Designation: ~~D7398 – 11 (Reapproved 2021)~~ D7398 – 21

Standard Test Method for
Boiling Range Distribution of Fatty Acid Methyl Esters (FAME) in the Boiling Range from 100 °C to 615 °C by Gas Chromatography[1]

This standard is issued under the fixed designation D7398; 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.

1. ~~Scope~~ Scope*

1.1 This test method covers the determination of the boiling range distribution of fatty acid methyl esters (FAME). This test method is applicable to FAMES (biodiesel, B100) having an initial boiling point greater than 100 °C and a final boiling point less than 615 °C at atmospheric pressure as measured by this test method.

1.2 The test method can also be applicable to blends of diesel and biodiesel (B1 through B100), however precision for these samples types has not been evaluated.

1.3 The test method is not applicable for analysis of petroleum containing low molecular weight components (for example naphthas, reformates, gasolines, crude oils).

1.4 Boiling range distributions obtained by this test method are not equivalent to results from low efficiency distillation such as those obtained with Test Method D86 or D1160, especially the initial and final boiling points.

1.5 This test method uses the principles of simulated distillation methodology. See Test Methods D2887, D6352, and D7213.

1.6 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure

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

D1160 Test Method for Distillation of Petroleum Products at Reduced Pressure
D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
D2892 Test Method for Distillation of Crude Petroleum (15-Theoretical Plate Column)
D4626 Practice for Calculation of Gas Chromatographic Response Factors
D6352 Test Method for Boiling Range Distribution of Petroleum Distillates in Boiling Range from 174 °C to 700 °C by Gas Chromatography
D6751 Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
D7213 Test Method for Boiling Range Distribution of Petroleum Distillates in the Boiling Range from 100 °C to 615 °C by Gas Chromatography
E355 Practice for Gas Chromatography Terms and Relationships
E594 Practice for Testing Flame Ionization Detectors Used in Gas or Supercritical Fluid Chromatography
E1510 Practice for Installing Fused Silica Open Tubular Capillary Columns in Gas Chromatographs

3. Terminology

3.1 *Definitions:*

3.1.1 This test method makes reference to many common gas chromatographic procedures, terms, and relationships. Detailed definitions of these can be found in Practices E355, E594, and E1510.

3.1.2 *biodiesel, n*—fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *area slice, n*—area resulting from the integration of the chromatographic detector signal within a specified retention time interval. In area slice mode (6.4.2), peak detection parameters are bypassed and the detector signal integral is recorded as area slices of consecutive, fixed duration time intervals.

3.2.2 *atmospheric equivalent temperature (AET), n*—temperature converted from the measured vapor temperature obtained at sub-ambient pressure to atmospheric equivalent temperature (AET) corresponding to the equivalent boiling point at atmospheric pressure, 101.3 kPa (760 mm Hg), The AET is the expected distillate temperature if the distillation was performed at atmospheric pressure and there was no thermal decomposition.

3.2.3 *corrected area slice, n*—area slice corrected for baseline offset, by subtraction of the exactly corresponding area slice in a previously recorded blank (non-sample) analysis.

3.2.4 *cumulative corrected area, n*—accumulated sum of corrected area slices from the beginning of the analysis through a given retention time, ignoring any non-sample area (for example, solvent).

3.2.5 *initial boiling point (IBP), n*—temperature (corresponding to the retention time) at which a cumulative corrected area count equal to 0.5 % of the total sample area under the chromatogram is obtained.

3.2.6 *final boiling point (FBP), n*—temperature (corresponding to the retention time) at which a cumulative corrected area count equal to 99.5 % of the total sample area under the chromatogram is obtained.

3.2.7 *slice rate, n*—frequency of data sampling or the frequency of data bunching provided that the frequency of data acquisition is larger than the frequency of bunching. The unit of frequency is points/seconds or Hz.

3.2.8 *slice time, n*—cumulative slice rate (analysis time) associated with each area slice throughout the chromatographic analysis. The slice time is the time at the end of each contiguous area slice.

3.2.9 *total sample area, n*—cumulative corrected area, from the initial point to the final area point.

3.3 *Abbreviations:*

3.3.1 A common abbreviation of hydrocarbon compounds is to designate the number of carbon atoms in the compound. A prefix is used to indicate the carbon chain form, while a subscripted suffix denotes the number of carbon atoms (for example, normal decane n-C_{10}; iso-tetradecane = i-C_{14}).

3.3.2 A common abbreviation for FAME compounds is to designate the number of carbon atoms and number of double bonds in the compound. The number of carbon atoms is denoted by a number after the "C" and the number following a colon indicates the number of double bonds (for example, C16:2 ; FAME with 16 carbon atoms and 2 double bonds).

4. Summary of Test Method

4.1 The boiling range distribution by distillation is simulated by the use of gas chromatography. A non-polar open tubular (capillary) gas chromatographic column is used to elute the hydrocarbon and FAME components of the sample in order of increasing boiling point.

4.2 A sample aliquot is diluted with a viscosity reducing solvent and introduced into the chromatographic system. The solvent shall be apolar and not interfere with measurement of the sample in the 100 °C to 615 °C range. Sample vaporization is provided by separate heating of the point of injection or in conjunction with column oven heating.

4.3 The column oven temperature is raised at a reproducible linear rate to effect separation of the FAME components in order of increasing boiling point relative to a n-paraffin calibration mixture. The elution of sample components is quantitatively determined using a flame ionization detector. The detector signal integral is recorded as area slices for consecutive retention time intervals during the analysis.

4.4 Retention times of known normal paraffin hydrocarbons, spanning the scope of the test method ($C_5 - C_{60}$), are determined and correlated to their boiling point temperatures. The normalized cumulative corrected sample areas for each consecutive recorded time interval are used to calculate the boiling range distribution. The boiling point temperature at each reported percent off increment is calculated from the retention time calibration.

4.5 The retention time versus boiling point curve is calibrated with normal paraffin hydrocarbons since these boiling points are well defined. A mixture of FAMEs is analyzed to check column resolution. A triglyceride is analyzed to verify the system's ability to detect unreacted oil.

5. Significance and Use

5.1 The boiling range distribution of FAMES provides an insight into the composition of product related to the transesterification process. This gas chromatographic determination of boiling range can be used to replace conventional distillation methods for product specification testing with the mutual agreement of interested parties.

5.2 Biodiesel (FAMES) exhibits a boiling point rather than a distillation curve. The fatty acid chains in the raw oils and fats from which biodiesel is produced are mainly comprised of straight chain hydrocarbons with 16 to 18 carbons that have similar boiling temperatures. The atmospheric boiling point of biodiesel generally ranges from 330 °C to 357 °C. The Specification D6751 value of 360 °C max at 90 % off by Test Method D1160 was incorporated as a precaution to ensure the fuel has not been adulterated with high boiling contaminants.

6. Apparatus

6.1 *Chromatograph*—The following gas chromatographic system performance characteristics are required:

6.1.1 *Column Oven*—Capable of sustained and linear programmed temperature operation from near ambient (for example 35 °C to 50 °C) up to 400 °C.

6.1.2 *Column Temperature Programmer*—The chromatograph must be capable of linear programmed temperature operation up to 400 °C at selectable linear rates up to 20 °C∕min. The programming rate must be sufficiently reproducible to obtain the retention time repeatability of 0.03 min (3 s) for each component in the calibration mixture described in 7.3.

6.1.3 *Detector*—This test method requires a flame ionization detector (FID). The detector must meet or exceed the following specifications as detailed in Practice E594. The specification of flame jet orifice is approximately 0.45 mm (0.018 in.).

6.1.3.1 *Operating Temperature,* 400 °C.

6.1.3.2 *Sensitivity,* >0.005 coulombs/g carbon.

6.1.3.3 *Minimum Detectability,* 1×10^{-11} g carbon / *s*.

6.1.3.4 *Linear Range,* $>10^6$

6.1.3.5 Connection of the column to the detector must be such that no temperature below the column temperature exists. Refer to Practice E1510 for proper installation and conditioning of the capillary column.

6.1.4 *Sample Inlet System*—Any sample inlet system capable of meeting the performance specification in 6.1.5 and 7.3 may be used. Programmed temperature vaporization (PTV) and programmable cool on-column injection systems have been used successfully.

6.1.5 *Carrier Gas Flow Control*—The chromatograph shall be equipped with carrier flow control capable of maintaining constant carrier gas flow control through the column throughout the column temperature program cycle as measured with the use of flow a sensor. Flow rate must be maintained within 1 % through out the temperature program.

6.2 *Microsyringe*—A microsyringe with a 23 gauge or smaller stainless steel needle is used for on-column sample introduction. Syringes of 0.1 µL to 10 µL capacity are available.

6.2.1 Automatic syringe injection is recommended to achieve best precision.

6.3 *Column*—This test method is limited to the use of non-polar wall coated open tubular (WCOT) columns of high thermal stability. Glass, fused silica, and stainless steel columns, with a 0.53 mm diameter have been successfully used. Cross-linked or bonded 100 % dimethyl-polysiloxane stationary phases with film thickness of 0.5 µm to 1.0 µm have been used. The column length and liquid phase film thickness shall allow the elution of at least C_{60} *n*-paraffin (BP = 615 °C) and triolein. The column and conditions shall provide separation of typical petroleum hydrocarbons and saturated FAMES in order of increasing boiling point and meet the column resolution requirements of 8.2.1. The column shall provide a resolution between five (5) and fifteen (15) using the test method operating conditions.

6.4 *Data Acquisition System:*

6.4.1 *Recorder*—A 0 mV to 1 mV range recording potentiometer or equivalent, with a full-scale response time of 2 s or less may be used to provide a graphical display.

6.4.2 *Integrator*—Means shall be provided for determining the accumulated area under the chromatogram. This can be done by means of an electronic integrator or computer based chromatography data system. The integrator/computer system shall have normal chromatographic software for measuring the retention time and areas of eluting peaks (peak detection mode). In addition, the system shall be capable of converting the continuously integrated detector signal into area slices of fixed duration (area slice mode). These contiguous area slices, collected for the entire analysis, are stored for later processing. The electronic range of the integrator/computer (for example, 1 V, 10 V) shall be operated within the linear range of the detector/electrometer system used.

NOTE 1—Some gas chromatographs have an algorithm built into their operating software that allows a mathematical model of the baseline profile to be stored in memory. This profile is automatically subtracted from the detector signal on subsequent sample runs to compensate for the column bleed. Some integration systems also store and automatically subtract a blank analysis from subsequent analytical determinations.

7. Reagents and Materials

7.1 *Gases*—The following compressed gases are utilized for the operation of the gas chromatograph.

7.1.1 *Helium,* 99.999 %. (**Warning**—Compressed gas under high pressure.) This gas can be used as carrier gas. Ensure sufficient pressure for a constant carrier gas flow rate. It is not to contain more than 5 mL/m^3 of oxygen and the total amount of impurities are not to exceed 10 mL/m^3.

7.1.2 *Nitrogen,* 99.999 %. (**Warning**—Compressed gas under high pressure.) This gas can be used as carrier gas. Ensure sufficient pressure for a constant carrier gas flow rate. It is not to contain more than 5 mL/m^3 of oxygen and the total amount of impurities are not to exceed 10 mL/m^3.

7.1.3 *Hydrogen,* 99.999 %. (**Warning**—Extremely flammable gas under high pressure.) The total impurities are not to exceed 10 mL/m^3. This gas can be used as carrier gas. Ensure sufficient pressure for a constant carrier gas flow rate. It is also used as fuel for the flame ionization detector (FID).

7.1.4 *Air,* 99.999 %. (**Warning**—Compressed gas under high pressure and supports combustion.) Total impurities are not to exceed 10 mL/m^3. This gas is used to sustain combustion in the flame ionization detector (FID).

7.2 *Solvents*—Unless otherwise indicated, it is intended that all solvents conform to the specifications of the committee on analytical Reagents of the American Chemical Society where such specifications are available.[3] Other grades may be used provided it is first ascertained that the solvent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2.1 *Carbon Disulfide* (CS$_2$), 99+ % pure. (**Warning**—Extremely flammable and toxic liquid.) Used as a viscosity reducing solvent and as a means of reducing mass of sample introduced onto the column to ensure linear detector response and reduced peak skewness. It is miscible with FAMES and provides a relatively small response with the FID. The quality (hydrocarbon content) is determined by this test method prior to use as a sample diluent.

7.2.2 *Cyclohexane* (C$_6$H$_{12}$), (99+ % pure) (**Warning**—Flammable. Health hazard.) Used as a viscosity reducing solvent. It is miscible with asphaltic hydrocarbons, however, it responds well to the FID. Cyclohexane will interfere with the elution of lower boiling normal paraffins. The quality (hydrocarbon content) is determined by this test method prior to use as a sample diluent.

7.3 *Calibration Mixture*—A qualitative mixture of *n*-paraffins (nominally C$_5$ to C$_{60}$) dissolved in a suitable solvent. A final concentration of approximately one part of *n*-paraffin mixture to one hundred parts of solvent is required. At least one compound in the mixture must have a boiling point lower than the initial boiling point of the sample being analyzed, as defined in the scope of this test method (1.1). The calibration mixture must contain at least 13 known *n*-paraffins (for example, C$_6$, C$_7$, C$_8$, C$_9$, C$_{10}$, C$_{12}$, C$_{16}$, C$_{20}$, C$_{30}$, C$_{40}$, C$_{50}$, C$_{52}$, C$_{60}$). Boiling points of *n*-paraffins are listed in Table 1.

Note 2—A suitable calibration mixture can be obtained by dissolving a polyolefin wax in a volatile solvent (for example, carbon disulfide or cyclohexane). Solutions of one part polyolefin wax to one hundred parts solvent can be prepared. Lower boiling point paraffins will have to be added to ensure conformance with 7.3. Fig. 1 illustrates a typical calibration mixture chromatogram.

7.3.1 *Qualitative FAME Mixture*—A qualitative mixture of FAMES (nominally C8:0 to C24:0) dissolved in a suitable solvent. A final concentration of approximately one part of FAME mixture to one hundred parts of solvent is required. The qualitative mixture contains at least 9 known FAMES (for example, C8:0, C10:0, C12:0, C14:0, C16:0, C18:0, C20:0, C22:0, C24:0). Boiling points of FAMES are listed in Table 2. This FAME qualitative mixture is used to calculate resolution of C16:0 and C18:0 (see 8.2.1). It may also be used to insure that retention time shifts as column ages does not exceed ±0.15 min (to be determined from the experimental BP versus RT curve).

7.3.2 *Quantitative Triglyceride Mixture*—A quantative mixture of triglyceride (triolein) dissolved in a suitable solvent. A final concentration of approximately 10 mass ppm is required. One qualitative mixture meeting the requirement of 7.3.1 and 7.3.2 may be used. This triglyceride reponse mixture is used to verify response to unreacted oils (see 8.2.2.1).

7.4 *Response Linearity Mixture*—Prepare a quantitatively weighed mixture of at least ten individual paraffins (>99 % purity), covering the boiling range of the test method. The highest boiling point component shall be at least *n*-C60. The mixture shall contain *n*-C40. Use a suitable solvent to provide a solution of each component at approximately 0.5 % to 2.0 % by mass.

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[3] *ACS Reagent Chemicals, Specifications and Procedures for Reagents and Standard-Grade Reference Materials*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

TABLE 1 Boiling Points of _n_-Paraffins[A,B]

Carbon Number	Boiling Point °C	Boiling Point °F	Carbon Number	Boiling Point °C	Boiling Point °F
5	36	97	33	474	885
6	69	156	34	481	898
7	98	209	35	489	912
8	126	258	36	496	925
9	151	303	37	503	937
10	174	345	38	509	948
11	196	385	39	516	961
12	216	421	40	522	972
13	235	456	41	528	982
14	254	488	42	534	993
15	271	519	43	540	1004
16	287	548	44	545	1013
17	302	576	45	550	1022
18	316	601	46	556	1033
19	330	626	47	561	1042
20	344	651	48	566	1051
21	356	674	49	570	1058
22	369	695	50	575	1067
23	380	716	51	579	1074
24	391	736	52	584	1083
25	402	755	53	588	1090
26	412	774	54	592	1098
27	422	791	55	596	1105
28	431	808	56	600	1112
29	440	825	57	604	1119
30	449	840	58	608	1126
31	458	856	59	612	1134
32	466	870	60	615	1139

[A] API Project 44, 72-10-31, is believed to have provided the original normal paraffin boiling point data that are listed in Table 1. However, over the years some of the data contained in both API Project 44 (Thermodynamics Research Center Hydrocarbon Project) and Test Method D7398 have changed, and they are no longer equivalent. Table 1 represents the current normal paraffin boiling point values accepted by Subcommittee D02.04 and found in all test methods under the jurisdiction of Section D02.04.0H.
[B] Test Method D7398 has traditionally used _n_-paraffin boiling points rounded to the nearest whole degree for calibration. The boiling points listed in Table 1 are correct to the nearest whole number in both degrees Celsius and degrees Fahrenheit. However, if a conversion is made from one unit to the other and then rounded to a whole number, the results will not agree with the table values for a few carbon numbers. For example, the boiling point of _n_-heptane is 98 425 °C which is correctly rounded to 98 °C in the table. However, converting 98.425 °C gives 209.165 °F, which rounds to 208 °F, while converting 98 °C gives 208.4 °F, which rounds to 208 °F. Carbon numbers 2, 4, 7, 8, 9, 13, 14, 15, 16, 25, 27, and 32 are affected by rounding.

7.5 _Reference Material_—A reference sample that has been analyzed by laboratories participating in the test method cooperative study. Consensus values for the boiling range distribution of this sample is being determined.

8. Preparation of Apparatus

8.1 _Gas Chromatograph Setup:_

8.1.1 Place the gas chromatograph and ancillary equipment into operation in accordance with the manufacturers instructions. Recommended operating conditions are shown in Table 3.

8.1.2 When attaching the column to the detector inlet, ensure that the end of the column terminates as close as possible to the FID jet. Follow the instructions in Practice E1510.

8.1.3 Periodically inspect the FID and, if necessary, remove any foreign deposits formed in the detector from combustion of silicone liquid phase or other materials. Such deposits will change the response characteristics of the detector.

8.1.4 The inlet liner and initial portion of the column must be periodically inspected and replaced if necessary to remove extraneous deposits or sample residue.

8.1.5 _Column Conditioning_—A new column will require conditioning at the upper test method operating temperature to reduce or eliminate significant liquid phase bleed, resulting in a stable chromatographic baseline. Follow the guidelines outlined in Practice E1510.
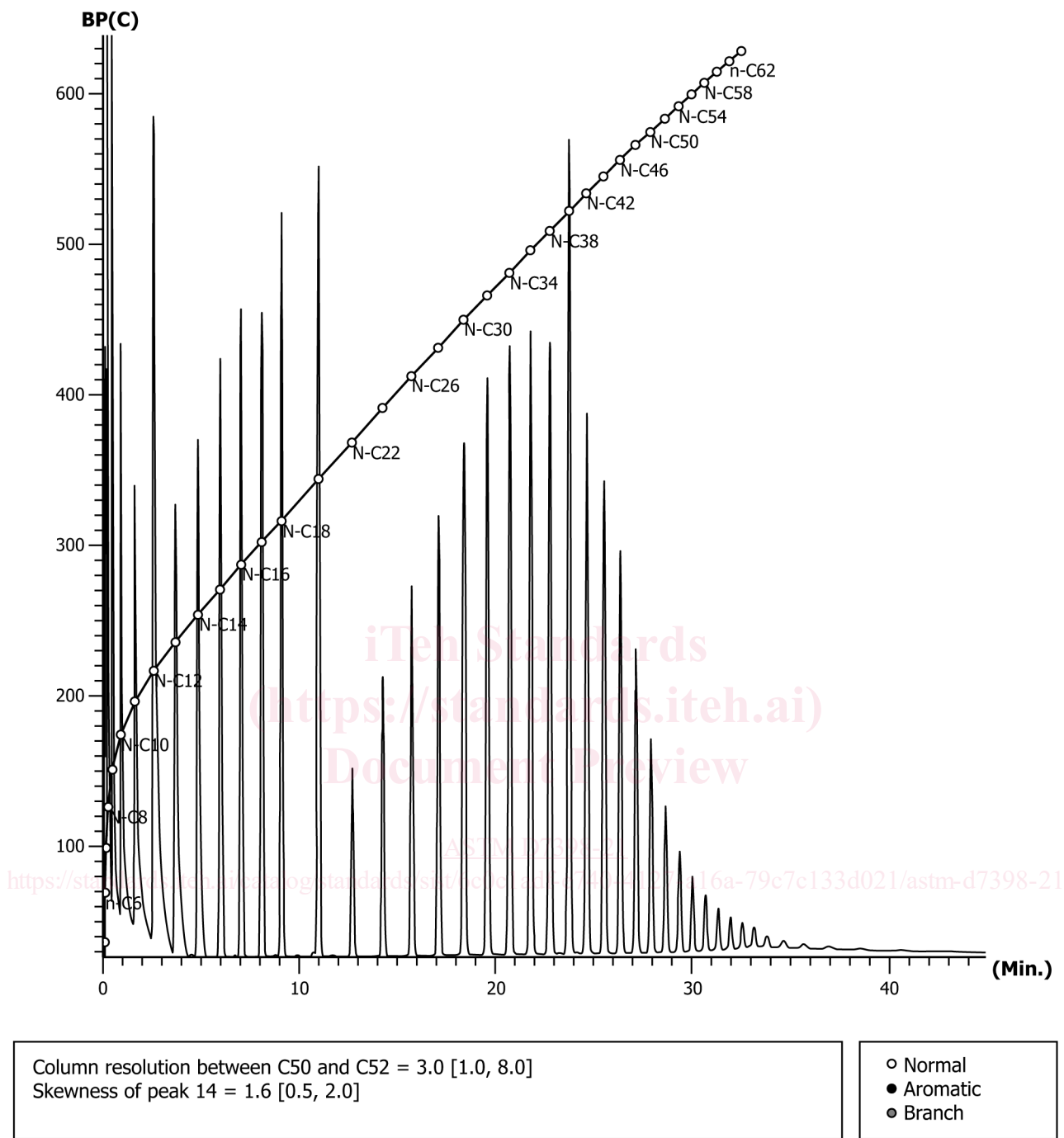
8.2 _System Performance Specification:_

FIG. 1 Typical Calibration Curve with Plot

8.2.1 *Column Resolution*—The column resolution, influenced by both the column physical parameters and operating conditions, affects the overall determination of boiling range distribution. Resolution is therefore specified to maintain equivalence between different systems (laboratories) employing this test method. Resolution is determined using Eq 1 and the C16:0 and C18:0 FAMES from a calibration mixture analysis (or a retention time boiling point mixture) (see 7.3.1). Resolution (*R*) shall be at least five (5) and not more than fifteen (15), using the identical conditions employed for sample analyses.

$$R = 2\,(t_2 - t_1)/(1.699\,(w_2 + w_1))\tag{1}$$

where:

R = resolution,