Designation: D4814 – 18

Standard Specification for
Automotive Spark-Ignition Engine Fuel[1]

This standard is issued under the fixed designation D4814; 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.

1. Scope*

1.1 This specification covers the establishment of requirements of liquid automotive fuels for ground vehicles equipped with spark-ignition engines.

1.2 This specification describes various characteristics of automotive fuels for use over a wide range of operating conditions. It provides for a variation of the volatility and water tolerance of automotive fuel in accordance with seasonal climatic changes at the locality where the fuel is used. For the period May 1 through Sept. 15, the maximum vapor pressure limits issued by the United States (U.S.) Environmental Protection Agency (EPA) are specified for each geographical area except Alaska and Hawaii. Variation of the antiknock index with seasonal climatic changes and altitude is discussed in Appendix X1. This specification neither necessarily includes all types of fuels that are satisfactory for automotive vehicles, nor necessarily excludes fuels that can perform unsatisfactorily under certain operating conditions or in certain equipment. The significance of each of the properties of this specification is shown in Appendix X1.

1.3 The spark-ignition engine fuels covered in this specification are gasoline and its blends with oxygenates, such as alcohols and ethers and where gasoline is the primary component by volume in the blend. The concentrations and types of oxygenates are not specifically limited in this specification. The composition of both unleaded and leaded fuel is limited by economic, legal, and technical consideration, but their properties, including volatility, are defined by this specification. In many countries, regulatory authorities having jurisdiction have set laws and regulations that limit the concentration of oxygenates and certain other compounds found in spark-ignition engine fuel. In the United States, oxygenate types and concentrations are limited to those approved under the U.S. Environmental Protection Agency's (EPA) substantially similar rule (see X3.3.1), waivers, and partial waivers including some restrictions on vehicle and equipment use (see X3.3.2). With regard to fuel properties, including volatility, this specification can be more or less restrictive than the EPA rules, regulations, and waivers. Refer to Appendix X3 for discussions of EPA rules relating to fuel volatility, lead and phosphorous contents, sulfur content, benzene content, deposit control additive certification, and use of oxygenates in blends with unleaded gasoline. Contact the EPA for the latest versions of the rules and additional requirements.

1.4 This specification does not address the emission characteristics of reformulated spark-ignition engine fuel. Reformulated spark-ignition engine fuel is required in some areas to lower emissions from automotive vehicles, and its characteristics are described in the research report on reformulated spark-ignition engine fuel.[2] However, in addition to the legal requirements found in this research report, reformulated spark-ignition engine fuel should meet the performance requirements found in this specification.

1.5 This specification represents a description of automotive fuel as of the date of publication. The specification is under continuous review, which can result in revisions based on changes in fuel, automotive requirements, or test methods, or a combination thereof. All users of this specification, therefore, should refer to the latest edition.

NOTE 1—If there is any doubt as to the latest edition of Specification D4814, contact ASTM International Headquarters.

1.6 Tests applicable to gasoline are not necessarily applicable to its blends with oxygenates. Consequently, the type of fuel under consideration must first be identified in order to select applicable tests. Test Method D4815 provides a procedure for determining oxygenate concentration in mass percent. Test Method D4815 also includes procedures for calculating mass oxygen content and oxygenate concentration in volume percent. Appendix X4 provides a procedure for calculating the mass oxygen content of a fuel using measured oxygenate type, oxygenate concentration in volume percent, and measured density or relative density of the fuel.

---

[1] This specification is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.A0.01 on Gasoline and Gasoline-Oxygenate Blends.

Current edition approved Jan. 1, 2018. Published February 2018. Originally approved in 1988. Last previous edition approved in 2017 as D4814 – 17. DOI: 10.1520/D4814-18.

[2] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting MONO12, U.S. Reformulated Spark-Ignition Engine Fuel and the U.S. Renewable Fuels Standard.

---

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

TABLE 1 Vapor Pressure and Distillation Class Requirements[A]

| | Vapor Pressure/Distillation Class | | | | | | ASTM Test Method |
	AA	A	B	C	D	E	
Vapor Pressure,[B] at 37.8 °C (100 °F) max, kPa (psi)	54 (7.8)	62 (9.0)	69 (10.0)	79 (11.5)	93 (13.5)	103 (15.0)	D4953, D5191, D5482, or D6378
Distillation Temperatures, °C (°F), at % Evaporated[C]							D86 or D7345[D, E]
10 volume %, max	70. (158)	70. (158)	65 (149)	60. (140.)	55 (131)	50. (122)	
50 volume %							
min[F]	77 (170.)	77 (170.)	77 (170.)	77 (170.)	77 (170.)[G]	77 (170.)[G]	
max	121 (250.)	121 (250.)	118 (245)	116 (240.)	113 (235)	110. (230.)	
90 volume %, max	190. (374)	190. (374)	190. (374)	185 (365)	185 (365)	185 (365)	
End Point, max	225 (437)	225 (437)	225 (437)	225 (437)	225 (437)	225 (437)	
Distillation Residue, volume %, max	2	2	2	2	2	2	D86 or D7345[D, E]
Driveability Index,[H] max, °C (°F)	597 (1250.)	597 (1250.)	591 (1240.)	586 (1230.)	580. (1220.)	569 (1200.)	Derived[I, J]

[A] See 1.7 for determining conformance with specification limits in this table. When using this table to determine the conformance of gasoline volatility, the reader is advised to review other applicable national, state, provincial, or local requirements. (For example, in the U.S. these may include the EPA Substantially Similar rule, California Air Resources Board (CARB), Clean Burning Gasoline (CBG), other state or local and pipeline specifications). See Appendix X3 for a summary of applicable U.S. EPA regulations for spark-ignition engine fuels.

[B] Consult EPA for approved test methods for compliance with EPA vapor pressure regulations.

[C] At 101.3 kPa pressure (760 mm Hg).

[D] Test Method D86 shall be the referee method.

[E] Test Method D7345, results shall be reported as "Predicted D86" as determined by applying the corrections described in Test Method D7345 to convert to D86 equivalent values. The use of Test Method D7345 shall be limited to gasoline and gasoline-ethanol blends up to maximum 20 % by volume ethanol.

[F] Gasolines that may be blended with 1 % to 15 % by volume ethanol or all other gasolines whose disposition with ethanol blending is not known shall meet a minimum 50 % evaporated distillation temperature of 77 °C (170. °F) prior to blending with ethanol. Gasoline-ethanol blends that contain 1 % to 15 % by volume ethanol shall meet a minimum 50 % evaporated distillation temperature of 66 °C (150. °F) after blending.

[G] Gasolines known from the origin to retail that will not be blended with ethanol may meet a minimum 50 % evaporated distillation temperature of 66 °C (150. °F) for volatility classes D and E only. Gasolines meeting these limits are not suitable for blending with ethanol.

[H] See 5.2.3 for Driveability Index equations for gasoline and gasoline-ethanol blends containing no more than 15 % by volume ethanol.

[I] The DI specification limits are applicable at the refinery or import facility as defined by 40 CFR Part 80.2 and are not subject to correction for precision of the test method.

[J] Since DI is an index and has no units, the standard temperature conversion from U.S. customary to SI units is not appropriate. The following equation is to be used to make the conversion: $DI_{°C} = (DI_{°F} - 176)/1.8$

1.7 The following applies to all specified limits in this standard: For purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded "to the nearest unit" in the right-most significant digit used in expressing the specification limit, in accordance with the rounding method of Practice E29. For a specification limit expressed as an integer, a trailing zero is significant only if the decimal point is specified. For a specified limit expressed as an integer, and the right-most digit is non-zero, the right-most digit is significant without a decimal point being specified. This convention applies to specified limits in Tables 1, 3, and X8.1, and it will not be observed in the remainder of this specification.

1.8 The values stated in SI units are the standard, except when other units are specified by U.S. federal regulation. Values given in parentheses are provided for information only.

NOTE 2—Many of the values shown in Table 1 were originally developed using U.S. customary units and were subsequently soft-converted to SI values. As a result, conversion of the SI values will sometimes differ slightly from the U.S. customary values shown because of round-off. In some cases, U.S. federal regulations specify non-SI units.

1.9 *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.*

1.10 *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:*[3]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

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

D381 Test Method for Gum Content in Fuels by Jet Evaporation

D439 Specification for Automotive Gasoline (Withdrawn 1990)[4]

D525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)

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

D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry

D2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel

D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel

[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.

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

D2885 Test Method for Determination of Octane Number of Spark-Ignition Engine Fuels by On-Line Direct Comparison Technique

D3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry

D3231 Test Method for Phosphorus in Gasoline

D3237 Test Method for Lead in Gasoline by Atomic Absorption Spectroscopy

D3341 Test Method for Lead in Gasoline—Iodine Monochloride Method

D3831 Test Method for Manganese in Gasoline By Atomic Absorption Spectroscopy

D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

D4176 Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products

D4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination

D4806 Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark-Ignition Engine Fuel

D4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary-Amyl Alcohol and C_1 to C_4 Alcohols in Gasoline by Gas Chromatography

D4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)

D5059 Test Methods for Lead in Gasoline by X-Ray Spectroscopy

D5188 Test Method for Vapor-Liquid Ratio Temperature Determination of Fuels (Evacuated Chamber and Piston Based Method)

D5191 Test Method for Vapor Pressure of Petroleum Products (Mini 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

D5482 Test Method for Vapor Pressure of Petroleum Products (Mini Method—Atmospheric)

D5500 Test Method for Vehicle Evaluation of Unleaded Automotive Spark-Ignition Engine Fuel for Intake Valve Deposit Formation

D5598 Test Method for Evaluating Unleaded Automotive Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling

D5599 Test Method for Determination of Oxygenates in Gasoline by Gas Chromatography and Oxygen Selective Flame Ionization Detection

D5842 Practice for Sampling and Handling of Fuels for Volatility Measurement

D5845 Test Method for Determination of MTBE, ETBE, TAME, DIPE, Methanol, Ethanol and tert-Butanol in Gasoline by Infrared Spectroscopy

D5854 Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products

D6378 Test Method for Determination of Vapor Pressure (VP_X) of Petroleum Products, Hydrocarbons, and Hydrocarbon-Oxygenate Mixtures (Triple Expansion Method)

D6469 Guide for Microbial Contamination in Fuels and Fuel Systems

D6920 Test Method for Total Sulfur in Naphthas, Distillates, Reformulated Gasolines, Diesels, Biodiesels, and Motor Fuels by Oxidative Combustion and Electrochemical Detection

D7039 Test Method for Sulfur in Gasoline, Diesel Fuel, Jet Fuel, Kerosine, Biodiesel, Biodiesel Blends, and Gasoline-Ethanol Blends by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry

D7220 Test Method for Sulfur in Automotive, Heating, and Jet Fuels by Monochromatic Energy Dispersive X-ray Fluorescence Spectrometry

D7345 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure (Micro Distillation Method)

D7667 Test Method for Determination of Corrosiveness to Silver by Automotive Spark-Ignition Engine Fuel—Thin Silver Strip Method

D7671 Test Method for Corrosiveness to Silver by Automotive Spark–Ignition Engine Fuel–Silver Strip Method

D7757 Test Method for Silicon in Gasoline and Related Products by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *Government Regulations:*

16 CFR Part 306 Automotive Fuel Ratings, Certification and Posting[5]

CFR 40 Code of Federal Regulations[5]

CCR Title 17, §60100-§60114 California Code of Regulations[6]

2.3 *Other Documents:*

API Recommended Practice 1640 Product Quality in Light Product Storage and Handling Operations[7]

CRC Report No. 638 Intermediate-Temperature Volatility Program, 2003[8]

CRC Report No. 666 Intermediate-Temperature E15 Cold-start and Warm-up Vehicle Driveability Program, 2013[8]

CRC Report No. 667 Diesel Fuel Storage and Handling Guide, September 2014[8]

---

[5] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

[6] Available from Barclays, 50 California Street, San Francisco, CA 94111.

[7] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org/pubs.

[8] Available from Coordinating Research Council (CRC), 5755 North Point Pkwy #265, Alpharetta, GA 30022, http://www.crcao.org.

TABLE 2 Detailed Requirements for all Volatility Classes[A,B]

Property	Limit	ASTM Test Method
Lead content, max, g/L (g/U.S. gal)[C]		D3237 or D5059
Unleaded	0.013 (0.05)	D3237 or D5059
Leaded	1.1 (4.2)	D3341 or D5059
Sulfur, max, % by mass		D1266, D2622, D3120, D5453, D6920, or D7039
Unleaded	0.0080	
Leaded	0.15	
Manganese content, max, mg/L (mg/U.S. gal)[D]	See 6.3	D3831[E]
Copper strip corrosion, max	No. 1	D130
Silver strip corrosion, max	No. 1	D7667 or D7671
Solvent-washed gum content, mg/100 mL, max	5	D381
Oxidation stability, minimum, minutes	240.	D525

[A] See Appendix X1 for information on Antiknock Index.
[B] See X3.7 for information on U.S. Environmental Protection Agency regulations for benzene in gasoline.
[C] See Appendix X3 for U.S. EPA maximum limits for lead and phosphorus contents in unleaded gasoline (X3.2.1) and maximum average lead limits for leaded gasoline (X3.2.2). The reader is advised to review other applicable national, state, provincial, or local requirements.
[D] See X3.8 for information on U.S. EPA and California Air Resources Board regulations for manganese in gasoline.
[E] See Note 8.

3. Terminology

3.1 For general terminology, refer to Terminology D4175.

3.2 *Definitions:*

3.2.1 *antiknock index, n*—the arithmetic average of the Research octane number (RON) and Motor octane number (MON), that is, (RON + MON)⁄2.

3.2.2 *dry vapor pressure equivalent (DVPE), n*—value calculated by a defined correlation equation that is expected to be comparable to the vapor pressure value obtained by Test Method D4953, Procedure A. **D4953**

3.2.3 *finished fuel, n*—a homogeneous mixture of blendstocks and fuel additives meeting all specification and regulatory requirements for its intended use at the location where sold.

3.2.4 *gasoline, n*—a volatile mixture of liquid hydrocarbons, generally containing small amounts of additives, suitable for use as a fuel in spark-ignition, internal combustion engines.

3.2.5 *gasoline-alcohol blend, n*—a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 % by mass oxygen, or more than 0.15 % by mass oxygen if methanol is the only oxygenate) of one or more alcohols.

3.2.6 *gasoline-ethanol blend, n*—a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 % by mass oxygen) of ethanol. **D4806**

3.2.7 *gasoline-ether blend, n*—a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 % by mass oxygen) of one or more ethers.

3.2.8 *gasoline-oxygenate blend, n*—a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 % by mass oxygen, or more than 0.15 % by mass oxygen if methanol is the only oxygenate) of one or more oxygenates.

3.2.9 *oxygenate, n*—an oxygen-containing, ashless, organic compound, such as an alcohol or ether, which can be used as a fuel or fuel supplement.

3.2.10 *refinery, n*—a plant at which gasoline or diesel fuel is produced.

3.2.10.1 *Discussion*—This definition is from U.S. CFR 40 Part 80.2. In the federal definition, a plant not only covers the conventional refinery, but also covers oxygenate blending and other facilities where gasoline is produced.

3.2.11 *water tolerance, n*—the ability to absorb small quantities of water without creating a separate phase in the fuel.

3.2.11.1 *Discussion*—Improved water tolerance is the ability to absorb larger quantities of water without phase separation.

3.3 *Applicability*—To determine when a fuel contains a substantial amount of an oxygenate, a gasoline-oxygenate blend is defined as a fuel that contains more than 0.35 % by mass oxygen, or more than 0.15 % by mass oxygen if methanol is the only oxygenate. The definitions in this section do not apply to fuels that contain an oxygenate as the primary component; for example, fuel methanol (M85).

NOTE 3—The criteria in 3.3 were selected with consideration given to current oxygenate levels in the marketplace, state labeling practices, and consistency with U.S. federal legislation and regulations.

NOTE 4—Refer to Test Method D4815 to calculate the mass oxygen content of a fuel using oxygenate concentration in percent by mass. Refer to Appendix X4 to calculate mass oxygen content of a fuel using oxygenate concentration in percent by volume.

4. Ordering Information

4.1 The purchasing agency shall:

4.1.1 State the antiknock index as agreed upon with the seller,

4.1.2 Indicate the season and locality in which the fuel is to be used,

4.1.3 Indicate the lead level required (Table 2), and

4.1.4 State the concentration and types of oxygenates present as agreed upon with the seller.

TABLE 3 Vapor Lock Protection Class Requirements[A, B, C]

| | Vapor Lock Protection Class | | | | | | ASTM Test Method |
	1	2	3	4	5	6	
Temperature, °C (°F) for a Vapor-Liquid Ratio of 20, min	54 (129)	50. (122)	47 (116)	42 (107)	39 (102)	35 (95)	D5188
Special Requirements for Area V of D4814 Temperature, °C (°F) for a Vapor-Liquid Ratio of 20, min	54 (129)	50. (122)	47 (116)	47 (116)	41 (105)	35 (95)	D5188

[A] See 1.7 for determining conformance with numerical specification limits in this table. When using this table to determine the conformance of the temperature for a vapor-liquid ratio of 20, the reader is advised to review other applicable national, state, provincial, or local requirements (for example, EPA's "Substantially Similar" rule, CARB regulations, and other state and local regulations).
[B] Gasoline, or blend of oxygenate and gasoline as sold to the consumer, shall meet these limits. Certain gasolines meeting these limits of this table may not be suitable for blending with ethanol.
[C] Gasolines and gasoline-oxygenate blends sold at retail sites located in Area V shown in Fig. X1.2 (generally high elevations) shall use the special limits shown in Row 2 of this table, regardless of ethanol content.

5. Performance Requirements

5.1 Some requirements and test methods applicable to automotive spark-ignition engine fuel depend on whether the fuel is a gasoline, or a gasoline-oxygenate blend. Test Methods D4815 and D5599, gas chromatographic test methods, are the recommended procedures to detect the types and amounts of oxygenates. Once the type of fuel is known, the appropriate requirements and test methods can be identified by reference to Table 1, Table 3, and Section 7.

5.2 Volatility of fuels is varied for seasonal climatic changes and conformance to U.S. EPA volatility regulations by providing six vapor pressure/distillation classes and six vapor lock protection classes for fuel. Volatility of fuel is specified by an alphanumeric designation that uses a letter from Table 1 and a number from Table 3.

5.2.1 The seasonal and geographic distribution of the combined vapor pressure/distillation-vapor lock classes is shown in Table 4. For sea-level areas outside of the United States, the following ambient temperatures are for guidance in selecting the appropriate alphanumeric designation:

Alphanumeric Volatility Designation	10th Percentile 6 h Minimum Daily Temperature, °C (°F)	90th Percentile Maximum Daily Temperature, °C (°F)
A-1	>16 (60.)	≥43 (110.)
B-2	>10. (50.)	<43 (110.)
C-3	>4 (40.)	<36 (97)
D-4	> −7 (20.)	<29 (85)
E-5	≤ −7 (20.)	<21 (69)

The 6 h minimum temperature is the highest temperature of the six coldest consecutive hourly temperature readings of a 24 h day. The 6 h minimum temperature provides information on the cold-soak temperature experienced by a vehicle. The 10th percentile of this temperature statistic indicates a 10 % expectation that the 6 h minimum temperature will be below this value during a month. The 90th percentile maximum temperature is the highest temperature expected during 90 % of the days, and provides information relative to peak vehicle operating temperatures during warm and hot weather. For areas above sea level, the 10th percentile 6 h minimum temperature should be increased by 3.6 °C/1000 m (2 °F/1000 ft) of altitude, and the 90th percentile maximum should be increased by 4.4 °C/1000 m (2.4 °F/1000 ft) of altitude before comparing them to the sea level temperature. These corrections compensate for changes in fuel volatility caused by changes in barometric pressure due to altitude. Tables 5-7 show the U.S.

federal ozone nonattainment areas at several vapor lock protection levels that require reduced vapor pressure in the summertime. Tables 8-11 show at several vapor lock protection levels the areas that require federal reformulated spark-ignition engine fuel in the summertime. Table 12 shows the areas with restrictive local vapor pressure limits that have been approved under the EPA state implementation plan (SIP).

5.2.2 The EPA vapor pressure regulations can cause the distillation of the fuel to be less volatile, which for some vehicles, results in a worse warm-up driveability performance.

5.2.3 Driveability Index (DI) is intended to provide control of distillation parameters and ethanol content that influence cold start and warm-up driveability. It is a function of the 10 %, 50 %, and 90 % evaporated distillation temperatures measured by Test Methods D86 or D7345 and the ethanol content measured by the test methods shown in 7.1.9. Equations are provided for gasoline and gasoline-ethanol blends containing up to 10 % by volume ethanol and for gasoline-ethanol blends containing greater than 10 % by volume and no more than 15 % by volume ethanol when distillation temperatures are determined in Celsius or Fahrenheit degrees.

5.2.3.1 For fuels containing 0 % to 10 % by volume ethanol:

For degrees Celsius:

$$\text{Driveability Index } (DI_C) = 1.5 \ T_{10} + 3.0 \ T_{50} + 1.0 \ T_{90} + 1.33 \times (\text{Ethanol \% by Volume}) \quad (1)$$

For degrees Fahrenheit:

$$\text{Driveability Index } (DI_F) = 1.5 \ T_{10} + 3.0 \ T_{50} + 1.0 \ T_{90} + 2.4 \times (\text{Ethanol \% by Volume}) \quad (2)$$

5.2.3.2 For fuels greater than 10 % and no more than 15 % by volume ethanol:

For degrees Celsius:

$$\text{Driveability Index } (DI_C) = 1.5 \ T_{10} + 3.0 \ T_{50} + 1.0 \ T_{90} + (1.33 + [(\text{Ethanol \% by Volume} - 10)/5] \times (5.26 - 1.33)) \times (\text{Ethanol \% by Volume}) \quad (3)$$

For degrees Fahrenheit:

$$\text{Driveability Index } (DI_F) = 1.5 \ T_{10} + 3.0 \ T_{50} + 1.0 \ T_{90} + (2.4 + [(\text{Ethanol \% by Volume} - 10)/5]$$

TABLE 4 Schedule of U.S. Seasonal and Geographical Volatility Classes[A]

Note 1—This schedule, subject to agreement between purchaser and seller, denotes the volatility properties of the fuel at the time and place of bulk delivery to the fuel dispensing facilities for the end user. For Sept. 16 through April 30 (the time period not covered by U.S. EPA Phase II vapor pressure requirements), volatility properties for the previous month or the current month are acceptable for the end user from the 1st through the 15th day of the month. From the 16th day through the end of the month, volatility properties of the fuel delivered to the end user shall meet the requirements of the specified class(es). To ensure compliance with EPA Phase II vapor pressure requirements, vapor pressure for finished gasoline tankage at refineries, importers, pipelines, and terminals during May and for the entire distribution system, including retail stations, from June 1 to Sept. 15 shall meet only the current month's class. Shipments should anticipate this schedule.

Note 2—Where alternative classes are listed, either class or intermediate classes are acceptable; the option shall be exercised by the seller.

Note 3—See Appendix X2 of Research Report: D02-1347[2] for detailed description of areas. Contact EPA for the latest information on areas requiring reformulated fuel.

State	Jan.	Feb.	Mar.	Apr.	May[B]	June	July	Aug.	Sept. 1–15	Sept. 16–30	Oct.	Nov.	Dec.
Alabama	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3	A-3	A-2	A-2	A-2/C-3	C-3	C-3/D-4	D-4
Alaska	E-6	E-6	E-6	E-6	E-6/D-4	D-4	D-4	D-4	D-4	D-4/E-6	E-6	E-6	E-6
Arizona:[C]													
N 34° Latitude and E111° Longitude	D-4	D-4	D-4/C-3	C-3/A-2	A-2 (B-2)	A-1	A-1	A-1	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4
Remainder of State	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2 (B-2)	A-1[D]	A-1[D]	A-1[D]	A-1[E]	A-1	A-1/B-2	B-2/C-3	C-3/D-4
Arkansas	E-5/D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4	D-4/E-5
California:[C,F]													
North Coast	E-5/D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[G]	A-2[E]	A-2[E]	A-2[E]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
South Coast	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-2[E,H]	A-2[E,H]	A-2[E,H]	A-2[E,H]	A-2/B-2	B-2/C-3	C-3/D-4	D-4
Southeast	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2 (B-2)	A-1[D]	A-1[D,I]	A-1[D,I]	A-1[D,I]	A-1	A-1/B-2	B-2/C-3	C-3/D-4
Interior	E-5/D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-2[E,H]	A-2[E,H]	A-2[E,H]	A-2[E,H]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Colorado	E-5	E-5/D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-2[E]	A-2[E]	A-2[E]	A-2[E]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Connecticut	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
Delaware	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
District of Columbia	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[K]	A-3[K]	A-3[K]	A-3[K]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Florida	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3	A-3	A-3	A-3	A-3/C-3	C-3	C-3/D-4	D-4
Georgia	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3[G]	A-3[G]	A-2[E]	A-2[E]	A-2/C-3	C-3	C-3/D-4	D-4
Hawaii	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3	C-3
Idaho:													
N 46° Latitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
S 46° Latitude	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Illinois:[C]													
N 40° Latitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
S 40° Latitude	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4	D-4/E-5
Indiana[C]	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Iowa	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Kansas[C]	E-5	E-5/D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-2[E]	A-2[E]	A-2[E]	A-2[E]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Kentucky	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Louisiana	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3[G]	A-3[G]	A-2[E]	A-2[E]	A-2/C-3	C-3	C-3/D-4	D-4
Maine[C]	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
Maryland	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J,K]	A-3[J,K]	A-3[J,K]	A-3[J,K]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Massachusetts	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
Michigan[C]	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Minnesota	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Mississippi	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3	A-3	A-2	A-2	A-2/C-3	C-3	C-3/D-4	D-4
Missouri[C]	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[G]	A-2[E]	A-2[E]	A-2[E]	A-2/C-3	C-3/D-4	D-4	D-4/E-5
Montana	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
Nebraska	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Nevada:													
N 38° Latitude	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-2[E]	A-2[E]	A-2[E]	A-2[E]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
S 38° Latitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2 (B-2)	A-1	A-1	A-1	A-1	A-1	A-1/B-2	B-2/C-3	C-3/D-4
New Hampshire	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
New Jersey	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
New Mexico:													
N 34° Latitude	E-5/D-4	D-4	D-4/C-3	C-3/A-2	A-2 (B-2)	A-1	A-1	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4
S 34° Latitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2 (B-2)	A-1	A-1	A-1	A-1	A-1/B-2	B-2/C-3	C-3/D-4	D-4
New York	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
North Carolina	E-5/D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-3	A-3	A-2	A-2	A-2/C-3	C-3/D-4	D-4	D-4/E-5
North Dakota	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
Ohio	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Oklahoma	E-5/D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Oregon:													
E122° Longitude	E-5	E-5/D-4	D-4	D-4/A-4	A-4 (D-4)	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
W 122° Longitude	E-5	E-5/D-4	D-4	D-4/A-4	A-4 (D-4)	A-3[G]	A-3[G]	A-3[G]	A-3[G]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Pennsylvania[C]	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Rhode Island	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/D-4	D-4	D-4/E-5	E-5
South Carolina	D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-3	A-3	A-2	A-2	A-2/C-3	C-3/D-4	D-4	D-4
South Dakota	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Tennessee	E-5/D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[G]	A-3[G]	A-2[E]	A-2[E]	A-2/C-3	C-3/D-4	D-4	D-4/E-5
Texas:[C]													

TABLE 4 *Continued*

State	Jan.	Feb.	Mar.	Apr.	May[B]	June	July	Aug.	Sept. 1–15	Sept. 16–30	Oct.	Nov.	Dec.
E99° Longitude	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3[G,K]	A-2[E,H]	A-2[E,H]	A-2[E,H]	A-2/B-2	B-2/C-3	C- 3/D-4	D-4
W 99° Longitude	D-4	D-4/C-3	C-3/B-2	B-2/A-2	A-2 (B-2)	A-1[D]	A-1[D]	A-1[D]	A-1[D]	A-1/B-2	B-2/C-3	C-3/D-4	D-4
Utah	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-2[E]	A-2[E]	A-2[E]	A-2[E]	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5
Vermont	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/D-4	D-4	D-4/E-5	E-5
Virginia	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[G,K]	A-3[G,K]	A-3[G ,K]	A-3[G,K]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Washington:													
E122° Longitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-2	A-2	A-2	A-2/C-3	C-3/D-4	D-4/E-5	E-5
W 122° Longitude	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
West Virginia	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Wisconsin	E-5	E-5	E-5/D-4	D-4/A-4	A-4 (D-4)	A-3[J]	A-3[J]	A-3[J]	A-3[J]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Wyoming	E-5	E-5	E-5/D-4	D-4/A-3	A-3 (C-3)	A-2	A-2	A-2	A-2	A-2/B-2	B-2/C-3	C-3/D-4	D-4/E-5

[A] For the period May 1 through September 15, the specified vapor pressure classes comply with 1992 U.S. EPA Phase II volatility regulations. Reformulated spark-ignition engine fuel blended to meet the requirements of the EPA "Complex Model" shall also meet the Phase II volatility regulations. EPA regulations (under the Phase II regulations) allow 1.0 psi higher vapor pressure for gasoline-ethanol blends containing 9 % to 10 % by volume ethanol for the same period, except for fuels blended to meet the "Complex Model" regulations. See Appendix X3 for additional federal volatility regulations.

[B] Values in parentheses are permitted for retail stations and other end users.

[C] See Table 12 for specific area requirements.

[D] See Table 7 for specific area requirements.

[E] See Table 6 for specific area requirements.

[F] Details of State Climatological Division by CARB air basin and county as indicated (Descriptions of the California Air Basins are found in the California Code of Regulations):

California, North Coast—CARB North Coast, Lake County, San Francisco Bay Area, and North Central Coast Air Basins (Alameda, Contra Costa, Del Norte, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, and Trinity Counties and part of Solano County).

California, interior—CARB Northeast Plateau, Sacramento Valley, Mountain Counties, Lake Tahoe, and San Joaquin Valley Air Basins (Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kings, Lassen, Madera, Mariposa, Merced, Modoc, Nevada, Placer, Plumas, Sacramento, San Joaquin, Shasta, Sierra, Siskiyou, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, and Yuba Counties, and parts of Kern and Solano Counties).

California, South Coast—CARB South Central Coast, San Diego, and South Coast Air Basins (Los Angeles, Orange, San Diego, San Luis Obispo, Santa Barbara, and Ventura Counties, and parts of Riverside and San Bernardino Counties).

California, Southeast—CARB Great Basin Valleys, Salton Sea, and Mojave Desert Air Basins (Alpine, Imperial, Inyo, and Mono Counties, and parts of Kern, Los Angeles, Riverside, San Bernardino Counties).

[G] See Table 5 for specific area requirements.

[H] See Table 10 for specific requirements.

[I] See Table 11 for specific area requirements.

[J] See Table 8 for specific area requirements.

[K] See Table 9 for specific area requirements.

TABLE 5 U.S. Ozone Nonattainment Areas Requiring Volatility Class AA-3

NOTE 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

California[A] —Alameda, Contra Costa, Marin, Monterey, Napa, San Francisco, San Benito, San Mateo, Santa Clara, Santa Cruz, and Solano (part) counties

Georgia—Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale counties

Louisiana—Ascension, Beauregard, Calcasieu, East Baton Rouge, Iberville, Jefferson, Lafayette, Lafourche, Livingston, Orleans, Point Coupee, Saint Bernard, Saint Charles, Saint James, Saint Mary, and West Baton Rouge parishes

Missouri—Franklin, Jefferson, Saint Charles, and Saint Louis counties; and the city of St. Louis

Oregon—Clackamas (part), Marion (part), Multnomah (part), Polk (part), and Washington (part) counties

Tennessee—Shelby County

Texas—Hardin, Jefferson, and Orange counties

Virginia—Smyth County (part)

[A] See Table 12 for local vapor pressure limits.

TABLE 6 U.S. Ozone Nonattainment Areas Requiring Volatility Class AA-2

NOTE 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

Arizona[A] —Maricopa County

California[A] —Alameda, Butte, Contra Costa, Fresno, Kern (part), Kings, Madera, Marin, Merced, Monterey, Napa, San Benito, San Francisco, San Joaquin, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Stanislaus, Tulare, and Yuba counties

Colorado—Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Jefferson, Larimer (part), and Weld (part) counties

Georgia—Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale counties

Kansas[A] —Johnson and Wyandotte counties

Louisiana—Ascension, Beauregard, Calcasieu, East Baton Rouge, Iberville, Jefferson, Lafayette, Lafourche, Livingston, Orleans, Point Coupee, Saint Bernard, Saint Charles, Saint James, Saint Mary, and West Baton Rouge parishes

Missouri—Franklin, Jefferson, Saint Charles, and Saint Louis counties; and the city of St. Louis

Nevada—Washoe County

Tennessee—Shelby County

Texas—Hardin, Jefferson, and Orange counties

Utah—Davis and Salt Lake counties

[A] See Table 12 for local vapor pressure limits.

$$\times (9.49 \ - \ 2.4)) \times (\text{Ethanol \% by Volume})$$

$$(4)$$

where:

T_{10} = distillation temperature at 10 % evaporated,
T_{50} = distillation temperature at 50 % evaporated, and
T_{90} = distillation temperature at 90 % evaporated.

5.2.4 Test Method D5188 is the method for determining vapor-liquid ratio temperatures by an evacuated chamber method for gasoline-oxygenate blends, as well as for gasoline. The methods for estimating temperature-*V/L* ($T_{V/L=20}$) (see

TABLE 7 U.S. Ozone Nonattainment Areas Requiring Volatility Class AA-1

Note 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

Arizona[A] —Maricopa County
California[A] —Imperial and Kern (part) counties
Texas[A] —El Paso County

[A] See Table 12 for local vapor pressure limits.

TABLE 8 U.S. Federal RFG Areas Requiring Volatility Class A-3

Note 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

Note 2—No waiver for gasoline-ethanol blends.

Connecticut—All counties
Delaware—All counties
Illinois[A] —Cook, Du Page, Grundy (part), Jersey, Kane, Kendall (part), Lake, Madison, McHenry, Monroe, St. Clair, and Will counties
Indiana[A] —Lake and Porter counties
Kentucky—Boone, Bullitt (part), Campbell, Jefferson, Kenton, and Oldham (part) counties
Maine[A] —Androscoggin, Cumberland, Kennebec, Knox, Lincoln, Sagadahoc, and York Counties
Maryland—Cecil County
Massachusetts—All counties
New Hampshire—Hillsborough, Merrimack, Rockingham, and Strafford counties
New Jersey—All counties
New York—Bronx, Dutchess, Essex (part), Kings, Nassau, New York, Orange, Putnam, Queens, Richmond, Rockland, Suffolk, and Westchester counties
Pennsylvania—Bucks, Chester, Delaware, Montgomery, and Philadelphia counties
Rhode Island—All counties
Wisconsin—Kenosha, Milwaukee, Ozaukee, Racine, Washington, and Waukesha counties

[A] See Table 12 for local vapor pressure limits.

TABLE 9 U.S. Federal RFG Areas Requiring Volatility Class AA-3

Note 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

Note 2—No waiver for gasoline-ethanol blends.

District of Columbia
Maryland—Anne Arundel, Baltimore, Calvert, Carroll, Charles, Frederick, Harford, Howard, Kent, Montgomery, Prince George's, and Queen Anne's counties
Texas—Brazoria, Chambers, Collin, Dallas, Denton, Fort Bend, Galveston, Harris, Liberty, Montgomery, Tarrant, and Waller counties
Virginia—Arlington, Charles City, Chesterfield, Fairfax, Hanover, Henrico, James City, Loudoun, Prince William, Stafford, and York counties and independent cities of Alexandria, Chesapeake, Colonial Heights, Fairfax, Falls Church, Hampton, Hopewell, Manassas, Manassas Park, Newport News, Norfolk, Poquoson, Portsmouth, Richmond, Suffolk, Virginia Beach, and Williamsburg

Appendix X2) are applicable for gasoline and gasoline-ethanol blends (1 % to 15 % by volume), but not for gasoline-ether blends.

5.3 Antiknock index (AKI) is very important to engine performance. The matching of engine octane requirement to fuel octane level (AKI) is critical to the durability and performance of engines; this cannot be accomplished with a single specified minimum level of antiknock index. Appendix X1 includes a discussion of antiknock indexes of fuels currently marketed and relates these levels to the octane needs of

TABLE 10 U.S. Federal RFG Areas Requiring Volatility Class AA-2

Note 1—See 40 CFR Part 81.305 for description of the geographic boundary for each area.

Note 2—No waiver for gasoline-ethanol blends.

California[A] —El Dorado (part), Los Angeles, Orange, Placer (part), Riverside (part), Sacramento, San Bernardino (part), San Diego, Solano (part), Sutter (part), Ventura, and Yolo Counties
Texas—Brazoria, Chambers, Collin, Dallas, Denton, Fort Bend, Galveston, Harris, Liberty, Montgomery, Tarrant, and Waller counties

[A] See Table 12 for local vapor pressure limits.

TABLE 11 U.S. Federal RFG Area Requiring Volatility Class AA-1

Note 1—See 40 CFR Part 81.300 for description of the geographic boundary for each area.

Note 2—No waiver for gasoline-ethanol blends.

California[A] —Los Angeles (part), Riverside (part), and San Bernardino (part) counties

[A] See Table 12 for local vapor pressure limits.

TABLE 12 U.S. Federally Approved State Implementation Plan Areas Requiring More Restrictive Maximum Vapor Pressure Limits

Note 1—Some areas are awaiting official EPA approval for the more restrictive local vapor pressure limits.

Arizona—Maricopa County, Pinal(part), and Yavapai (part)–48.2 kPa (7.0 psi) max June 1 - Sept. 30, 62.0 kPa (9.0 psi) max Oct. 1 - Mar. 31
California—48.26 kPa (7.00 psi) max April 1, May 1, or June 1 - Sept. 30 or Oct. 31 depending on air basin
Illinois—Madison, Monroe, and Saint Clair Counties area – 49.6 kPa (7.2 psi) max June 1 - Sept. 15
Indiana—Clark and Floyd counties area – 53.8 kPa (7.8 psi) max May 1 terminal/June 1 retail - Sept. 15[A]
Kansas—Johnson and Wyandotte counties–48.2 kPa (7.0 psi) max June 1 - Sept. 15[A]
Maine—Androscoggin, Cumberland, Kennebec, Knox, Lincoln, Sagadahoc, and York Counties–53.8 kPa (7.8 psi) max May 1-Sept 15
Michigan—Lenawee, Livingston, Macomb, Monroe, Oakland, Saint Clair, Washtenaw, and Wayne counties–48.2 kPa (7.0 psi) max June 1 - Sept 15[A]
Missouri—Clay, Jackson, and Platte counties–48.2 kPa (7.0 psi) max June 1 - Sept. 15[A]
Pennsylvania—Allegheny, Armstrong, Beaver, Butler, Fayette, Washington, and Westmoreland counties–53.8 kPa (7.8 psi) max May 1 Terminal/June 1 Retail - Sept. 15
Texas—El Paso County–48.2 kPa (7.0 psi) max May 1 terminal/June 1 retail - Sept. 15
Texas—Anderson, Angelina, Aransas, Atascosa, Austin, Bastrop, Bee, Bell, Bexar, Bosque, Bowie, Brazos, Burleson, Caldwell, Calhoun, Camp, Cass, Cherokee, Colorado, Comal, Cooke, Coryell, De Witt, Delta, Ellis, Falls, Fannin, Fayette, Franklin, Freestone, Goliad, Gonzales, Grayson, Gregg, Grimes, Guadalupe, Harrison, Hays, Henderson, Hill, Hood, Hopkins, Houston, Hunt, Jackson, Jasper, Johnson, Karnes, Kaufman, Lamar, Lavaca, Lee, Leon, Limestone, Live Oak, Madison, Marion, Matagorda, McLennan, Milam, Morris, Nacogdoches, Navarro, Newton, Nueces, Panola, Parker, Polk, Rains, Red River, Refugio, Robertson, Rockwall, Rusk, Sabine, San Jacinto, San Patricio, San Augustine, Shelby, Smith, Somervell, Titus, Travis, Trinity, Tyler, Upshur, Van Zandt, Victoria, Walker, Washington, Wharton, Williamson, Wilson, Wise, and Wood counties–53.8 kPa (7.8 psi) max May 1 terminal/June 1 retail - October 1

[A] A 1.0 psi higher vapor pressure is allowed for gasoline-ethanol blends containing 9 % to 10 % by volume ethanol.

broad groups of engines and vehicles. Also discussed is the effect of altitude and weather on vehicle antiknock requirements.

5.4 The denatured fuel ethanol used in gasoline-ethanol blends shall conform to the requirements of Specification D4806.

5.5 Additional fuel requirements are shown in Table 2.

5.6 The properties of gasoline-oxygenate blends can differ considerably from those of gasoline. Consequently, additional requirements are needed for gasoline-oxygenate blends. These requirements involve evaluation of compatibility with plastic and elastomeric materials in fuel systems, corrosion of metals, and especially in the case of gasoline-alcohol blends, water tolerance. Requirements for metal corrosion (other than copper and silver) and material compatibility are not given because test methods and appropriate limits are still under development. When these have been developed, they will be included in this specification.

5.7 Depending on oxygenate type and concentration in the blend, vehicle driveability with gasoline-oxygenate blends can differ significantly from that with gasolines having similar volatility characteristics.

5.8 Deposit control additives are added to fuel to help keep carburetors, fuel injectors, and intake valves clean.

5.8.1 In the United States, deposit control additives are required to be certified by the EPA as summarized in X3.5. Each additive is certified for use at a lowest additive concentration (LAC), which is the lowest level certified to be effective in preventing deposit formation. All parties who blend deposit control additives into fuel must complete mandatory volume additive reconciliation (VAR) accounting to establish that the product was additized at a concentration that was at least equal to the LAC.

5.8.2 Outside the U.S., the user of this document should consult the regulatory authorities in those countries for similar deposit control requirements.

6. Workmanship

6.1 The finished fuel shall be visually free of undissolved water, sediment, and suspended matter; it shall be clear and bright at the fuel temperature at the point of custody transfer or at a lower temperature agreed upon by the purchaser and seller.

Note 5—Test Method D4176 can be helpful for evaluating the product.

6.1.1 *Avoiding Water Haze and Phase Separation*—Finished spark-ignition engine fuel should not contain a separate water or water-alcohol phase at the time it is introduced into a vehicle or equipment fuel tank or under the conditions the fuel is used. Water that is dissolved in fuel at the point of use does not generally cause engine problems. However, if excess water is present in spark-ignition fuel, a separate phase, either 'free water' or a water-alcohol mixture, can form. Either condition can lead to engine damage, engine failing to start or failing to operate properly. A separated water-rich phase can be observed as a haze, as water droplets or as a distinct lower layer. This lower aqueous phase can be corrosive to many metals and the engine cannot operate on it. Similarly, the upper hydrocarbon phase may no longer meet volatility and antiknock properties. See Appendix X8 for additional information on water haze and phase separation.

Note 6—Finished fuel should be resistant to phase separation or undissolved matter at the lowest temperatures to which it is likely to be subjected, dependent on the time and place of its intended use. See Table X8.1 for guidance.

Note 7—Solubility is temperature dependent. As this fuel cools, water or water-alcohol and some high molecular weight additives can become insoluble.

6.2 The finished fuel shall also be free of any adulterant or contaminant that can render the fuel unacceptable for its commonly used applications.

6.2.1 Manufacturers and blenders of gasoline and gasoline-oxygenate blends shall avoid gasoline blending stocks (for example, purchased used toluene solvents) or denatured fuel ethanol (for example, improperly recycled ethanol) contaminated by silicon-containing materials, or both. Silicon contamination of gasoline and gasoline-oxygenate blends has led to fouled vehicle components (for example, spark plugs, exhaust oxygen sensors, catalytic converters) requiring parts replacement and repairs. Test Method D7757 is a procedure for determining silicon content but no specification limits have been established for silicon.

6.2.2 Manufacturers and blenders of gasoline and gasoline-oxygenate blends shall avoid gasoline blending stocks or denatured fuel ethanol contaminated by chloride salts. Chloride salts can contribute inorganic chloride ions to the blend component or the finished fuel. Contamination of the blend components or the finished fuel with inorganic chlorides has led to corrosion issues with vehicle fuel and emissions systems requiring parts replacement and repairs. Approved standard test methods are not available to determine the concentration of inorganic chloride in spark-ignition engine fuels.

6.3 For markets where vehicles meeting U.S. Tier 2, Euro 5, or more stringent emissions standards are required or in widespread use, MMT shall be limited in automotive spark-ignition engine fuel to a maximum manganese concentration of 0.25 mg/L, until such time as data are produced to support its use at higher concentrations, and incorporated into this specification. (See Note 8.)

Note 8—This level represents the lower limit of the Test Method D3831 scope.

7. Test Methods

7.1 The requirements of this specification shall be determined in accordance with the methods listed below. The scopes of some of the test methods listed below do not include gasoline-ethanol blends or other gasoline-oxygenate blends. Refer to the listed test methods to determine applicability or required modifications for use with gasoline-oxygenate blends. The precision of these test methods can differ from the reported precisions when testing gasoline-ethanol blends or other gasoline-oxygenate blends.

7.1.1 *Distillation*—Test Method D86 or D7345.

7.1.1.1 When using Test Method D7345, results shall be reported as "Predicted D86" as determined by applying the corrections described in Test Method D7345 to convert to D86 equivalent values. In case of dispute, Test Method D86 shall be the referee method.

7.1.1.2 The use of Test Method D7345 shall be limited to gasoline and gasoline-ethanol blends up to maximum 20 % by volume ethanol.

7.1.2 *Vapor-Liquid Ratio*—Test Method D5188 is an evacuated chamber method for determining temperatures for vapor-liquid ratios between 8 to 1 and 75 to 1. For this specification, it is conducted at a ratio of 20 to 1. It may be used for gasoline and gasoline-oxygenate blends.

7.1.3 *Vapor Pressure*—Test Methods D4953, D5191, D5482, or D6378.

7.1.3.1 When using Test Method D6378, determine VP_4 at 37.8 °C (100 °F) using a sample from a 1 L container and convert to DVPE (D5191 equivalence) using the following equation:

$$Predicted\ DVPE_C = VP_{4\ 37.8\ °C} - 1.005\ kPa \qquad (5)$$

$$Predicted\ DVPE_F = VP_{4\ 100\ °F} - 0.15\ psi \qquad (6)$$

7.1.4 *Corrosion, for Copper*—Test Method D130, 3 h at 50 °C (122 °F).

7.1.5 *Solvent-Washed Gum Content*—Test Method D381, air jet apparatus.

7.1.6 *Sulfur*—Test Methods D1266, D2622, D3120, D5453, D6920, D7039, or D7220. With Test Method D3120, fuels with sulfur content greater than 100 mg/kg (0.0100 % by mass) must be diluted with *iso*octane. The dilution of the sample may result in a loss of precision. Test Method D3120 cannot be used when the lead concentration is greater than 0.4 g/L (1.4 g/U.S. gal).

7.1.7 *Lead*—Test Methods D3341 or D5059 (Test Methods A or B). For lead levels below 0.03 g/L (0.1 g/U.S. gal), use Test Methods D3237 or D5059 (Test Method C).

7.1.8 *Oxidation Stability*—Test Method D525.

7.1.9 *Oxygenate Detection*—Test Methods D4815, D5599, or D5845. These test methods are designed for the quantitative determination of methyl *tert*-butyl ether (MTBE), ethyl *tert*-butyl ether (ETBE), *tert*-amyl methyl ether (TAME), diisopropyl ether (DIPE), methyl alcohol, ethyl alcohol, and *tert*-butyl alcohol. In addition, Test Methods D4815 and D5599 are designed for the quantitative determination of *n*-propyl alcohol, *iso*propyl alcohol, *n*-butyl alcohol, *sec*-butyl alcohol *iso*butyl alcohol, and *tert*-pentyl alcohol. Results for all of these test methods are reported in percent by mass. Test Method D4815 includes procedures for calculating oxygenate concentration in percent by volume and mass oxygen content using the percent by mass oxygenate results.

7.1.10 *Corrosion, for Silver*—Test Methods D7667 or D7671.

7.1.11 *Manganese*—Test Method D3831. (See Note 8.)

8. Sampling, Containers, and Sample Handling

8.1 The reader is strongly advised to review all intended test methods prior to sampling to understand the importance and effects of sampling technique, proper containers, and special handling required for each test method.

8.2 Correct sampling procedures are critical to obtain a sample representative of the lot intended to be tested. Use appropriate procedures in Practice D4057 for manual method sampling and in Practice D4177 for automatic method sampling, as applicable.

8.3 The correct sample volume and appropriate container selection are important decisions that can impact test results. Refer to Practice D4306 for aviation fuel container selection for tests sensitive to trace contamination. Refer to Practice D5854 for procedures on container selection and sample mixing and handling. For octane number determination, protection from light is important. Collect and store sample fuels in an opaque container, such as a dark brown glass bottle, metal can, or minimally reactive plastic container to minimize exposure to UV emissions from sources such as sunlight or fluorescent lamps.

8.4 For volatility determination of a sample, refer to Practice D5842 for special precautions recommended for representative sampling and handling techniques.

9. Precision and Bias[9]

9.1 The precision of each required test method for the properties specified is included in the standard applicable to each method, with the exception of Driveability Index. In many cases, the precision applicable to gasoline-oxygenate blends has not been established yet.

9.2 *Precision and Bias of Driveability Index (DI):*

9.2.1 The following statements apply to the precision and bias of DI, which is a derived quantity not addressed in any other standard.[9]

9.2.2 The precision of DI is a function of the individual precisions of the 10 %, 50 %, and 90 % evaporated temperatures from Test Method D86. The precisions of these percent evaporated temperatures vary for different apparatuses (manual or automatic), for fuels of different volatilities (for example, above and below 65.5 kPa (9.5 psi) vapor pressure) and with different distillation curve slopes.

9.2.3 *Repeatability*—The difference between two successive DI determinations using Test Method D86 results, where the two test results were obtained by one operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in normal and correct operation of the test method, exceed 9 °C (17 °F) derived units in only one case in twenty.

9.2.4 The repeatability value was calculated using the precision data from Test Method D86 and average distillation characteristics from the 1994 through 1998 ASTM Committee D02 Interlaboratory Crosscheck Program for Motor Gasoline and from the 1997 and 1998 ASTM Committee D02 Interlaboratory Crosscheck Program for Reformulated Gasoline.

9.2.5 *Reproducibility*—The difference between two single and independent DI determinations using Test Method D86 results, where the two test results were obtained by different operators in different laboratories on identical test material, would in the long run, in normal and correct operation of the test method, exceed 27 °C (48 °F) derived units in only one case in twenty.

9.2.6 The reproducibility values were determined directly using the distillation data from each laboratory participating in cooperative programs to calculate DI. The data used to calculate DI were available from the 1994 through 1998 ASTM Committee D02 Interlaboratory Crosscheck Program for Motor Gasoline, the 1997 and 1998 ASTM Committee D02 Interlaboratory Crosscheck Program for Reformulated Gasoline, the Auto/Oil Air Quality Improvement Research Program, the Auto/Oil AAMA Gasoline Inspections Program, and the 1995 to 1996 CRC volatility program.

9.2.7 *Bias*—Since there is no acceptable reference material suitable for determining bias for DI, bias has not been determined.

10. Keywords

10.1 alcohol; antiknock index; automotive fuel; automotive gasoline; automotive spark-ignition engine fuel; copper strip corrosion; corrosion; distillation; driveability; Driveability Index; EPA regulations; ethanol; ether; fuel; gasoline; gasoline-alcohol blend; gasoline-ethanol blend; gasoline-ether blend; gasoline-oxygenate blend; induction period; lead; leaded fuel; manganese; methanol; MTBE; octane number; octane requirement; oxidation stability; oxygenate; oxygenate detection; phase separation; phosphorous; solvent-washed gum; sulfur; $T_{V/L= 20}$; unleaded fuel; vapor-liquid ratio; vapor lock; vapor pressure; volatility; water tolerance

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF ASTM SPECIFICATION FOR AUTOMOTIVE SPARK-IGNITION ENGINE FUEL

X1.1 General

X1.1.1 Antiknock rating and volatility define the general characteristics of automotive spark-ignition engine fuel. Other characteristics relate to the following: limiting the concentration of undesirable components so that they will not adversely affect engine performance and ensuring the stability of fuel as well as its compatibility with materials used in engines and their fuel systems.

X1.1.2 Fuel for spark-ignition engines is a complex mixture composed of relatively volatile hydrocarbons that vary widely in their physical and chemical properties and may contain oxygenates. Fuel is exposed to a wide variety of mechanical, physical, and chemical environments. Thus, the properties of fuel must be balanced to give satisfactory engine performance over an extremely wide range of operating conditions. The prevailing standards for fuel represent compromises among the numerous quality and performance requirements. This ASTM specification is established on the basis of the broad experience and close cooperation of producers of fuel, manufacturers of automotive equipment, and users of both.

X1.2 Engine Knock

X1.2.1 The fuel-air mixture in the cylinder of a spark-ignition engine will, under certain conditions, autoignite in localized areas ahead of the flame front that is progressing from the spark. This is engine spark knock which can cause a ping that may be audible to the customer.

X1.2.2 The antiknock rating of a fuel is a measure of its resistance to knock. The antiknock requirement of an engine depends on engine design and operation, as well as atmospheric conditions. Fuel with an antiknock rating higher than that required for knock-free operation does not improve performance.

X1.2.3 A decrease in antiknock rating may cause vehicle performance loss. However, vehicles equipped with knock limiters can show a performance improvement as the antiknock quality of the fuel is increased in the range between customer-audible knock and knock-free operation. The loss of power and the damage to an automotive engine due to knocking are generally not significant until the knock intensity becomes very severe. Heavy and prolonged knocking may cause power loss and damage to the engine.

X1.3 Laboratory Octane Number

X1.3.1 The two recognized laboratory engine test methods for determining the antiknock rating of fuels are the Research method (Test Methods D2699 or D2885) and the Motor method (Test Methods D2700 or D2885). The following paragraphs define the two methods and describe their significance as applied to various equipment and operating conditions.

X1.3.2 Research octane number is determined by a method that measures fuel antiknock level in a single-cylinder engine under mild operating conditions; namely, at a moderate inlet mixture temperature and a low engine speed. Research octane number tends to indicate fuel antiknock performance in engines at wide-open throttle and low-to-medium engine speeds.

X1.3.3 Motor octane number is determined by a method that measures fuel antiknock level in a single-cylinder engine under more severe operating conditions than those employed in the Research method; namely, at a higher inlet mixture temperature and at a higher engine speed. It indicates fuel antiknock performance in engines operating at wide-open throttle and high engine speeds. Also, Motor octane number tends to indicate fuel antiknock performance under part-throttle, road-load conditions.

X1.4 Road Octane Number

X1.4.1 The road octane of a fuel is the measure of its ability to resist knock in customers' vehicles, and is ultimately of more importance than laboratory octane numbers. Since road octanes are difficult to measure and interpret, the industry has

agreed to use ASTM laboratory engine tests to estimate the road octane performance of spark-ignition engine fuel in vehicles.

X1.4.2 The antiknock index (AKI) is the arithmetic average of the Research octane number (RON) and Motor octane number (MON):

$$AKI = (RON + MON)/2 \qquad (X1.1)$$

This value is called by a variety of names, in addition to antiknock index, including:

Octane rating

Posted octane

(R + M)∕2 octane

X1.4.3 The AKI is posted on retail gasoline dispensing pumps in the United States and is referred to in car owners' manuals. The AKI is also required for certification at each wholesale fuel transfer and is referred to in United States federal law as "Octane Rating." Details of this regulation can be found in 16 CFR Part 306 Areas outside the United States may or may not use AKI as the standard means for reporting octane rating; for example, minimums for RON and MON may be required rather than the AKI.

X1.4.4 The most extensive data base that relates the laboratory engine test methods for Research and Motor octane to actual field performance of fuel in vehicles is the annual Coordinating Research Council (CRC)[10] Octane Number Requirement Survey conducted for new light-duty vehicles. Analysis of these data shows that the antiknock performance of a fuel in some vehicles may correlate best with Research octane number, while in others, it may correlate best with Motor octane number. These correlations also differ from model year to model year or from vehicle population to vehicle population, reflecting changes in engine designs over the years.

X1.4.5 The antiknock index of a fuel approximates the CRC road octane ratings for many vehicles. However, the user must also be guided by experience as to which fuel is most appropriate for an individual vehicle. The antiknock index formula is reviewed periodically and may have to be adjusted in the future as engines and fuels continue to evolve. The present (RON + MON)∕2 formula is an estimate and is not an absolute measure of fuel antiknock performance in general or in any specific vehicle.

X1.4.6 Car antiknock requirements vary, even within a single model, so the statistical distribution of the octane needs of any car population are usually shown in graphical form, as shown in Fig. X1.1. As antiknock index increases, larger and larger fractions of the car population in question will be free of knock, that is, be "satisfied" with the octane quality of fuels at or above that level of antiknock index. The data in Fig. X1.1 are for new model cars and trucks sold in the United States in the model year 1988 and are included as an example of the antiknock requirement distribution, not as a data reference.

X1.4.7 According to the winter 1988–1989 motor gasoline survey published by the National Institute for Petroleum and
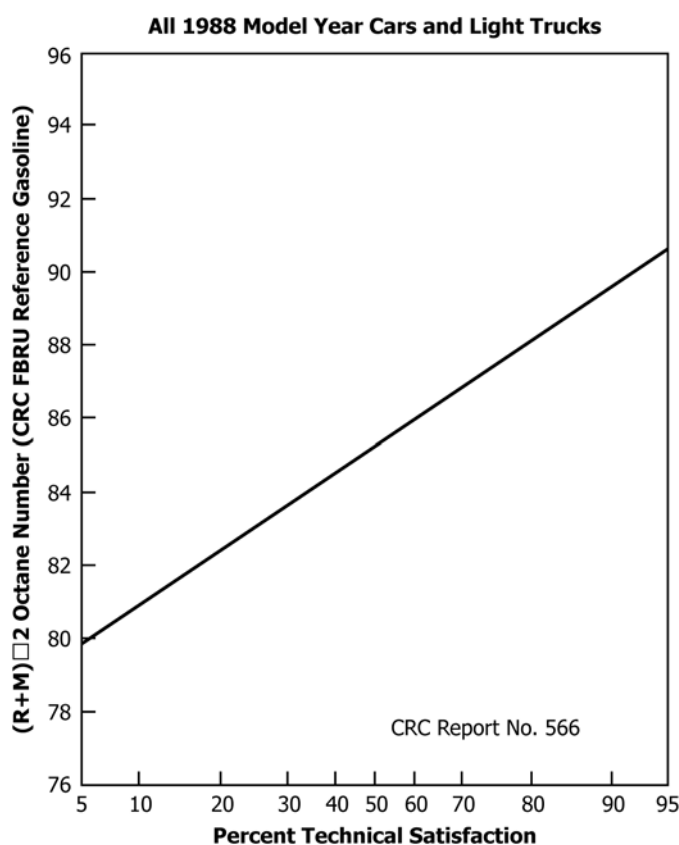

FIG. X1.1 An Example of the Statistical Distribution of Vehicle Antiknock Requirements

Energy Research, unleaded fuel antiknock indexes in current practice range from a low near 84 in the mountain areas to a high of near 94. Companies typically market two or three unleaded grades of fuel, one of which usually has a minimum antiknock index of 87, for which most post-1971 vehicles are designed. Most companies also market a higher octane fuel with an antiknock index of 91 or above. This fuel is intended to satisfy those vehicles with a higher octane requirement. Some companies offer three grades of unleaded fuel. The third grade usually has an antiknock index of 89. Leaded fuel is still available in some markets and usually has an antiknock index of 88 or 89.

X1.4.8 Marketers set the grades and octane based on their perception of the technical and competitive needs in the market.

X1.4.9 Antiknock indexes of fuel sold in current practice in the United States are shown in Table X1.1 for both unleaded and leaded fuels.

X1.5 Precision and Bias of Antiknock Index

X1.5.1 The following statements apply to the precision and bias of antiknock index of fuel, which is a composite quantity not addressed in any other standard.

X1.5.2 The precision of the antiknock index, (RON + MON)/2, is a function of the individual precisions of Research (Test Method D2699) and Motor (Test Method D2700) octane numbers. The repeatability and reproducibility variances for

---

[10] Coordinating Research Council, Inc., 3650 Mansell Rd., Ste. 140, Alpharetta, GA 30022–8246.

TABLE X1.1 Automotive Spark-Ignition Engine Fuel Antiknock Indexes in Current Practice

Unleaded Fuel[A] (for vehicles that can or must use unleaded fuel)	
Antiknock Index[B,C,D,E] (RON + MON) /2	Application
87	Designed to meet antiknock requirements of most 1971 and later model vehicles
89	Satisfies vehicles with somewhat higher antiknock requirements
91 and above	Satisfies vehicles with high antiknock requirements
Leaded Fuel (for vehicles that can or must use leaded fuel)	
Antiknock Index[B,C,D,E] (RON + MON) /2	Application
88	For most vehicles that were designed to operate on leaded fuel

[A] Unleaded fuel having an antiknock index of at least 87 should also have a minimum Motor octane number of 82 in order to adequately protect those vehicles that are sensitive to Motor octane quality.
[B] Reductions in vehicle antiknock requirements for altitude are shown in Fig. X1.2.
[C] Reductions in vehicle antiknock requirements for seasonal variations are shown in Fig. X1.3.
[D] Not all antiknock index levels listed in this table are available at all locations.
[E] The Federal Trade Commission requires octane posting and certification in accordance with 16 CFR Part 306.

these test methods are summed and divided by four to obtain the variance of the antiknock index.

X1.5.2.1 *Repeatability*—The difference between two sets of antiknock index determinations, where two test results by each octane number method were obtained by one operator, with the same apparatus under constant operating conditions on identical test material would, in the long run, and in the normal and correct operation of the test methods, exceed the values in the following table in only one case in twenty.

X1.5.2.2 *Reproducibility*—The difference between two independent sets of antiknock index determinations, obtained by different operators working in different laboratories on identical test material would, in the long run, and in the normal and correct operation of the test methods, exceed the values in the following table in only one case in twenty.

Antiknock Index	Repeatability, Antiknock Index Units	Reproducibility, Antiknock Index Units
83	0.2	0.7
85	0.2	0.7
87	0.2	0.6
89	0.2	0.6
91	0.2	0.6
93	0.2	0.6
95	—	0.6
97	—	0.7

NOTE X1.1—These precision values were calculated from Research and Motor octane number results utilizing exchange sample test data obtained by the ASTM National Exchange Group (NEG), the Institute of Petroleum, or the Institut Français du Petrole, or combination thereof, participating in cooperative testing programs. The precision values for 83, 85, 95, and 97 AKI were obtained from NEG data during the period 1980 through 1982 and have been analyzed in accordance with RR:D02-1007, "Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants," Spring 1973.[11] The precision values for 87 though 93 AKI were calculated using the data from RR:D02-1383, "Research and Motor Octane Number Precision Study Report, 1988
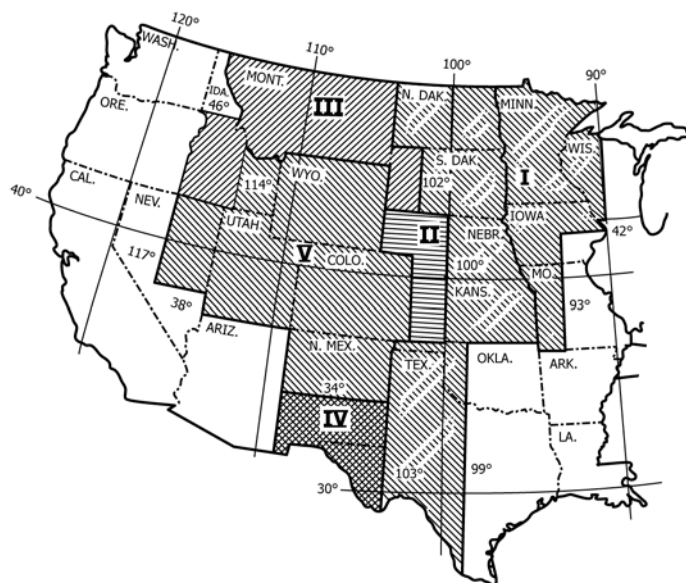
FIG. X1.2 Reduction in U.S. Vehicle Antiknock Requirements for Altitude[A,B]

Area	Less than 89 AKI	89 AKI or Greater[A,B]
I	0.7	0.5
II	1.5	1.5
III	2.2	1.5
IV	3.0	2.0
V	4.5	3.0

[A] Fuel may be marketed using these reductions, but actual antiknock index minimums must be posted.
[B] While the reductions in this table apply to most pre-1984 vehicles, the control technology on almost all new vehicles will cause them to have no reduction in antiknock requirement at higher altitudes.

through 1994," December 1995.[12]

X1.5.2.3 *Bias*—Since knock ratings are determined by the conditions of the empirical test methods involved, bias cannot be determined.

X1.6 Effects of Altitude and Weather on Vehicle Antiknock Requirement

X1.6.1 A vehicle's antiknock requirement can vary with changes in altitude, ambient temperature, and humidity, depending on the control system of the vehicle. New vehicles have sensors to measure and engine management computers, which take into account such conditions as air charge temperature and barometric pressure. These vehicles are designed to have the same antiknock requirement at all altitudes and a reduced sensitivity to changes in ambient temperature. This more sophisticated control technology began to be used extensively in 1984. This technology, while constantly evolving and improving, is used on almost all new vehicles. This means that many vehicles in today's fleet require fuel having the same antiknock index regardless of changes in altitude or ambient temperatures. Older vehicles, which do not have sophisticated control systems, will likely experience changes in antiknock

[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1007.

[12] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1383.

requirement due to changes in altitude and weather conditions. However, the changes in antiknock requirement indicated in the following sections apply to a continually smaller part of the vehicle fleet.

X1.6.2 The antiknock requirement of an older vehicle decreases as altitude increases, primarily due to reduction in mixture density caused by reduced atmospheric pressure. The change in antiknock requirement for altitude for older vehicles is given in Fig. X1.2. Boundaries of the areas defined and the corresponding antiknock index reductions were established to protect vehicles driven from a higher altitude to a lower altitude (and, hence higher antiknock requirement) area while using a fuel obtained in the high altitude area.

X1.6.3 Tests by CRC and other organizations have shown that the decrease in antiknock requirements with altitude is larger for most models between 1971 and 1984, designed to use a fuel with an antiknock index of 87, than for pre-1971 vehicles. Generally the pre-1971 vehicles have high compression ratios and were designed for fuels with an antiknock index of 88 or higher. Fuels with antiknock indexes below 89 are adjusted by a larger factor than those with an antiknock index of 89 or greater.

X1.6.4 The antiknock requirements of older vehicles rise with increasing ambient temperature on the average by 0.097 MON per degree Celsius (0.054 MON per degree Fahrenheit).

X1.6.5 The antiknock requirements of both older and new vehicles decrease with increasing specific humidity by 0.245 MON per gram of water per kilogram of dry air (0.035 MON per grain of water per pound of dry air).

X1.6.6 Because temperature and humidity of geographical areas are predictable throughout the year from past weather records, antiknock index levels can be adjusted to match seasonal changes in vehicle antiknock requirements. Fig. X1.3 defines the boundaries of areas and the typical reduction in vehicle antiknock requirements for weather for older vehicles. This figure may not apply to newer vehicles.

X1.7 Leaded Versus Unleaded Fuel Needs

X1.7.1 In addition to selecting the appropriate antiknock index to meet vehicle antiknock needs, a choice must be made between leaded and unleaded fuel. Vehicles manufactured for sale in the U.S. that must use unleaded fuel are required by Environmental Protection Agency regulation to have permanent labels on the instrument panel and adjacent to the fuel tank filler inlet reading "Unleaded Fuel Only." Most 1975 and later model passenger cars and light trucks are in this category. Most 1971-1974 vehicles can use leaded or unleaded fuel. Pre-1971 vehicles were designed for leaded fuel; however, unleaded fuel of suitable antiknock index may generally be used in these vehicles, except that leaded fuel should be used periodically (after a few tankfuls of unleaded fuel have been used). Leaded fuel may be required in some vehicles, particularly trucks, in heavy-duty service and some farm equipment. Instructions on fuel selection are normally provided in publications of vehicles manufacturers (for example, owner's manuals, service bulletins, and so forth). Antiknock agents other than lead alkyls may be used to increase the antiknock index of fuels, and their
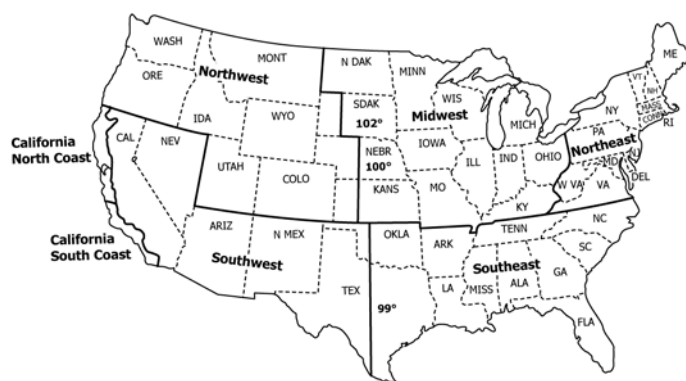

FIG. X1.3 Reduction in U.S. Vehicle Antiknock Requirements for Weather[A]

	J	F	M	A	M	J	J	A	S	O	N	D
Northeast	1.0	0.5	0.5	0	0	0	0	0	0	0.5	0.5	1.0
Southeast	0.5	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0.5
Midwest	1.0	0.5	0.5	0	0	0	0	0	0	0	0.5	1.0
Northwest	1.0	1.0	0.5	0.5	0	0	0	0	0	0.5	1.0	1.0
Southwest	1.0	0.5	0	0	0	0	0	0	0	0	0.5	1.0
California[A,B]												
No Coast	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0.5	0.5
So Coast	0	0	0.5	0.5	1.0	1.0	1.0	0.5	0.5	0	0	0
Alaska	1.0	1.0	0.5	0.5	0	0	0	0	0	0.5	1.0	1.0
Hawaii	0	0	0	0	0	0	0	0	0	0	0	0

[A] Fuel may be marketed using these reductions, but actual antiknock index minimums must be posted.
[B] Details of California coastal areas are shown in Footnote G of Table 4.

concentrations may also be limited due to either performance or legal requirements.

X1.8 Volatility

X1.8.1 In most spark-ignition internal combustion engines, the fuel is metered in liquid form through the carburetor or fuel injector, and is mixed with air and partially vaporized before entering the cylinders of the engine. Consequently, volatility is an extremely important characteristic of motor fuel.

X1.8.2 At high operating temperatures, fuels can boil in fuel pumps, lines, or carburetors. If too much vapor is formed, the fuel flow to the engine can be decreased, resulting in loss of power, rough engine operation, or engine stoppage. These conditions are known as "vapor lock." Conversely, fuels that do not vaporize sufficiently can cause hard starting of cold engines and poor warm-up performance. These conditions can be minimized by proper selection of volatility requirements, but cannot always be avoided. For example, during spring and fall, a fuel of volatility suitable for satisfactory starting at low ambient temperatures can cause problems in some engines under higher ambient temperature operating conditions.

X1.8.3 Six vapor pressure/distillation classes and six vapor lock protection (vapor-liquid ratio) classes of fuel are provided to satisfy vehicle performance requirements under different climatic conditions and to comply with U.S. EPA vapor pressure limits for the control period of May 1 through September 15. Class A and Class AA specify the EPA maximum vapor pressure limits of 9.0 psi and 7.8 psi, respectively. Volatility of fuel is specified by an alphanumeric designation. The letter specifies the vapor pressure/distillation class and the

number specifies the vapor lock protection class. The vapor pressure/distillation classes are needed in the U.S. to comply with the EPA vapor pressure regulations and are not based on vehicle performance during the EPA control period. The separate vapor lock protection classes are provided because under most ambient conditions, the EPA regulations specify a lower vapor pressure than would be required to prevent hot fuel handling problems. If the corresponding and unnecessarily more restrictive vapor-liquid ratios were specified when the EPA regulations are in effect, it could result in reduced fuel production, manufacturing hardships, and increased fuel costs. The schedule for seasonal and geographical distribution indicates the appropriate alphanumeric volatility requirement or requirements for each month in all areas of the United States, based on altitude and expected air temperatures, and on EPA vapor pressure regulations. Volatility limits are established in terms of vapor-liquid ratio, vapor pressure, and distillation properties.

X1.9 Vapor Pressure

X1.9.1 The vapor pressure of fuel must be sufficiently high to ensure ease of engine starting, but it must not be so high as to contribute to vapor lock or excessive evaporative emissions and running losses.

X1.9.2 Test Methods D4953, D5191, D5482 or D6378 provide procedures for determining the vapor pressures of gasoline or gasoline-oxygenate blends.

X1.10 Vapor-Liquid Ratio

X1.10.1 Vapor-liquid ratio (*V/L*) is the ratio of the volume of vapor formed at atmospheric pressure to the volume of fuel. The *V/L* increases with temperature for a given fuel. Test Method D5188 is an evacuated chamber method for determining temperatures for vapor-liquid ratios between 8 to 1 and 75 to 1. Test Method D5188 is applicable to both gasoline and gasoline-oxygenate blends.

X1.10.2 The temperature of the fuel system and the *V/L* that can be tolerated without vapor lock or hot fuel handling problems vary from vehicle to vehicle and with operating conditions. The tendency of a fuel to cause vapor lock or hot fuel handling problems, as evidenced by loss of power during full-throttle accelerations or hot starting and idling problems, is indicated by the gasoline temperature at a *V/L* of approximately 20. A similar relationship for gasoline-oxygenate blend has also been determined. The minimum temperature at which *V/L* = *20* is specified for each gasoline volatility class is based on the ambient temperatures and the altitude associated with the use of the class.

X1.11 Vapor-Liquid Ratio (Estimated)

X1.11.1 Two techniques for estimating temperature-*V/L* values using vapor pressure (Test Methods D4953, D5191, D5482, or D6378) and distillation (Test Methods D86 or D7345) results are given in Appendix X2; they apply to only gasoline and gasoline-ethanol blends containing from 1 % to 15 % by volume ethanol.

X1.12 Distillation

X1.12.1 Test Methods D86 or D7345 for distillation provides another measure of the volatility of fuels. Table 1 designates the limits for endpoint temperature and the temperatures at which 10 %, 50 %, and 90 % by volume of the fuel is evaporated. These distillation characteristics, along with vapor pressure and *V/L* characteristics, affect the following vehicle performance characteristics: starting, driveability, vapor lock, dilution of the engine oil, fuel economy, and carburetor icing.

X1.12.2 The 10 % evaporated temperature of fuel should be low enough to ensure starting under normal temperatures.

X1.12.3 Fuels having the same 10 % and 90 % evaporated temperatures can vary considerably in driveability performance because of differences in the boiling temperatures of the intermediate components, or fractions. Driveability and idling quality are affected by the 50 % evaporated temperature. The 90 % evaporated and endpoint temperatures should be low enough to minimize dilution of the engine oil.

X1.12.4 The ASTM Driveability Task Force has determined from data collected by CRC and others that a relationship exists between fuel distillation temperatures and vehicle cold start and warm-up driveability performance. This relationship can be expressed by a Driveability Demerit model that can estimate vehicle driveability demerits during cold start and warm-up conditions. The predictive model is a function of ambient temperature and fuel volatility expressed as the distillation temperatures at which 10 %, 50 %, and 90 % by volume of the fuel is evaporated. The original Driveability Index (DI = 1.5 T_{10} + 3.0 T_{50} + 1.0 T_{90}) is a simplified and more easily applied form of the Driveability Demerit model. A more detailed explanation of the DI equation development can be found in SAE Paper 881668.[13] Another CRC driveability study (CRC Report No. 638) has investigated the effect of ethanol addition on cold start and warm-up driveability. The ASTM Driveability Task Force decided that an upward adjustment for ethanol is needed in the DI equation as follows: For degrees Celsius:

$$DI_C = 1.5\,T_{10} + 3.0\,T_{50} + 1.0\,T_{90} + 1.33 \times (\text{Ethanol \% by Volume})$$
(X1.2)

For degrees Fahrenheit:

$$DI_F = 1.5\,T_{10} + 3.0\,T_{50} + 1.0\,T_{90} + 2.4 \times (\text{Ethanol \% by Volume})$$
(X1.3)

where*:*

T_{10} = distillation temperature at 10 % evaporated,
T_{50} = distillation temperature at 50 % evaporated, and
T_{90} = distillation temperature at 90 % evaporated.

X1.12.4.1 The CRC driveability study (CRC Report No. 666) has investigated the effect of ethanol addition on cold-start and warm-up driveability at higher ethanol concentrations. The results showed that the current DI equation had acceptable application up to 10 % by volume ethanol. A new

---

[13] Barker, D. A., Gibbs, L. M., and Steinke, E. D., "The Development and Implementation of the ASTM Driveability Index," SAE Paper 881668, 1988. Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

DI equation developed to cover "from greater than 10 % and up to 15 % by volume ethanol" changes the ethanol coefficients to the following values:
For degrees Celsius:

$$DI_C = 1.5\, T_{10} + 3.0\, T_{50} + 1.0\, T_{90} + 5.26 \times (\text{Ethanol \% by Volume}) \tag{X1.4}$$

For degrees Fahrenheit:

$$DI_F = 1.5\, T_{10} + 3.0\, T_{50} + 1.0\, T_{90} + 9.49 \times (\text{Ethanol \% by Volume}) \tag{X1.5}$$

X1.12.4.2 There are insufficient data for fuels with ethanol concentrations between 10 % and 15 % by volume to establish the type of change in this range. The consensus approach is to proportionally change the ethanol coefficient from the current 1.33 °C (2.4 °F) at 10 % by volume ethanol to 5.26 °C (9.49 °F) at 15 % by volume. API report "Determination of the Potential Property Ranges of Mid-Level Ethanol Blends"[14] provides data to support a linear relationship. This proportional approach will be reconsidered when additional data become available. The resulting linear proportional DI equations are:
For degrees Celsius:

$$DI_C = 1.5\, T_{10} + 3.0\, T_{50} + 1.0\, T_{90} + (1.33 + [(\text{Ethanol \% by Volume} - 10)/5] \times (5.26 - 1.33)) \times (\text{Ethanol \% by Volume}) \tag{X1.6}$$

For degrees Fahrenheit:

$$DI_F = 1.5\, T_{10} + 3.0\, T_{50} + 1.0\, T_{90} + (2.4 + [(\text{Ethanol \% by Volume} - 10)/5] \times (9.49 - 2.4)) \times (\text{Ethanol \% by Volume}) \tag{X1.7}$$

X1.12.5 A typical distillation curve of gasoline containing only hydrocarbon molecules has a smooth and steady upward slope between the 10 % and 90 % evaporated temperatures. Gasoline containing ethanol at 5 % to 15 % by volume will display a distillation curve with a much decreased slope between the 30 % and 50 % evaporated temperatures that rejoins the expected slope once all the ethanol has distilled off. The lower the ethanol content, the sooner this part of the distillation curve rejoins the expected slope. Addition of certain hydrocarbon components or streams in large quantities to gasoline can cause a hump in the part of the distillation range where the hydrocarbons boil. For example, high levels of certain blending components (such as reformate) can cause the distillation curve to have a hump between the 50 % and 90 % evaporated temperatures that is centered at the 70 % evaporated temperature. In some cases, the lack of material boiling in this temperature range can result in a distillation curve that resembles a dumbbell. Elevated distillation temperatures result in a less volatile fuel, which can affect vehicle driveability while it is in open loop operation. For vehicles calibrated to the latest emissions standards, excess fuel is injected during startup to ensure a quick start, but as soon as the engine engages, fueling is cut back quickly to minimize emissions while the catalyst warms up. If the volatility of the fuel is lower than expected, the cut back in fuel can be too extreme, resulting in a lean air-fuel mixture delivered to the cylinders. A misfire can result that is manifested as a driveability problem. During open loop operation, a vehicle relies on the ECM for a standard

fueling strategy, and it cannot adjust the air-fuel mixture until closed loop operation begins, which is about 30 s after startup for the newest vehicles, and up to several minutes for older vehicles. The extent of a fuel's deviation from a normal distillation slope can be quantified by determining the difference between the measured 70 % evaporated temperatures and a calculated value, which is approximated by the arithmetic average of the 50 % and 90 % evaporated temperatures. Vehicle testing has shown if the difference between the measured and calculated 70 % evaporated temperature is less than 12 °C (22 °F), average vehicle driveability, as measured by trained raters is comparable to fuel with a standards distillation curve. When the difference is greater than 12 °C (22 °F), average vehicle driveability is degraded. The difference is determined using the following equation:

$$T_{70}\ \text{Bump Difference} = T_{70} - (T_{50} + T_{90})/2 \tag{X1.8}$$

where:

T_{50} = 50 % evaporated distillation temperatures, as determined by Test Methods D86 or D7345,

T_{70} = 70 % evaporated distillation temperatures, as determined by Test Methods D86 or D7345, and

T_{90} = 90 % evaporated distillation temperatures, as determined by Test Methods D86 or D7345.

X1.13 Corrosion

X1.13.1 While fuels shall meet the copper strip and silver strip corrosion requirements to minimize corrosion in fuel systems due to reactive sulfur compounds in the fuel, some fuel contaminants can corrode other fuel system metals. ASTM test methods to evaluate corrosion of these other metals might not be established.

X1.13.1.1 Reactive sulfur compounds present in automotive spark-ignition engine fuel under some circumstances can corrode or tarnish silver alloy in-tank fuel level sender units, resulting in an erroneous signal to the fuel gauge.

X1.14 Solvent-Washed Gum Content

X1.14.1 The test for solvent-washed gum content measures the amount of residue after evaporation of the fuel and following a heptane wash. The heptane wash removes the heptane-soluble, non-volatile material such as additives, carrier oils used with additives, and heavier hydrocarbons such as diesel fuels, and so forth. Solvent-washed gum consists of heptane-insoluble gum. The portion of the gum that is also insoluble in spark-ignition engine fuel (gasoline or gasoline-oxygenate blends) can clog fuel filters. Both soluble and insoluble gum can be deposited on surfaces when the fuel evaporates.

X1.14.2 Solvent-washed gum can contribute to deposits on the surfaces of carburetors, fuel injectors, and intake manifolds, ports, valves, and valve guides. The impact of solvent-washed gum on malfunctions of modern engines is not well established and the current specification limit is historic rather than the result of recent correlative studies. It depends on where the deposits form; the presence of other deposit precursors, such as airborne debris, blowby and exhaust gas recirculation gases, and oxidized engine oil; and the amount of deposits.

---

[14] American Petroleum Institute, Washington, DC, April 23, 2010.

X1.14.3 The difference between the unwashed and solvent-washed gum content values can be used to assess the presence and amount of nonvolatile material in the fuel. Additional analytical testing is required to determine if the material is additive, carrier oil, diesel fuel, and so forth.

X1.14.4 Unwashed gum content is a useful measure and indicator of contamination of gasoline with polymeric material not intended for gasoline. Appendix X7 describes a method to detect such contamination.

X1.15 Sulfur

X1.15.1 The limit on sulfur content is included to protect exhaust emission control systems. Fuel sulfur also can promote engine wear, deterioration of engine oil, and corrosion of exhaust system parts.

X1.16 Oxidation Stability

X1.16.1 The induction period as measured in the oxidation stability test is used as an indication of the resistance of fuel to gum formation in storage. Experience indicates that fuels with an induction period equal to or greater than that in Table 2 generally have acceptable short-term storage stability. However, correlation of the induction period with the formation of gum in storage can vary markedly under different storage conditions and with different fuels.

X1.17 Appearance

X1.17.1 Turbidity, phase separation or evidence of precipitation normally indicates contamination.

X1.17.2 Fuels can encounter conditions in the bulk distribution system that could cause the material to fail a workmanship visual evaluation. Some fuels can contain water, dirt, or rust particles during distribution. Terminals and bulk plants can address these issues with proper operating procedures, for example by allowing sufficient time for the water, dirt, or rust particles to settle in a tank, by filtration or by other means.

X2. ESTIMATING TEMPERATURE-*V/L* VALUES FOR GASOLINE

X2.1 Scope

X2.1.1 Two techniques are presented here for estimating temperature-*V/L* data from vapor pressure and distillation test results.[15] They are provided for use as a guideline when *V/L* data measured by Test Method D5188 are not available. One method is designed for computer processing, and one is a simpler linear technique. The techniques were originally only applicable to gasoline and not to gasoline-oxygenate blends. A program was undertaken to modify the techniques to make them also applicable to gasoline-ethanol blends (1 % to 15 % by volume).[16]

X2.1.2 These techniques are not optional procedures for measuring temperature–*V/L*. They are supplementary tools for estimating temperature-*V/L* relationships with reasonable accuracy when used with due regard for their limitations.

X2.1.3 Test Method D5188 is the referee *V/L* procedure and shall be used when calculated values are questionable.

X2.1.4 These techniques are not intended for, nor are they necessarily applicable to, fuels of extreme distillation or chemical characteristics, such as would be outside the range of normal commercial motor gasoline or gasoline-ethanol blends.

Thus, they are not applicable in all instances to gasoline blending stocks or specially blended fuels.

X2.2 Computer Method

X2.2.1 *Summary*—The values of four intermediate functions, *A*, *B*, *C*, and *D*, are derived from the gasoline vapor pressure and distillation temperatures at 10, 20, and 50 % evaporated. Values for *A*, *B*, *C*, and *D* can be obtained either from equations or from a set of charts. Sections X2.2.2.1 – X2.2.2.3 provide *A*, *B*, *C*, and *D* values using SI units; X2.2.2.7 – X2.2.2.9 provide *A*, *B*, *C*, and *D* values using inch-pound units. Estimated temperatures at a *V/L* of 4, 10, 20, 30, and 45 are then calculated from *A, B, C,* and *D*. Estimated temperatures at an intermediate *V/L* can be obtained by interpolation.

X2.2.2 *Procedure:*

X2.2.2.1 Establish input data for gasoline or gasoline-ethanol blends from vapor pressure (Test Methods D4953, D5191, D5482, or D6378) and distillation (Test Methods D86 or D7345) test results as follows:

E = distillation temperature, °C at 10 % evaporated,
F = distillation temperature, °C at 20 % evaporated,
G = distillation temperature, °C at 50 % evaporated,

$$H = G - E, °C, \qquad (X2.1)$$

P = vapor pressure, kPa,

$$Q = F - E, °C, \text{ and} \qquad (X2.2)$$

$R = H/Q$, except that if H/Q is greater than 6.7, make $R = 6.7$.

$$(X2.3)$$

X2.2.2.2 If *A, B, C,* and *D* are to be calculated, use the following equations:

---

[15] A correlation of temperature-*V/L* ratio data with vapor pressure and distillation data was developed in 1943 and restudied in 1963 by panels of the Coordinating Research Council, Inc. See "Correlation of Gasoline Vapor Forming Characteristics with Inspection Test Data," *CRC Report No. 159*, Jan. 28, 1943 (or SAE Transaction, Vol 52, August 1944, pp. 364–367) and "Study of CRC Calculated Temperature-*V/L* Technique," *CRC Report No. 370*, February 1963. The CRC correlation was modified by a task group of Subcommittee A of Committee D02 to adapt it for computer processing, as well as the linear equation.

[16] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1650.
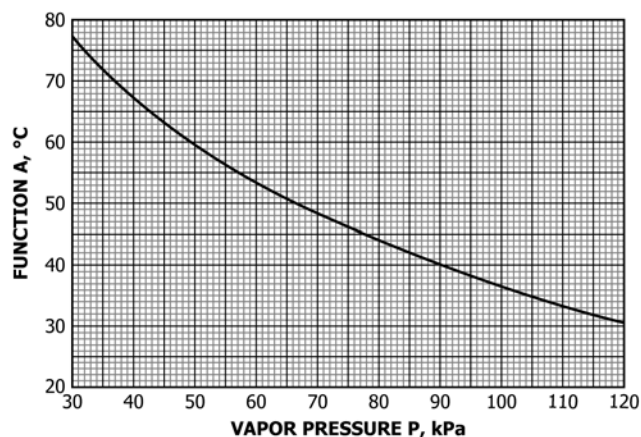
FIG. X2.1 Function *A* versus Vapor Pressure *P*

FIG. X2.2 Function *B* versus Distillation Temperature Difference *Q*

$$A = 102.859 - 1.36599P + 0.009617\,P^2 - 0.000028281P^3$$

$$\text{(X2.4)}$$

$$+\,207.0097/P$$

$$B = -5.36868 + 0.910540Q - 0.040187\,Q^2 \qquad \text{(X2.5)}$$

$$+\,0.00057774Q^3 + 0.254183/Q$$

$$S = -0.00525449 - 0.3671362/(P - 9.65) - 0.812419/(P - 9.65)^2$$
$$+\,0.0009677R - 0.0000195828R^2 - 3.3502318R/P^{\,2}$$
$$+\,1241.1531R/P^4 - 0.06630129R^2/P + 0.00627839R^{\,3}/P$$
$$+\,0.0969193R^2/P^2 \qquad \text{(X2.6)}$$

$$C = 0.34205P + 0.55556/S \qquad \text{(X2.7)}$$

$$D = 0.62478 - 0.68964R + 0.132708R^2 \qquad \text{(X2.8)}$$

$$-\,0.0070417R^3 + 5.8485/R$$

X2.2.2.3 If *A, B, C,* and *D* are to be obtained from charts, read them from Fig. X2.1, Fig. X2.2, Fig. X2.3, or Fig. X2.4, respectively.

X2.2.2.4 Calculate the estimated temperature (°C or °F) at *V/L* ratios 4, 10, 20, 30, and 45 from the following equations:

$$TVL4 = A + B \qquad \text{(X2.9)}$$

$$TVL45 = F + 0.125H + C \qquad \text{(X2.10)}$$

$$TVL10 = TVL4 + 0.146341\,(TVL45 - TVL4) + D \qquad \text{(X2.11)}$$

$$TVL20 = TVL4 + 0.390244\,(TVL45 - TVL4) + 1.46519D$$

$$\text{(X2.12)}$$

$$TVL30 = TVL4 + 0.634146\,(TVL45 - TVL4) + D \qquad \text{(X2.13)}$$

where:
TVL4, TVL10, TVL20, TVL30, and *TVL45* are estimated temperatures at *V/L* ratios, 4, 10, 20, 30, and 45, respectively.

X2.2.2.5 If the temperature at an intermediate *V/L* ratio is to be estimated, either plot the values calculated in X2.2.2.4 and read the desired value from a smooth curve through the points, or use the Lagrange interpolation formula as follows:

$$TX = T4\left(\frac{X - 10}{4 - 10} \times \frac{X - 30}{4 - 30} \times \frac{X - 45}{4 - 45}\right) \qquad \text{(X2.14)}$$

$$+\,T10\left(\frac{X - 4}{10 - 4} \times \frac{X - 30}{10 - 30} \times \frac{X - 45}{10 - 45}\right)$$

$$+\,T30\left(\frac{X - 4}{30 - 4} \times \frac{X - 10}{30 - 10} \times \frac{X - 45}{30 - 45}\right)$$

$$+\,T45\left(\frac{X - 4}{45 - 4} \times \frac{X - 10}{45 - 10} \times \frac{X - 30}{45 - 30}\right)$$

where:
X = the desired V/L ratio between 4 and 45, and
TX = the estimated temperature at V/L ratio X.

X2.2.2.6 *Temperature-V/L = 20 ($T_{V/L = 20}$)*—To calculate an estimated $T_{V/L = 20}$ in SI units for gasoline, use the *TVL*20 value from X2.2.2.4 (Eq X2.12) or for gasoline-ethanol blends, insert the *TVL*20 value determined in X2.2.2.4 (Eq X2.12) into Eq X2.15 and make the calculation.

$$\textit{Ethanol Blend } T_{V/L=20} = 0.857(TVL20) + 6.90 \qquad \text{(X2.15)}$$

X2.2.2.7 If inch-pound units are used, establish input data for gasoline or gasoline-ethanol blends from vapor pressure (Test Methods D4953, D5191, D5482, or D6378) and distillation (Test Methods D86 or D7345) test results as follows:

E = distillation temperature, °F at 10 % evaporated,

F = distillation temperature, °F at 20 % evaporated,

G = distillation temperature, °F at 50 % evaporated,

$$H = G - E,\ °F \qquad \text{(X2.16)}$$

P = vapor pressure, psi,

$$Q = F - E,\ °F,\ \text{and} \qquad \text{(X2.17)}$$

$$R = H/Q,\ \text{except that if } H/Q\ \text{is greater than 6.7,} \qquad \text{(X2.18)}$$

make *R* = 6.7.

X2.2.2.8 If *A, B, C,* and *D* are to be calculated in inch-pound units, use the following equations:
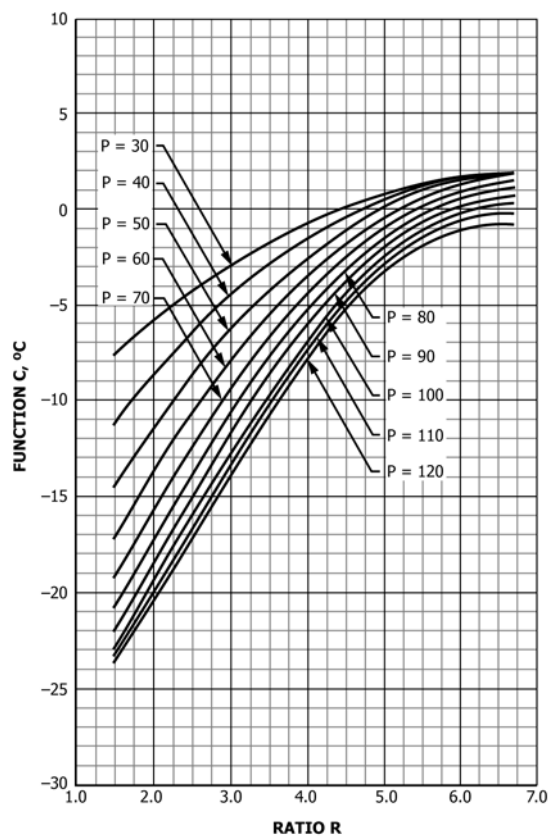
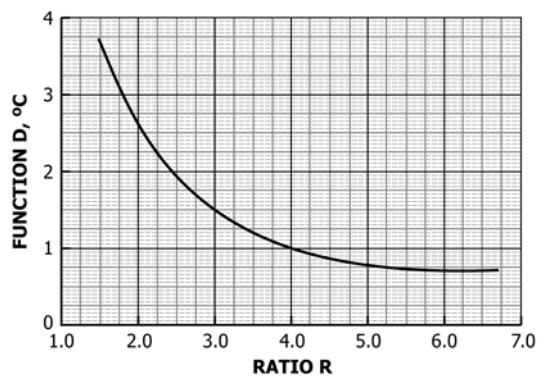FIG. X2.3 Function C versus Ratio R and Vapor Pressure P

FIG. X2.4 Function D versus Ratio R

$$A = 217.147 - 16.9527P + 0.822909P^2 - 0.0166849P^3 \quad (X2.19)$$

$$+ 54.0436/P$$

$$B = -9.66363 + 0.910540Q - 0.0223260Q^2 \quad (X2.20)$$

$$+ 0.000178314Q^3 + 0.823553/Q$$

$$S = -0.00525449 - 0.0532486/(P - 1.4) \quad (X2.21)$$

$$-0.0170900/(P - 1.4)^2 + 0.0009677R-$$

$$0.0000195828R^2 - 0.0704753R/P^2 + 0.549224R/P^4$$

$$-0.00961619R^2/P + 0.000910603R^3/P$$

$$+ 0.00203879R^2/P^2$$

$$C = 4.245P + 1.0/S \quad (X2.22)$$

$$D = 1.12460 - 1.24135R + 0.238875R^2 \quad (X2.23)$$
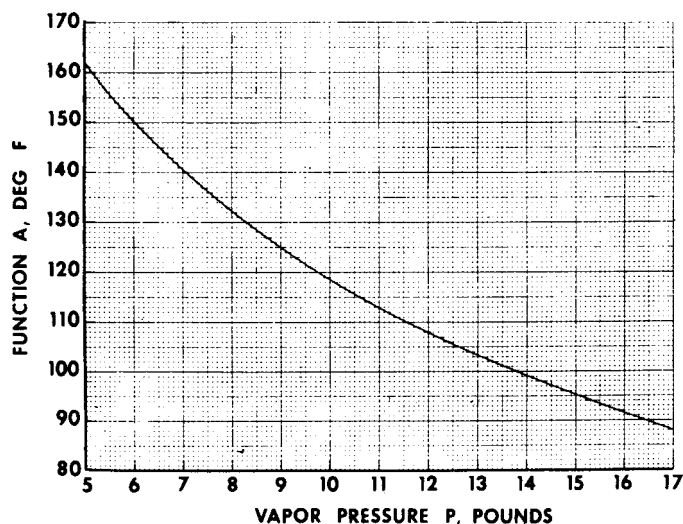
$$-0.0126750R^3 + 10.5273/R$$

FIG. X2.5 Function *A* versus Vapor Pressure *P*

FIG. X2.6 Function *B* versus Distillation Temperature Difference *Q*

X2.2.2.9 If *A, B, C,* and *D* are to be obtained from charts in inch-pound units, read them from Figs. X2.5-X2.8, respectively.

X2.2.2.10 Calculate the estimated temperatures, °F, at *V/L* ratios 4, 10, 20, 30, and 45 using the equations in X2.2.2.4 and X2.2.2.5.

X2.2.2.11 *Temperature-V/L = 20 ($T_{V/L\ =\ 20}$)*—To calculate an estimated $T_{V/L\ =\ 20}$ in inch-pound customary units for gasoline, use the *TVL* 20 value from X2.2.2.4 or for gasoline-ethanol blends, insert the *TVL*20 value determined in X2.2.2.4 into Eq X2.24 and make the calculation.

$$\text{Gasoline} - \text{Ethanol Blend } T_{V/L=20} = 0.857\,(TVL20) + 17.00$$
(X2.24)

X2.3 Linear Equation Method

X2.3.1 *Summary*—As given, these two equations provide only the temperatures (°C or °F) at which a *V/L* value of 20 exists. They make use of two points from the distillation curve, T_{10} and T_{50} (°C or °F), and the vapor pressure (kPa or psi) of the gasoline with constant weighting factors being applied to each. Experience has shown that data obtained with these simple linear equations generally are in close agreement with those obtained by the computerized version given above. The limitations pointed out in X2.1.1 – X2.1.4 must be kept in mind when use is made of this procedure.

X2.3.2 *Procedure*—Obtain 10 % evaporated and 50 % evaporated points for gasoline or gasoline-ethanol blends from the distillation curve (Test Methods D86 or D7345) along with the vapor pressure value (Test Methods D4953, D5191, D5482, or D6378); apply these directly in the equation.

$$TVL20 = 52.47 - 0.33\,(VP) + 0.20\,T_{10} + 0.17\,T_{50}\quad\text{(X2.25)}$$

where:
$TVL20$ = intermediate temperature, °C, at *V/L* of 20:1,
VP = vapor pressure, kPa,
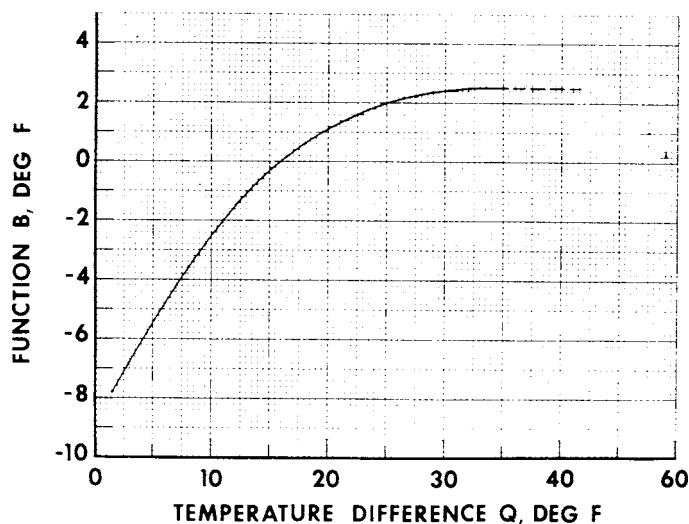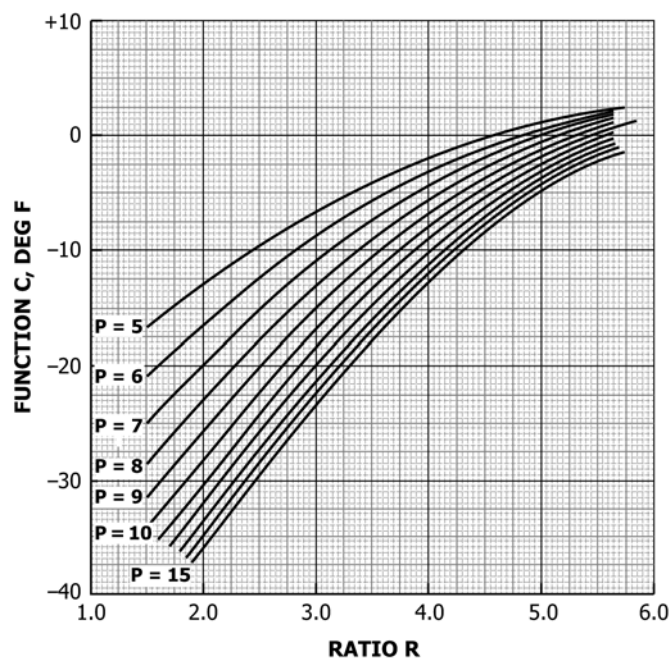T_{10} = distillation temperature, °C, at 10 % evaporated, and

FIG. X2.7 Function *C* versus Ratio *R* and Vapor Pressure *P*

T_{50} = distillation temperature, °C, at 50 % evaporated.

or in the inch-pound customary unit equation:

$$TVL20 = 114.6 - 4.1\,(VP) + 0.20\,T_{10} + 0.17\,T_{50}\quad\text{(X2.26)}$$

where:
$TVL20$ = intermediate temperature, °F, at *V/L* of 20:1,
VP = vapor pressure, psi,
T_{10} = distillation temperature, °F, at 10 % evaporated, and
T_{50} = distillation temperature, °F, at 50 % evaporated.

X2.3.3 *Temperature-V/L = 20 ($T_{V/L\ =\ 20}$)*—To calculate an estimated $T_{V/L\ =\ 20}$ for gasoline, use the value for *TVL*20 value determined in X2.3.2 (SI Eq X2.25 or inch-pound Eq X2.26) or
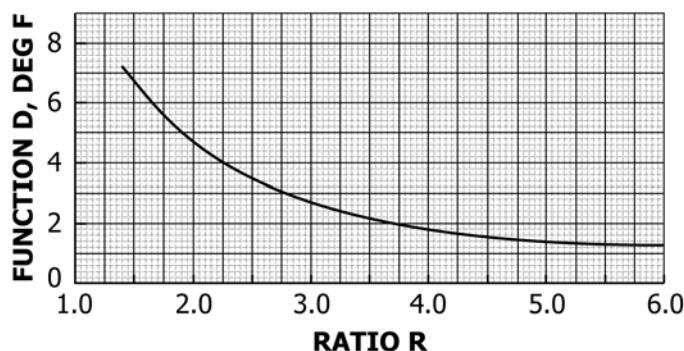
FIG. X2.8 Function *D* versus Ratio *R*

$$\text{(SI units) Gasoline} - \text{Ethanol Blend } T_{V/L=20} = 0.782(TVL20) + 10.57 \tag{X2.27}$$

$$\text{(Inch} - \text{Pound Units) Gasoline} - \text{Ethanol Blend } T_{V/L=20}$$
$$= 0.782(TVL20) + 26.00 \tag{X2.28}$$

for gasoline-ethanol blends, insert the *TVL*20 values determined in X2.3.2 (SI or inch-pound as appropriate) into Eq X2.27 for SI units and Eq X2.28 for inch-pound customary units.

X2.4 Precision

X2.4.1 The precision of agreement between temperature-*V/L* data estimated by any one of these two techniques and data obtained by Test Method D5188 has not been established. An estimate of the reproducibility of the two calculation techniques reported in the research report[16] as ranging from 2.1 °C to 1.0 °C (3.8 °F to 1.8 °F) for the computer method and from 1.9 °C to 0.8 °C (3.5 °F to 1.5 °F) for the linear method as $T_{V/L=20}$ increased from 43 °C to 66 °C (110 °F to 150 °F).

X3. SUMMARY OF U.S. EPA REGULATIONS APPLICABLE TO SPARK-IGNITION ENGINE FUEL

X3.1 EPA Applicable Vapor Pressure Standards

X3.1.1 Under authority of the Clean Air Act, the U.S. Environmental Protection Agency (EPA) issued, effective May 1992, vapor pressure control standards for leaded and unleaded gasoline and leaded and unleaded gasoline-oxygenate blends. Some states, notably California, have more restrictive vapor pressure limits.

X3.1.2 Details of the EPA regulations and test methods are available in Part 80 of Title 40 of the Code of Federal Regulations (40 CFR Part 80). For specific state vapor pressure regulations, the state of interest should be contacted.

X3.1.3 In the U.S., the EPA maximum vapor pressure limits of 7.8 psi and 9.0 psi are included in Table 1 as Classes AA and A, respectively. The maximum vapor pressures in Table 1 include vapor pressure waivers permitted by the U.S. EPA during the summer control period. Under EPA regulations, from June 1 through September 15, only blends containing 9 % to 10 % by volume ethanol in conventional gasoline areas are provided a 1.0 psi higher vapor pressure than gasoline. This 1.0 psi exemption does not apply to reformulated gasoline and some SIP area fuels (see Table 12). Other ethanol blends containing less than 9 % by volume or over 10 % volume ethanol and up to 15 % by volume ethanol shall be required to meet a maximum vapor pressure standard in the U.S. of either 9.0 psi or 7.8 psi from June 1 to September 15 in conventional gasoline areas. Higher vapor pressure limits for gasoline-ethanol blends under U.S. state regulations vary for other time periods, and specific states of interest should be contacted to determine if higher limits apply.

X3.1.4 In the U.S., the EPA requirements for each distribution area are shown in Table 4 for the period May 1 through September 15. For the month of May, the EPA limits only apply to finished gasoline and gasoline-oxygenate blend tankage at refineries, importers, pipelines, and terminals. For the period June 1 through September 15, the EPA limits apply to all locations of the distribution system. Footnotes C, D, and F of Table 4 indicate the ozone nonattainment areas which are limited to 7.8 psi maximum and the appropriate vapor lock protection class. California has controls that vary for the different air basins from as early as March 1 at refineries through as late as October 31. There are no EPA vapor pressure limits for the states of Alaska or Hawaii.

X3.2 EPA Lead and Phosphorus Regulations

X3.2.1 *Unleaded Fuel*—The intentional addition of lead or phosphorus compounds to unleaded fuel is not permitted by the EPA. EPA regulations limit their maximum concentrations to 0.05 g lead/U.S. gal (0.013 g/L) and 0.005 g of phosphorus/U.S. gal (0.0013 g/L) (see Test Method D3231), respectively.

X3.2.2 *Leaded Fuel*—EPA regulations after December 31, 1995 prohibit the sale, supply, dispensing, transporting, or introducing into commerce a fuel for use in any motor vehicle which is produced with the use of lead additives or which contains more than 0.05 g lead/U.S. gal (0.013 g/L).

X3.2.2.1 The regulations define motor vehicle to include any self-propelled vehicle designed for transporting persons or property on a street or highway.

X3.2.2.2 The regulations do not prohibit the use of lead additives in fuel used in aircraft, racing cars, and nonroad engines, such as farm equipment engines and marine engines.

X3.3 EPA Oxygenate Regulations Applicable to Unleaded Gasoline-Oxygenate Blends

X3.3.1 *Substantially Similar Rule:*

X3.3.1.1 Section 211(f) (1) of the Clean Air Act prohibits introducing into commerce or increasing the concentration in use of, any fuel or fuel additive, which is not substantially similar to any fuel or fuel additive utilized for emissions certification of any model year 1975, or subsequent model year vehicle or engine, unless a waiver is obtained from the EPA.

X3.3.1.2 Gasoline-oxygenate blends are considered "substantially similar" if the following criteria are met.

(1) The fuel must contain carbon, hydrogen, and oxygen, nitrogen, or sulfur, or combination thereof, exclusively, in the form of some combination of the following:

(a) Hydrocarbons;

(b) Aliphatic ethers;

(c) Aliphatic alcohols other than methanol;

(d) (i) Up to 0.3 % by volume methanol;

(ii) Up to 2.75 % by volume methanol with an equal volume of butanol, or higher molecular weight alcohol;

(2) The fuel must contain no more than 2.0 % by mass oxygen except fuels containing aliphatic ethers and/or alcohols (excluding methanol) must contain no more than 2.7 % by mass oxygen.

(3) The fuel must possess, at the time of manufacture, all of the physical and chemical characteristics of an unleaded gasoline as specified by Specification D4814–88 for at least one of the Seasonal and Geographical Volatility Classes specified in the standard.

X3.3.2 *Waivers:*

X3.3.2.1 In the U.S., unleaded automotive spark-ignition engine fuels are required to meet the EPA Substantially Similar Rule (see X3.3.1) or have obtained an EPA waiver before being introduced into commerce.

X3.3.2.2 EPA has issued waivers for blends of gasoline and ethanol (gasohol), gasoline and ethanol with cosolvents, and gasoline and methanol with cosolvents that are less limiting than the "substantially similar" rule. For the latest listing of waivers, consult the EPA web site.[17] This EPA document provides a listing of all waivers that have been applied for, granted, denied, or withdrawn. It also provides the Federal Register reference for each waiver which lists the waiver's requirements.

X3.3.2.3 Gasoline-ethanol blends containing up to 10 % by volume ethanol are not required by EPA to meet Specification D4814 volatility limits (see X3.1.4 for vapor pressure limits). EPA has specified in other waivers that the volatility of the finished gasoline-oxygenate blend must comply with Specification D439 or D4814 climatic and geographical limits.

X3.3.2.4 On December 16, 1978, EPA granted a waiver by operation of the law to permit the use of 10 % by volume anhydrous ethanol (200 proof) in unleaded gasoline. On May 5, 1982, EPA issued an Interpretive Rule providing that unleaded gasoline containing up to 10 % by volume anhydrous ethanol is permissible under the Gasohol Waiver.

X3.3.2.5 The EPA E15 partial waivers ("contain greater than 10 volume % ethanol and up to 15 volume % ethanol") impose a number of conditions designed to help ensure that E15 is introduced into commerce for use only in MY 2001 and newer light-duty motor vehicles and in flexible-fueled vehicles,

and not for use in any other vehicles, engines, or equipment. Consult the EPA waiver decisions[18] and the EPA misfueling mitigation rule.[19]

X3.4 EPA Reformulated Gasoline (RFG)

X3.4.1 Reformulated gasoline (RFG) is a spark-ignition engine fuel formulated to reduce motor vehicle emissions of toxic and tropospheric ozone-forming compounds. The Clean Air Act Amendments of 1990 require that RFG be sold in nine metropolitan areas with the worst summertime ozone levels. Other areas that do not meet ambient ozone standards may petition EPA to require RFG. The various RFG regulations have been established by the EPA. EPA has also placed limits on conventional gasoline sold in the rest of the U.S. to prevent RFG producers from using conventional gasoline as an outlet for undesirable fuel components (anti-dumping requirements). The EPA requirements became effective at the retail level on January 1, 1995.

X3.4.2 The characteristics of reformulated spark-ignition engine fuel, beyond those described by this specification, are described in the research report on reformulated spark-ignition engine fuel.[2] The research report also includes information on California Air Resources Board Phase 2 gasoline requirements, which are more restrictive than the EPA RFG requirements and take effect at the retail level on June 1, 1996. When the oxygen concentration is greater than 4.0 % by mass and not more than 5.8 % by mass, the VOC emissions performance of RFG using the EPA Complex Model shall be evaluated as if the oxygen content were 4.0 % by mass.

X3.5 EPA Certification Standards for Deposit Control Gasoline Additives

X3.5.1 Beginning August 1, 1997, except for some fuel specific certifications, fuel sold or transferred to the ultimate consumer must contain detergent additive(s) meeting the EPA certification requirements. The regulation applies to fuels whether intended for on-highway or nonroad use, including conventional, reformulated, oxygenated, and leaded gasolines, as well as fuels used in marine service, and the gasoline component of M85 and E85 fuel alcohols. Racing fuel for non-highway use in racing vehicles and aviation fuel used in aircraft are exempted. Fuels used for research, development, and testing and federal emissions certification fuels can be exempted.

X3.5.2 As of July 1, 1997, only certified detergents may be used by detergent blenders, and distributors may only sell or transfer fuel that is properly additized with certified detergents. Detergent additives may be certified for nationwide use, for geographical use based on Petroleum Administration Districts for Defense (PADDs), or for a fuel-specific option for segregated gasoline pools. Certification sub-options allow a detergent to be certified for use in premium-grade, nonoxygenated,

---

[17] http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100GY6O.PDF

[18] http://www.gpo.gov/fdsys/pkg/FR-2010-11-04/pdf/2010-27432.pdf and http://www.gpo.gov/fdsys/pkg/FR-2011-01-26/pdf/2011-1646.pdf

[19] http://www.gpo.gov/fdsys/pkg/FR-2011-07-25/pdf/2011-16459.pdf

or oxygenate-specific fuel. A California Air Resources Board additive certification will be accepted for fuel additized or used only in California. Specific minimum fuel properties (aromatics, sulfur content, olefins content, and 90 % evaporated point) for each option are required for certification and the certification fuels must also meet the requirements of Specification D4814-95c. For some options, the addition of 10 % by volume ethanol is required for certification fuel. Other oxygenates may also be required. Testing is required to demonstrate that the certification fuels without additives form a minimum level of intake valve deposits if specially formulated from refinery blend stocks. Such deposit demonstration testing is not required for test fuels sampled directly from finished fuels, fuel-specific test fuels, CARB-based certifications, and leaded gasoline certifications.

X3.5.3 Under the current regulations, detergents certified utilizing the current national certification fuel would satisfy detergency requirements for 15 % by volume ethanol blends.

X3.5.4 For federal additive certification, the test fuel containing the detergent additive(s) must form less than 100 mg/valve average intake valve deposit weight after 10 000 miles of testing in accordance with Test Method D5500-94. In addition, after 10 000 miles of testing, there may be no more than 5 % flow restriction in any one fuel injector in accordance with Test Method D5598-94.

X3.6 EPA Gasoline Sulfur Requirements (Tier 2)[20]

X3.6.1 Beginning in 2004, the basic EPA sulfur regulations required refiners and importers to meet a corporate pool annual average sulfur maximum level of 120 parts per million (ppm), with a per gallon cap of 300 ppm. The current requirements for refineries and importers is an annual average sulfur maximum level of 30 ppm, with a per-gallon cap at 80 ppm at the point of production or importation. The downstream enforcement standard is 95 ppm maximum (80 ppm refinery or importer cap plus 15 ppm test reproducibility).

X3.6.2 Under the EPA Tier 3 fuel program, gasoline and gasoline-oxygenate blends must contain no more than 10 ppm sulfur on an annual average basis beginning January 1, 2017. The current 80 mg/kg refinery gate and 95 mg/kg downstream

per-gallon caps are being maintained. The program allows refineries with annual crude oil throughput of 75 000 barrels per day or less to delay compliance until January 1, 2020.

X3.7 EPA Gasoline Benzene Regulations (MSAT2)[21]

X3.7.1 Beginning January 1, 2011, the EPA Control of Hazardous Air Pollutants from Mobile Sources rule (also known as Mobile Source Air Toxics rule or MSAT2) required that refiners and importers shall not exceed an annual average gasoline benzene content standard of 0.62 % by volume on all their gasoline, including reformulated and conventional, nationwide. Gasoline sold in California is exempted, because California has already implemented more stringent standards similar to EPA's. The regulations include a nationwide averaging, banking, and trading program. Qualified small refineries have until January 1, 2015 to comply with the requirements. Beginning on July 1, 2012 the regulations also required that no refinery or importer have an actual maximum average gasoline benzene level greater than 1.30 % by volume. The current compliance period is January 1 through December 31 of each year. After achieving an actual annual average benzene level of 1.30 % by volume, refiners and importers may use benzene credits to reduce their annual average benzene level to 0.62 % by volume. The actual average benzene level and average benzene level requirements apply on an individual refinery or importer basis.

X3.8 EPA and CARB Gasoline Manganese Regulations

X3.8.1 EPA granted a Clean Air Act Section 211(f)(1) waiver for the use of manganese in conventional U.S. unleaded gasoline in 1995, at a maximum permissible manganese concentration of 8.3 mg/L (0.031 g/gal).[22] Manganese limits for other fuels are as follows:

X3.8.1.1 The use of MMT in conventional fuel containing oxygenates is under review by the EPA.

X3.8.1.2 MMT is not permitted in U.S. reformulated gasoline.[23]

X3.8.1.3 MMT is not permitted in California gasoline.[24]

---

[20] Details of the sulfur regulations, including definitions, specific limits, effective dates, exceptions, and enforcement, are available in Parts 80.190 through 80.415 of Title 40 of the Code of Federal Regulations (40 CFR Parts 80.190-80.415).

[21] Details of U.S. EPA gasoline benzene regulations, including requirements, dates, bank and trading, exceptions, and enforcement, are provided in Parts 80.1220 through 80.1363 of Title 40 of the Code of Federal Regulations (40 CFR Parts 80.1220-80.1363).

[22] *Federal Register*, Vol. 60, July 17, 1995, pp. 36414.

[23] Code of Federal Regulations, Title 40, Part 80, Section 41.

[24] California Code of Regulations, Title 13, Section 2254.

X4. METHOD FOR CALCULATING MASS PERCENT OXYGEN OF GASOLINE-OXYGENATE BLENDS

X4.1 Scope

X4.1.1 Test Method D4815 provides a procedure for calculating the mass oxygen content of fuels using oxygenate concentration in mass percent. When oxygenate concentration in mass percent is not available, the oxygen concentration of these fuels can be determined indirectly by: (*1*) measuring the volume concentration of the oxygenates in the blend, which may be reported from Test Method D4815 or equivalent method, (*2*) measuring the density or relative density of the blend, (*3*) converting the oxygenate concentrations from volume to mass concentrations, and (*4*) converting the mass oxygenate concentrations to mass oxygen concentrations using the oxygen mass fractions of the oxygenates present.

X4.2 Procedure

X4.2.1 The following steps are used to determine the total mass oxygen concentration of gasoline-oxygenate blends when indirect calculation is necessary.

X4.2.1.1 Determine the volume concentrations of oxygenates in a gasoline-oxygenate blend (Test Method D4815 or equivalent test method).

X4.2.1.2 Determine the density or relative density of the gasoline-oxygenate blend (Test Methods D287, D1298, or D4052).

X4.2.1.3 The oxygen mass percent of the gasoline-oxygenate blend is calculated using the following general equation. The densities or relative densities and oxygen mass fractions of a number of pure oxygenates are provided in Table X4.1 for use in Eq X4.1. The choice of density or relative density must be the same as determined in X4.2.1.2 for the gasoline-oxygenate blend.

$$\text{Oxygen, Mass \%} = \hspace{3cm} (X4.1)$$

$$\frac{V_1 \times d_1 \times O_1 + V_2 \times d_2 \times O_2 \ldots + V_n \times d_n \times O_n}{V_b \times d_b} \times 100$$

where:

V_n = % by volume of oxygenates 1 through n,
d_n = density or relative density of oxygenates 1 through n,
O_n = mass fraction oxygen in oxygenates 1 through n,

TABLE X4.1 Densities, Relative Densities, and Oxygen Mass Fractions of Pure Oxygenates

Oxygenate	Density, g/mL 20 °C (68 °F)	Relative Density 15.56/15.56 °C (60/60 °F)	Oxygen Mass Fraction
Methyl Alcohol	0.7913	0.7963	0.4993
Ethyl Alcohol	0.7894	0.7939	0.3473
n-Propyl Alcohol	0.8038	0.8080	0.2662
Isopropyl Alcohol	0.7855	0.7899	0.2662
n-Butyl Alcohol	0.8097	0.8137	0.2158
Isobutyl Alcohol	0.8016	0.8058	0.2158
sec-Butyl Alcohol	0.8069	0.8114	0.2158
tertiary-Butyl Alcohol	0.7866[A]	0.7922[A]	0.2158
Methyl tertiary-Butyl Ether	0.7406	0.7460	0.1815
Ethyl tertiary-Butyl Ether	0.7399	0.7452	0.1566
tertiary-Amyl Methyl Ether	0.7707	0.7758	0.1566
tertiary-Hexyl Methyl Ether	0.7815	0.7860	0.1377
Diisopropyl Ether	0.7235	0.7282	0.1566

[A] Extrapolated, below freezing temperature.

V_b = % by volume of gasoline-oxygenate blend = 100, and
d_b = density or relative density of gasoline-oxygenate blend.

X4.3 Example Calculation

X4.3.1 Assume that a gasoline-oxygenate blend is reported to contain 9.5 % by volume ethanol and 2.0 % by volume methyl tertiary-butyl ether and that the relative density of the blend is measured to be 0.7450, 15.56/15.56 °C (60/60 °F).

X4.3.2 Using the relative density and oxygen mass fraction data for ethanol and methyl tertiary-butyl ether from Table X4.1, the following % by mass oxygen is calculated for this gasoline-oxygenate blend.

$$\text{Oxygen, Mass \%} = \hspace{3cm} (X4.2)$$

$$\frac{9.5 \times 0.7939 \times 0.3473 + 2.0 \times 0.7460 \times 0.1815}{100 \times 0.7450} \times 100 = 3.88$$

X4.4 Precision

X4.4.1 The precision of this calculation method is a function of the individual precisions of density or relative density (Test Methods D287, D1298, or D4052) and oxygenate analysis (Test Method D4815 or equivalent). Because the repeatability and reproducibility vary with the analyses used, no estimate is provided.

X5. MICROBIAL CONTAMINATION

X5.1 Uncontrolled microbial contamination in fuel systems can cause or contribute to a variety of problems including increased corrosivity, and decreased stability, filterability, and caloric value. Microbial processes in fuel systems can also cause or contribute to system damage.

X5.2 Available (free) water is required for microorganisms to thrive. Small amounts of water will dissolve in the fuel components. The dissolved water is unavailable for microbes to use. Should the fuel or fuel components encounter water during distribution or storage the additional water could allow microorganisms to thrive by using the fuel components as an energy source. Additional discussion of microbial contamination of fuels can be found in CRC report No. 667 and Guide D6469.

X5.3 Because the microbes contributing to the aforementioned problems may not be present in the fuel itself, no microbial quality criterion for fuels is recommended. However, it is important that personnel responsible for fuel quality understand how uncontrolled microbial contamination can affect fuel quality.

X5.4 Guide D6469 provides personnel with limited microbiological background an understanding of the symptoms, occurrences, and consequences of chronic microbial contamination. Guide D6469 also suggests means for detecting and controlling microbial contamination in fuels and fuel systems.

X6. FUEL FILTRATION

X6.1 During the distribution of spark-ignition fuels, it is possible for them to become contaminated with potential filter blocking materials. While proper handling will minimize the contamination levels, it is recommended that all fuel dispensers be equipped with filters of 10 μm or less nominal pore size at point of delivery to the customer.

X7. UNWASHED GUM AND CONTAMINATION OF GASOLINE

X7.1 In recent years there have been several incidents of fuel contamination by polymeric materials from chemical plants not intended for gasoline that have affected the motoring public in the U.S. These incidents of fuel contamination may have been prevented or their impact reduced by measurements of the unwashed gum content prior to blending with deposit control additives providing the basis for subsequent action to correct the contamination.

X7.2 It is advised that refiners, other fuel producers, blendstock producers and blenders monitor the unwashed gum content determined by Test Method D381 of gasoline and gasoline blendstocks (for example, subgrades, reformulated blendstock for oxygenate blending, and conventional blendstock for oxygenate blending) prior to blending with deposit control additives. Such monitoring can provide an early indication of contamination by polymeric materials not intended for gasoline when unwashed gum values increase beyond the "normal" range of values established from trends of uncontaminated gasolines and blendstocks as determined by the refiner, fuel producer, blendstock producer, or blender.

X8. PHASE SEPARATION AND WATER IN SPARK-IGNITION ENGINE FUELS

X8.1 Spark-ignition engine fuel should not contain a separate water or water-alcohol phase at the time it is introduced into a vehicle or equipment fuel tank or under the conditions the fuel is used. The lower aqueous phase can be corrosive to many metals (see X1.13), support microbial growth (see Appendix X5) and the engine cannot operate on it. This can result in damage to distribution, retail and vehicle fuel systems and to engines. In addition, the upper hydrocarbon phase may no longer meet needed volatility (see X8.2.2.1) and antiknock properties. The solubility of water in the fuel is related to the composition (including all blend components, additives, and impurities) and temperature of the fuel. The primary factor affecting phase separation is exposure of the fuel to additional water. A secondary factor is a significant drop in temperature. The separate phase in the finished fuel is a fuel contaminant.

X8.2 Phase separation can usually be avoided if the fuel components are sufficiently water-free initially and care is taken during blending, storage and distribution to prevent contact with water. A good industry practice is to drain any free water (separate water phase) from a hydrocarbon storage tank before the fuel is moved further through the distribution system, and before alcohol is added to a fuel blend. Fuel tanks utilized for process flow control without sufficient settling time cannot be utilized for water separation. For those tanks, water removal can be required downstream prior to the delivery to the retail outlet or distributor. Options for water removal include the addition of settling time in tankage with water draw-off, using appropriate water-absorption techniques, or

adding water-coalescing facilities at the point of fueling equipment to ensure that only fuel with no free water ("dry fuel") goes into the equipment's fuel tank. Water-absorbing cartridge filters, which are designed to stop flowing on exposure to excessive water, can be used to remove small amounts of free water or to act as an alert mechanism for the presence of excessive free water in the fuel storage tank. Water-absorbing filters are available for hydrocarbon only and for hydrocarbon-ethanol blended fuels. There is insufficient data to confirm that filters which are appropriate for hydrocarbon only or hydrocarbon-ethanol blended fuel will be appropriate for blends containing butanol or other oxygenates. Filter manufacturers should be consulted on proper filter selection. Once the water is removed from the fuel it is important to ensure that equipment and procedures are in place to prevent contamination of the fuel with additional water. Water removed from tanks could be considered a hazardous waste. Consult the appropriate regulatory agencies to ensure that the material is properly handled for disposal.

X8.2.1 Hydrocarbon-only spark-ignition engine fuels have a low solubility for water and can be saturated with water throughout the distribution chain and at point of use. Contact with additional water could create a separate water phase seen as a haze, water droplets or a distinct separate layer. The volume of the separated phase is approximately equal to the volume of water contaminating the gasoline beyond the saturation concentration. While the hydrocarbons from these tanks can be saturated with dissolved water, it is important that there not be a separate water phase when the product is sent to the loading rack for distribution to retail. To remove (manage) free water, terminals can follow practices such as API Recommended Practice 1640. At retail stations, many fuel systems in the past were designed with the expectation that a separate water phase of up to 2.5 cm or 1 in. could exist without water or wet fuel being dispensed into the vehicle fuel tank.

X8.2.2 Hydrocarbon-ethanol blends are not saturated with water at the time the fuel blend is produced, normally at a terminal rack. It is therefore important that the hydrocarbon used to make the fuel blend contains no free water. A gasoline (hydrocarbon)-ethanol fuel blend can normally dissolve trace water contamination that can occur during distribution. Larger concentrations of water can cause a separate phase to form with a significant portion of the ethanol originally contained in the hydrocarbon-ethanol blend being transferred into the water phase. The volume of the water-ethanol phase will be larger than the amount of water in the fuel, and can, if sufficient water contamination occurs, approach the volume of the water plus ethanol in the fuel blend.

X8.2.2.1 *In the United States*—The decrease in ethanol concentration could result in a fuel that is no longer acceptable for the volatility waiver allowed in the U.S. under certain conditions. For example, in the U.S. a gasoline-ethanol blend containing at least 9 % and no more than 10 % by volume ethanol may qualify for a vapor pressure waiver under 40 CFR 80.27(d). If the ethanol concentration falls below 9 % by volume the blend would no longer be eligible for the waiver.

X8.3 Temperature is an important factor which governs the ability of a fuel to dissolve water. The ability to dissolve water is especially important when the temperature of the fuel in use is much colder than the temperature the fuel had been in storage. As the temperature of the fuel decreases, water solubility decreases. In other words, fuel stored at warmer temperatures can have a significantly higher concentration of dissolved water than a fuel stored at cold temperatures. Fuels should be resistant to haze, water droplets and phase separation at the lowest temperatures to which they are likely to be subjected, dependent on the time and place of their intended use.

X8.3.1 In the United States, the values in Table X8.1 are the 10th percentile 6 h minimum temperatures, with each reading specifically defined as the highest temperature of the six coldest consecutive hourly temperature readings of a 24 h day. For April through September (and occasionally October, and year-round for Hawaii), Table X8.1 specifies a minimum phase separation temperature of 10 °C (50 °F), even though the 10th percentile 6 h minimum temperature can be higher. Use of this temperature limit also reduces the risk of phase separation of the fuel in underground storage tanks where temperatures can be lower than ambient air temperature.

NOTE X8.1—The values in Table X8.1 are taken from the U.S. Army Mobility Equipment Research & Development Center, Coating and Chemical Lab Aberdeen Proving Ground MD (CCL) Report No. 316, entitled, "A Predictive Study for Defining Limiting Temperatures and Their Application in Petroleum Product Specifications." This can be obtained as Publication AD0756420 from DTIC Online, http://www.dtic.mil/.

X8.4 The composition of a fuel can affect its ability to dissolve water. As the concentration of aromatics and/or alcohols increase, the water solubility will increase. For example, a hydrocarbon fuel with higher aromatic content can hold slightly more dissolved water than a highly paraffinic fuel, and a blend containing alcohol can hold more dissolved water than a blend without alcohol, while all of the fuels still meet all of the requirements of Specification D4814. A hydrocarbon-only fuel can dissolve up to 0.03 % by mass of water. When hydrocarbons are blended with an alcohol to create spark-ignition engine fuels, the hydrocarbons should be free from undissolved water at the time of blending and the alcohol should meet the water limits in the appropriate ASTM specification. The resulting hydrocarbon-alcohol blend can dissolve more water than exists at the time of blending and will provide protection against phase separation should small amounts of additional water contaminate the blended fuel as long as the blend's temperature does not decrease. The level of improvement in water tolerance (the amount of water that can be dissolved before phase separation occurs) will increase with the concentration of alcohol in the fuel.

X8.4.1 When hydrocarbon-alcohol blends are exposed to a greater amount of water than they can dissolve, they can separate into a lower aqueous phase and an upper hydrocarbon phase. The distribution of the alcohol between these two phases will depend on the relative solubility of the alcohol in water, the relative solubility of alcohol in the hydrocarbons and the temperature of the blend. When properly blended, the

TABLE X8.1 U.S. Maximum Temperature for Phase Separation, °C[A,B]

Temperature Conversion °F = (°C × 1.8) + 32°

State	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alabama	−4	−3	0.	5	10.	10.	10.	10.	10.	6	0.	−4
[C] Alaska:												
Southern Region	−27	−26	−23	−11	1	7	9	7	1	−9	−19	−23
South Mainland	−41	−39	−31	−14	−1	7	9	5	−2	−18	−32	−41
N of 62° Latitude												
Arizona:												
N of 34° Latitude	−11	−7	−7	−2	2	6	10.	10.	6	1	−6	−9
S of 34° Latitude	−2	−1	2	7	10.	10.	10.	10.	10.	9	2	−1
Arkansas	−9	−6	−2	6	10.	10.	10.	10.	10.	4	−2	−6
[D] California:												
North Coast	−2	0.	1	4	5	8	9	9	8	6	2	−2
South Coast	−2	−1	2	4	7	9	10.	10.	9	6	1	−2
Southeast	−7	−3	−1	3	8	10.	10.	10.	9	4	−3	−6
Interior	−4	−3	−3	−1	3	9	10.	10.	10.	6	0.	−2
Colorado:												
E of 105° Longitude	−14	−12	−9	−3	4	10.	10.	10.	7	1	−8	−11
W of 105° Longitude	−24	−20.	−12	−6	−1	4	8	6	1	−6	−14	−21
Connecticut	−14	−13	−8	−1	5	10.	10.	10.	7	1	−4	−12
Delaware	−9	−8	−3	0.	8	10.	10.	10.	10.	4	−1	−8
District Columbia	−8	−7	−3	3	9	10.	10.	10.	10.	5	0.	−7
Florida:												
N of 29° Latitude	−1	1	4	9	10.	10.	10.	10.	10.	9	3	−1
S of 29° Latitude	4	7	8	10.	10.	10.	10.	10.	10.	10.	9	5
Georgia	−5	−2	1	6	10.	10.	10.	10.	10.	6	0.	−3
Hawaii	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.
Idaho	−17	−16	−11	−3	−5	4	10.	9	3	−2	−11	−15
Illinois:												
N of 40° Latitude	−18	−16	−9	−1	4	10.	10.	10.	7	1	−7	−16
S of 40° Latitude	−15	−12	−7	1	7	10.	10.	10.	9	3	−6	−13
Indiana	−16	−13	−7	−1	4	10.	10.	10.	7	1	−6	−14
Iowa	−23	−19	−13	−3	4	10.	10.	10.	6	0.	−12	−20.
Kansas	−17	−12	−9	−3	5	10.	10.	10.	7	0.	−8	−13
Kentucky	−12	−9	−4	1	8	10 .	10.	10.	9	3	−4	−11
Louisiana	−3	0.	3	8	10.	10.	10.	10.	10.	7	2	−1
Maine	−24	−22	−16	−4	1	7	10.	8	3	−2	−8	−20.
Maryland	−9	−8	−3	3	9	10.	10.	10.	10.	4	−2	−8
Massachusetts	−15	−14	−7	−1	4	10.	10.	10.	6	0.	−4	−13
[E] Michigan:												
Lower Michigan	−18	−17	−12	−3	1	7	10.	9	5	0.	−6	−14
Upper Michigan	−21	−20.	−15	−6	−1	6	9	9	4	−1	−9	−18
Minnesota	−31	−28	−20.	−7	0.	6	10.	8	1	−3	−16	−28
Mississippi	−3	−1	2	7	10.	10.	10.	10.	10.	7	1	−3
Missouri	−14	−11	−6	1	8	10.	10.	10.	10.	3	−5	−12
Montana	−28	−24	−19	−6	1	5	9	8	1	−5	−17	−23
Nebraska	−19	−14	−11	−3	4	9	10.	10.	5	−2	−10.	−16
Nevada:												
N of 38° Latitude	−18	−13	−8	−3	1	5	9	7	2	−3	−11	−14
S of 38° Latitude	−9	−5	−1	1	9	10.	10.	10.	10.	4	−3	−6
New Hampshire	−18	−17	−9	−2	3	9	10.	9	3	−1	−6	−16
New Jersey	−10.	−9	−4	2	7	10.	10.	10.	10 .	4	−1	−8
New Mexico:												
N of 34° Latitude	−14	−11	−7	−2	1	7	10.	10.	7	1	−8	−12
S of 34° Latitude	−7	−5	−1	6	10.	10.	10.	10.	10.	7	−2	−5
New York:												
N of 42° Latitude	−21	−20.	−13	−3	2	9	10.	10.	4	−1	−6	−18
S of 42° Latitude	−13	−13	−7	1	6	10.	10.	10.	8	2	−3	−12
North Carolina	−9	−7	−3	1	7	10.	10.	10.	8	1	−5	−8
North Dakota	−29	−27	−11	−6	1	8	10.	10.	3	−2	−17	−24
Ohio	−14	−13	−8	−2	6	10.	10.	10.	7	1	−5	−13
Oklahoma	−12	−6	−5	1	7	10.	10.	10.	10.	4	−4	−9
Oregon:												
E of 122° Longitude	−17	−12	−6	−3	0.	4	6	6	2	−3	−8	−12
W of 122° Longitude	−5	−3	−1	2	5	8	10.	10.	7	2	−3	−3
Pennsylvania:												
N of 41° Latitude	−17	−19	−13	−4	1	6	9	8	2	−1	−6	−16
S of 41° Latitude	−13	−14	−9	−1	5	10.	10.	10.	7	2	−4	−12
Rhode Island	−11	−11	−5	1	6	10.	10.	10.	8	3	−2	−10.
South Carolina	−3	−2	0.	6	10.	10.	10.	10.	10.	7	1	−3
South Dakota	−24	−21	−16	−4	3	10.	10.	10.	4	−2	−12	−21
Tennessee	−9	−7	−3	2	9	10.	10.	10.	10.	2	−3	−8
Texas:												
N of 31° Latitude	−11	−8	−4	2	8	10.	10.	10.	10.	5	−3	−7
S of 31° Latitude	−1	1	4	10.	10.	10.	10.	10.	10.	10.	3	1
Utah	−15	−11	−7	−2	2	8	10.	10.	7	2	−11	−12

TABLE X8.1 *Continued*

State	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature Conversion °F = (°C × 1.8) + 32°						
Vermont	−20.	−21	−12	−2	2	9	10.	10.	5	0.	−6	−17
Virginia	−8	−7	−3	3	9	10.	10.	10.	10.	4	−2	−7
Washington:												
E of 122° Longitude	−13	−6	−3	1	4	7	10.	10.	7	1	−5	−7
W of 122° Longitude	−6	−2	−2	1	4	7	9	9	6	2	−2	−2
West Virginia	−13	−12	−7	−2	4	9	10.	10.	5	−2	−7	−12
Wisconsin	−25	−21	−15	−3	3	8	10.	10.	5	−1	−11	−21
Wyoming	−23	−17	−14	−6	0.	5	10.	10.	3	−2	−13	−16

[A] See 1.7 for determining conformance with specification limits in this table.

[B] A maximum phase separation temperature of 10 °C (50 °F) is specified, even if the 6-h 10th percentile minimum temperature for the area and month can be higher.

[C] The designated areas of Alaska are divided as follows: *Southern Region*—The Aleutians, Kodiak Island, the coastal strip East of Longitude 141°, and the Alaskan Peninsula South of Latitude 52°.

    South Mainland—The portion of Alaska south of Latitude 62°, except the Southern Region.

    North of Latitude 62°—The specification test temperature must be agreed between the vendor and purchaser having regard to equipment design, expected weather conditions, and other relevant factors.

[D] The designated areas of California are divided by county as follows: *North Coast*—Alameda, Contra Costa, Del Norte, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity.

    Interior—Lassen, Modoc, Plumas, Sierra, Siskiyou, Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kern (except that portion lying east of the Los Angles County Aqueduct), Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada.

    South Coast—Orange, San Diego, San Luis Obispo, Santa Barbara, Ventura, Los Angeles (except that portion lying north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct).

    Southeast—Imperial, Riverside, San Bernardino, Los Angeles (that portion lying north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct), Mono, Inyo, Kern (that portion lying east of the Los Angeles County Aqueduct).

[E] The designated areas of Michigan are divided as follows: *Lower Michigan*—That portion of the state lying east of Lake Michigan.

    Upper Michigan—That portion of the state lying north of Wisconsin and of Lake Michigan.

initial hydrocarbon-alcohol blend can dissolve more water than exists in the fuel at the time of blending. The common industry practice is to ensure that the storage tank is clean and dry before adding a hydrocarbon-alcohol blend, and equipment and procedures are in place to prevent exposure of the fuel blend to water. Historically the term "water tolerance" has been used to describe the ability of a fuel, especially a gasoline-ethanol blend fuel, to dissolve water without phase separation. The amount of water that can be dissolved by a hydrocarbon-alcohol blend will depend on the type and concentration of alcohol, the specific hydrocarbons present, and the temperature of the blend.

X8.4.1.1 *Hydrocarbon-ethanol Blends*—Ethanol will provide some improvement to the water tolerance of the finished fuel relative to a hydrocarbon-only fuel. The level of improvement will increase with the concentration of ethanol in the fuel. For example, a 10 % by volume ethanol blend with a typical hydrocarbon mixture at room temperature can dissolve up to 0.7 % by mass (0.5 % by volume) water. For ethanol blends, if substantial water contamination and phase separation occurs, the volume of the lower phase can be significantly greater than that of the additional water, and the upper hydrocarbon phase may no longer meet needed volatility and antiknock properties.

X8.4.1.2 *Hydrocarbon-butanol Blends*—Butanol will provide some improvement to the water tolerance of the finished fuel relative to a hydrocarbon-only fuel. For example a 16 % by volume butanol blend with a typical hydrocarbon mixture at room temperature can dissolve up to 0.6 % by mass (0.4 % by volume) water. For butanol blends, if phase separation occurs, the volume of the lower phase will not be much larger than that of the additional water because of the low solubility of butanol in water. When the water solubility limit is exceeded the majority of the butanol will stay in the hydrocarbon phase and the excess water will separate.

SUMMARY OF CHANGES

Subcommittee D02.A0.01 has identified the location of selected changes to this standard since the last issue (D4814 – 17) that may impact the use of this standard. (Approved Jan. 1, 2018.)

(1) Revised Table 4 and Table 12 for information about Ohio Federal SIP vapor pressure requirements.

(2) Revised Table 5 and Table 6 for information about Tennessee Federal vapor pressure requirements.

Subcommittee D02.A0.01 has identified the location of selected changes to this standard since the last issue (D4814 – 16e$^{\varepsilon 1}$) that may impact the use of this standard. (Approved May 1, 2017.)

(1) Deleted former subsection X3.1.5 to eliminate duplicate wording.

(2) Added Test Method D7345 to Referenced Documents and to Table 1, 5.2.3, 7.1, X1.11.1, X1.12.1, X1.12.5, X2.2.2.1, X2.2.2.7, and X2.3.2.