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

This standard is issued under the fixed designation D3338/D3338M; 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 U.S. Department of Defense.

ε[1] NOTE—Section 3 was corrected editorially in September 2014.
ε[2] NOTE—SI units formatting was corrected editorially in July 2015.

1. Scope

1.1 This test method covers the estimation of the net heat of combustion (megajoules per kilogram or [Btu per pound]) of aviation gasolines and aircraft turbine and jet engine fuels in the range from 40.19 to 44.73 megajoules per kilogram or [17 280 to 19 230 Btu per pound]. The precision for estimation of the net heat of combustion outside this range has not been determined for this test method.

1.2 This test method is purely empirical and is applicable to liquid hydrocarbon fuels that conform to the specifications for aviation gasolines or aircraft turbine and jet engine fuels of grades Jet A, Jet A-1, Jet B, JP-4, JP-5, JP-7, and JP-8.

NOTE 1—The experimental data on heat of combustion from which the Test Method D3338 correlation was devised was obtained by a precision method similar to Test Method D4809.

NOTE 2—The estimation of the net heat of combustion of a hydrocarbon fuel is justifiable only when the fuel belongs to a well-defined class for which a relation between heat of combustion and aromatic and sulfur contents, density, and distillation range of the fuel 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 fuels used to establish the correlation presented in this method are defined as follows:

Fuels:
Aviation gasoline—Grades 100/130 and 115/145 **(1, 2)**[2]
Kerosines, alkylates, and special WADC fuels **(3)**
Pure hydrocarbons—paraffins, naphthenes, and aromatics **(4)**
Fuels for which data were reported by the Coordinating Research Council **(5)**.

NOTE 3—The property ranges used in this correlation are as follows:

Aromatics—from 0 mass percent to 100 mass percent
API Gravity—from [25.7 ° to 81.2 °API]
Volatility—from [160 °F to 540 °F], average boiling point

1.3 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.

1.3.1 Although the test method permits the calculation of net heat of combustion in either SI or inch-pound units, SI units are the preferred units.

1.3.2 The net heat of combustion can also be estimated in inch-pound units by Test Method D1405 or in SI units by Test Method D4529. Test Method D1405 requires calculation of one of four equations dependent on the fuel type with a precision equivalent to that of this test method. Test Method D4529 requires calculation of a single equation for all aviation fuels with a precision equivalent to that of this test method. Unlike Test Method D1405 and D4529, Test Method D3338/D3338M does not require the use of aniline point.

1.4 *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:*[3]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
D240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

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

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] 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.

D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D1405 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D1552 Test Method for Sulfur in Petroleum Products by High Temperature Combustion and IR Detection
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
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
D6379 Test Method for Determination of Aromatic Hydrocarbon Types in Aviation Fuels and Petroleum Distillates—High Performance Liquid Chromatography Method with Refractive Index Detection

2.2 *Energy Institute Standard:*[4]
IP 436 Test Method for Determination of Aromatic Hydrocarbon Types in Aviation Fuels and Petroleum Distillates—High Performance Liquid Chromatography Method with Refractive Index Detection

3. Terminology

3.1 *Definitions:*

3.1.1 *gross heat of combustion, Qg (MJ/kg), n*—quantity of energy released when a unit mass of fuel is burned in a constant volume enclosure, with the products being gaseous, other than water, which is condensed to the liquid state.

3.1.2 *net heat of combustion, Qn (MJ/kg), n*—quantity of energy released when a unit mass of fuel is burned at constant pressure, with all of the products, including water, being gaseous.

4. Summary of Test Method

4.1 A correlation (**6**) in inch-pound units has been established between the net heat of combustion and gravity, aromatic content, and average volatility of the fuel. This correlation was converted to SI units; the relationships are given by the following equations:

Type Fuel

All aviation gasolines, aircraft turbine, and jet engine fuels

Equation

$$Q_{p1} = 16.24(G) - 3.007(A) + 0.01714(G \times V) \quad (1)$$
$$- 0.2983(A \times G) + 0.00053(A \times G \times V) + 17685$$

or in SI units

$$Q_{p2} = [5528.73 - 92.6499\,A + 10.1601\,T \quad (2)$$
$$+ 0.314169\,AT]/D + 0.0791707A$$
$$- 0.00944893T - 0.000292178AT + 35.9936$$

where:

Q_{p1} = net heat of combustion, [Btu/lb] sulfur-free basis,
Q_{p2} = net heat of combustion, MJ/kg, sulfur-free basis,
A = aromatics, volume %
G = gravity, API,
V = volatility: boiling point or average of Test Method D86 or D2887 10 %, 50 %, and 90 % points, [°F],
D = density, kg/m^3 at 15 °C
T = volatility: boiling point or average of Test Method D86 or D2887 10 %, 50 %, and 90 % points, °C.

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

$$Q = Q_p \times [1 - 0.01(S_1)] + C(S_1) \quad (3)$$

where:

Q = net heat of combustion, MJ/kg or [Btu/lb], of the fuel containing S_1 weight percent sulfur,
Q_p = Q_{p1} [inch-pound units] or Q_{p2} (SI units),
S_1 = sulfur content of the fuel, mass %, and
C = 0.10166 (SI units) or [43.7 (inch-pound units)] = a constant based on the thermochemical data on sulfur compounds.

4.3 The empirical equations for the estimated net heat of combustion, sulfur-free basis, were derived by stepwise linear regression methods using data from 241 fuels, most of which conform to specifications for aviation gasolines and aircraft turbine or jet engine fuels.

5. Significance and Use

5.1 This test method is intended for use as a guide in cases where 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. Table 1 shows a summary for the range of each variable

TABLE 1 Mean and Standard Deviation of the Variables

Variable	Mean	Standard Deviation
Aromatics, volume %	13.5	23.9
Density, kg/m^3 [°API]	779.3 [50.0]	58.0 [13.5]
Volatility, °C [°F]	171.11 [340]	57.2 [103]
Heat of combustion, MJ/kg [Btu/lb]	43.421 [18 668]	0.862 [371]

[4] Available from Energy Institute, 61 New Cavendish St., London, WIG 7AR, U.K., http://www.energyinst.org.uk.

used in developing the correlation. The mean value and an estimate of its distribution about the mean, namely the standard deviation, is shown. This indicates, for example, that the mean density for all fuels used in developing the correlation was 779.3 kg/m^3 and that two thirds of the samples had a density between 721.4 kg/m^3 and 837.1 kg/m^3, that is, plus or minus one standard deviation. The correlation is most accurate when the values of the variables used are within one standard deviation of the mean, but is useful up to two standard deviations of the mean. The use of this correlation may be applicable to other hydrocarbon distillates and pure hydrocarbons; however, only limited data on non-aviation fuels over the entire range of the variables were included in the correlation.

NOTE 4—The procedures for the experimental determination of the gross and net heats of combustion are described in Test Methods D240 and D4809.

5.2 The calorimetric methods cited in Note 4 measure gross heat of combustion. However, net heat is used in aircraft calculations because all combustion products are in the gaseous state. This calculation method is based on net heat, but a correction is required for condensed sulfur compounds.

6. Procedure

6.1 Determine the aromatic content of the fuel to the nearest 0.1 % vol as described in Test Method D1319.

6.1.1 Test Method D6379 or IP 436 may be used as an alternative to Test Method D1319 for determining fuel aromatics content for use in this test method.

6.1.2 If Test Method D6379 or IP 436 is used, multiply the total aromatics content in vol% by 25/26.5 (=0.9434), and use this corrected value in place of aromatics determined by Test Method D1319 in Eq 2.

6.2 Determine the density at 15 °C or the API gravity of the fuel to the nearest 0.1 kg/m^3 or [0.1 ° API] as described in Test Method D1298 or in Test Method D4052.

6.3 Determine the 10 %, 50 %, and 90 % boiling points of the fuel to the nearest 1 °C or [1 °F] as described in Test Method D86. Average these three temperatures to obtain the T value (°C) or the V value [°F] used in the equations of 4.1. For a pure hydrocarbon, T or V is the normal boiling point.

6.3.1 Test Method D2887 may be used as an alternative to Test Method D86 for determining fuel volatility for use in this test method. The average of the 10 %, 50 %, and 90 % boiling points determined by Test Method D2887 may be used directly in place of the corresponding average determined by Test Method D86.

6.4 Determine the sulfur content of the fuel to the nearest 0.02 % sulfur as described in Test Methods D1266, D1552, D2622, D3120, D4294, or D5453, depending upon the volatility of the sample.

7. Calculation and Report

7.1 *SI Units:*

7.1.1 Calculate the net heat of combustion, sulfur-free basis, using Eq 2 of 4.1. Round the value obtained to the nearest one-thousandth.

Example:
Sample: Kerosine
Determined Values:
Aromatics, A = 12.5 % volume
Density, D = 805.0 kg/m^3
Distillation

$$T_{10} = 203\ ^\circ\text{C} \tag{4}$$

$$T_{50} = 233\ ^\circ\text{C}$$

$$T_{90} = 245\ ^\circ\text{C}$$

$$\textit{Calculated Value: } A \times T = 2837.5 \tag{5}$$

$$T = (203+233+245)/3 = 227\ ^\circ\text{C}$$

Substituting into Eq 2 in 4.1:

$$Q_{p2} = [5528.73 - 92.6499\ (12.5) + 10.1601\ (227) \tag{6}$$

$$+ 0.314169\ (2837.5)]/805.0 + 0.0791707(12.5)$$

$$-0.00944893(227) - 0.000292178(2837.5)$$

$$+35.9936$$

$$Q_{p2} = 43.411015 = 43.411 \text{ MJ/kg, sulfur} - \text{free basis} \tag{7}$$

7.1.2 Calculate the net heat of combustion corrected for the sulfur content of the fuel using Eq 3 of 4.2. Round the value obtained to the nearest one-thousandth.

Example: $Q_{p\,2}$ = 43.411 MJ/kg
Determined Value: Sulfur, S_1 = 0.10 mass %
Substituting into Eq 3 in 4.2:

$$Q = 43.411[1 - 0.01(0.1)] + 0.10166(0.1) \tag{8}$$

$$Q = 43.3778 = 43.378 \text{ MJ/kg} \tag{9}$$

7.2 *Inch-Pound Units:*

7.2.1 Calculate the net heat of combustion, sulfur-free basis, using Eq 1 in 4.1. Round the value obtained to the nearest integer.

Example:
Sample: Kerosine
Determined Values:
Aromatics, A = 12.5 % volume
Gravity, G = 44.2° API
Distillation

$$T_{10} = 398\ ^\circ\text{F} \tag{10}$$

$$T_{50} = 451\ ^\circ\text{F}$$

$$T_{90} = 473\ ^\circ\text{F}$$

$$T = (398+451+473)/3 = 440.7\ ^\circ\text{F}$$

Calculated Values:

$$G \times V = 19\ 478.9 \tag{11}$$

$$A \times G = 552.5 \tag{12}$$

$$A \times G \times V = 243486.8 \tag{13}$$

Substituting into Eq 1 in 4.1:

$$Q_{p1} = 16.24(44.2) - 3.007(12.5) + \tag{14}$$

$$0.01714(19\ 478.9) - 0.2983(552.5) +$$

$$0.00053(243\ 486.8) + 17\ 685$$

$$Q_{p1} = 18\ 663.3 = 18\ 663 \text{ Btu/lb, sulfur} - \text{free basis} \tag{15}$$

7.2.2 Calculate the net heat of combustion corrected for the sulfur content of the fuel and round the value obtained to the nearest integer.

Example: $Q_{p\ 1}$ = 18 663 Btu/lb
Determined Value: Sulfur, S_1 = 0.10 mass %

$$Q = 18\ 663[1 - 0.01(0.1)] + 43.7(0.1) \quad (16)$$

$$Q = 18\ 648.7 = 18\ 649\ \text{Btu/lb} \quad (17)$$

8. Report

8.1 Report the result from 7.1 to the nearest one-thousandth as net heat of combustion of the fuel in megajoules per kilogram or from 7.2 to the nearest integer as net heat of combustion of the fuel in [Btu per pound].

8.2 Report whether the result is determined on sulfur-free or sulfur-corrected basis.

9. Precision and Bias[5]

9.1 The following criteria should be used for judging the acceptability of estimated net heat of combustion results (95 % confidence):

9.1.1 *Repeatability*—The difference between successive results obtained by the same operator (using a second set of measured values for aromatics content, density, and distillation data) on identical test material would, in the long run, in the normal and correct use of the test method, exceed the following values (sulfur-free basis) in only one case in twenty.

$$\text{Repeatability} = 0.021\ \text{MJ/kg or}\ [9\ \text{Btu/lb}]$$

9.1.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, exceed the following values in only one case in twenty.

$$\text{Reproducibility} = 0.046\ \text{MJ/kg or}\ [20\ \text{Btu/lb}]$$

NOTE 5—The repeatability and reproducibility stated above is based on the summation of the repeatability and reproducibility of the test methods used in the calculations. It does not include the effect of the scatter of the original data about the regression line, described by Eq 1 and Eq 2. Therefore, the possibility that individual estimates may be in error in excess of the above precision should be recognized.

9.2 *Bias*—The correlation described by this test method is based on data obtained with methods equivalent to Test Method D4809 and the data scatter is described by Table 1. However, no statement on bias can be made because the bias for Test Method D4809 cannot be determined.

10. Keywords

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

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1183.

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