Designation: D 3338 – 00

An American National Standard

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

This standard is issued under the fixed designation D 3338; 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 (megajoules per kilogram or Btu per pound) of aviation gasolines and aircraft turbine and jet engine fuels.

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 D 3338 correlation was devised was obtained by a precision method similar to Test Method D 4809.

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).**

1.3 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.

1.4 The net heat of combustion can also be estimated in inch-pound units by Test Method D 1405 or in SI units by Test Method D 4529. Test Method D 1405 requires calculation of one of four equations dependent on the fuel type with a precision equivalent to that of this test method. Test Method D 4529 requires calculation of a single equation for all aviation fuels with a precision equivalent to that of this test method. Unlike D 1405 and D 4529, D 3338 does not require the use of aniline point.

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 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure[3]

D 240 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter[3]

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[3]

D 1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[3]

D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption[3]

D 1405 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels[3]

D 1552 Test Method for Sulfur in Petroleum Products (High–Temperature Method)[3]

D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-Ray Fluorescence Spectrometry[4]

D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry[4]

D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[4]

D 4294 Test Method for Sulfur in Petroleum Products by Energy Dispersive X-Ray Fluorescence Spectrometry[5]

D 4529 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels[4]

D 4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Intermediate Precision Method)[4]

D 5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence[5]

[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.B on Calorimetry of Liquid Hydrocarbon Fuels.

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[2] The boldface number in parentheses refers to the list of references at the end of this method.

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

[4] *Annual Book of ASTM Standards*, Vol 05.02.

[5] *Annual Book of ASTM Standards*, Vol 05.03.

3. Terminology

3.1 *Definitions:*

3.1.1 *gross heat of combustion, Qg (MJ/kg)*—the 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)*—the 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	Equation
All aviation gasolines, aircraft turbine and jet engine fuels	$Q_{p1} = 16.24(G) - 3.007(A) + 0.01714(G \times V) - 0.2983(A \times G) + 0.00053(A \times G \times V) + 17685$ (1)

or in SI units

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

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 D 86 10 %, 50 %, and 90 % points, °F,
D = density, kg/m^3 at 15°C
T = volatility: boiling point or average of Test Method D 86 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, megajoules/kilogram or BTU per pound, 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 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 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 3—The procedures for the experimental determination of the gross and net heats of combustion are described in Test Methods D 240 and D 4809.

5.2 The calorimetric methods cited in Note 3 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 D 1319.

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 D 1298 or in Test Method D 4052.

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 D 86. 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.

6.4 Determine the sulfur content of the fuel to the nearest 0.02 % sulfur as described in Test Methods D 1266, D 1552, D 2622, D 3120, D 4294, or D 5453, 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.

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, megajoules per kilogram (Btu per pound)	43.421 (18 668)	0.862 (371)

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

$$T_{10} = 203°C \quad (4)$$

$$T_{50} = 233°C$$

$$T_{90} = 245°C$$

$$T = (203 + 233 + 245)/3 = 227°C$$

Calculated Value: $A \times T = 2837.5$ (5)

Substituting into Eq 2 in 4.1:

$$Q_{p2} = [5528.73 - 92.6499(12.5) + 10.1601(227) + 0.314169(2837.5)]/805.0 + 0.0791707(12.5) - 0.00944893(227) - 0.000292178(2837.5) + 35.9936 \quad (6)$$

$$Q_{p2} = 43.4101015 = 43.410 \text{ MJ/kg, sulfur−free basis} \quad (7)$$

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_{p2} = 43.410 MJ/kg
Determined Value: Sulfur, S_1 = 0.10 mass %
Substituting into Eq 3 in 4.2:

$$Q = 43.410[1 - 0.01(0.1)] + 0.10166\,(0.1) \quad (8)$$

$$Q = 43.3768 = 43.377 \text{ MJ/kg} \quad (9)$$

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

$$T_{10} = 398°F \quad (10)$$

$$T_{50} = 451°F$$

$$T_{90} = 473°F$$

$$T = (398 + 451 + 473)/3 = 440.7°F$$

Calculated Values:

$$G \times V = 19\ 478.9 \quad (11)$$

$$A \times G = 552.5 \quad (12)$$

$$A \times G \times T = 24\ 3486.8 \quad (13)$$

Substituting into Eq 1 in 4.1:

$$Q_{p1} = 16.24(44.2) - 3.007(12.5) + 0.01714(19\ 478.9) - 0.2983(552.5) + 0.00053(243\ 486.8) + 17\ 685 \quad (14)$$

$$Q_{p1} = 18\ 663.3 = 18\ 663 \text{ Btu/lb, sulfur−free basis} \quad (15)$$

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_{p1} = 18 663 Btu/lb
Determined Value: Sulfur, S_1 = 0.10 mass %
Substituting into Eq 3 in 4.1:

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

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

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.

9. Precision and Bias [6]

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.

$$\text{Repeatability} = 0.021 \text{ MJ/kg or } 9 \text{ Btu/lb} \quad (18)$$

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.

$$\text{Reproducibility} = 0.046 \text{ MJ/kg or } 20 \text{ Btu/lb} \quad (19)$$

NOTE 4—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 equations (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 method is based on data obtained with methods equivalent to D4809 and the data scatter is described by Table 1. However, no statement on bias can be made because the bias for Test Method D 4809 cannot be determined.

10. Keywords

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

[6] Supporting data are available on loan from ASTM Headquarters. Request RR: D02-1183.

REFERENCES

(**1**) Armstrong, G. T., et al, "Net Heat of Combustion of Aviation Gasoline and its Correlation with Composition and Aniline-Gravity Product," *WADC Technical Report 56-504* July 1956.

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(**3**) Armstrong, G. T., et al, "Net Heat of Combustion and Other Properties of Kerosene and Related Fuels," *NBS Journal of Chemical and Engineering Data*, Vol 7, No. 1, January 1962, plus Method D 86 data on these fuels.

(**4**) Rossini, F. D., et al, "Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds," Carnegie Press, 1953.

(**5**) "Fuel Inspection Data," *Coordinating Research Council Report No. LD-132*, Sept. 1, 1963.

(**6**) Bert, J. A., and Painter, L. J., "A Broadly Applicable Method for Calculating Heat of Combustion," Chevron Research Co., Richmond, CA., Jan. 12, 1973.