.7630	43.9597
0.7800	42.5203	42.7785	43.0233	43.2547	43.4728	43.6775	43.8687
0.7900	42.4585	42.7114	42.9509	43.1771	43.3898	43.5892	43.7752
0.8000	42.3936	42.6413	42.8757	43.0967	43.3043	43.4985	43.6793
0.8100	42.3258	42.5685	42.7978	43.0138	43.2163	43.4055	43.5813
0.8200	42.2555	42.4933	42.7177	42.9287	43.1264	43.3106	43.4815
0.8300	42.1828	42.4158	42.6354	42.8417	43.0345	43.2140	43.3801
0.8400	42.1080	42.3363	42.5513	42.7528	42.9410	43.1158	43.2772
0.8500	42.0313	42.2551	42.4655	42.6624	42.8460	43.0163	43.1731
0.8600	41.9529	42.1722	42.3781	42.5707	42.7498	42.9156	43.0650
0.8700	41.8730	42.0879	42.2895	42.4777	42.6524	42.8138	42.9619
0.8800	41.7917	42.0024	42.1997	42.3836	42.5541	42.7112	42.8550
0.8900	41.7092	41.9157	42.1085	42.2886	42.4549	42.6079	42.7475

and independent results obtained by different operators working in different laboratories on identical test material 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:

Reproducibility	0.035 MJ/kg or 14 BTU/lb

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

NOTE 5—As a guide, an estimate of the precision on a volume basis calculated for a fuel with a density of 810.0 kg/m^3 is as follows:

Repeatability	9.7 MJ/m^3
Reproducibility	28 MJ/m^3

8.2 *Bias*—No general statement is made on bias for the test method 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