Designation: D 4814 – 00a

An American National Standard

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

This standard is issued under the fixed designation D 4814; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification guides in establishing requirements of 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 September 15, the maximum vapor pressure limits issued by the U.S. Environmental Protection Agency (EPA) are specified for each geographical area except Alaska and Hawaii. Variation of 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. This specification does not apply to fuels that contain an oxygenate as the primary component, such as Fuel Methanol (M85). The concentrations and types of oxygenates are not specifically limited in this specification. However, depending on oxygenate type, as oxygenate content increases above some threshold level, the likelihood for vehicle problems also increases. 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 addition, the composition of unleaded fuel is subject to the rules, regulations, and Clean Air Act waivers of the U.S. Environmental Protection Agency (EPA). 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, deposit control additive certification, and use of oxygenates in blends with unleaded gasoline. Contact 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 D 4814, contact ASTM 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 D 4815 provides a procedure for determining oxygenate concentration in mass percent. Test Method D 4815 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.

1.7 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 E 29. The use of a trailing decimal point in a limit indicates that the digit preceding the decimal point is a significant digit.

1.8 The values stated in SI units are the standard, except when other units are specified by federal regulation. Values

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[1] This specification is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.A on Gasoline and Oxygenated Fuels.

Current edition approved Dec. 10, 2000. Published February 2001. Originally published as D 4814 – 88. Last previous edition D 4814 – 00.

[2] Available from ASTM Headquarters. Request RR:D02-1347.

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, federal regulations specify non-SI units.

1.9 The following safety hazard caveat pertains only to the test method portion, Annex A1 of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 86 Test Method for Distillation of Petroleum Products[3]
D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[3]
D 287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)[3]
D 381 Test Method for Existent Gum in Fuels by Jet Evaporation[3]
D 439 Specification for Automotive Gasoline[4]
D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)[3]
D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[3]
D 1298 Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[3]
D 2533 Test Method for Vapor-Liquid Ratio of Spark-Ignition Engine Fuels[3]
D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[5]
D 2699 Test Method for Knock Characteristics of Motor Fuels by the Research Method[6]
D 2700 Test Method for Knock Characteristics of Motor and Aviation Fuels by the Motor Method[6]
D 2885 Test Method for Research and Motor Method Octane Ratings Using On-Line Analyzers[6]
D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry[5]
D 3231 Test Method for Phosphorus in Gasoline[5]
D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry[5]
D 3341 Test Method for Lead in Gasoline—Iodine Monochloride Method[5]
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[5]
D 4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary–Amyl Alcohol and C_1 to C_4 Alcohols in Gasoline by Gas Chromatography[7]
D 4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)[7]
D 5059 Test Methods for Lead in Gasoline by X-Ray Spectroscopy[7]
D 5188 Test Method for Vapor-Liquid Ratio Temperature Determination of Fuels (Evacuated Chamber Method)[7]
D 5190 Test Method for Vapor Pressure of Petroleum Products (Automatic Method)[7]
D 5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)[7]
D 5453 Test Method for the Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels, and Oils by Ultraviolet Fluorescence[7]
D 5482 Test Method for Vapor Pressure of Petroleum Products (Mini Method-Atmospheric)[7]
D 5500 Test Method for Vehicle Evaluation of Unleaded Automotive Spark-Ignition Engine Fuel for Intake Valve Deposit Formation[7]
D 5598 Test Method for Evaluating Unleaded Automotive

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[3] *Annual Book of ASTM Standards*, Vol 05.01.
[4] Discontinued—See 1990 *Annual Book of ASTM Standards*, Vol 05.01.
[5] *Annual Book of ASTM Standards*, Vol 05.02.
[6] *Annual Book of ASTM Standards*, Vol 05.04.
[7] *Annual Book of ASTM Standards*, Vol 05.03.

TABLE 1 Vapor Pressure and Distillation Class Requirements

Vapor Pressure/ Distillation Class	Vapor Pressure,[A] max, kPa(psi)	Distillation Temperatures, °C (°F), at % Evaporated. max[B]					Distillation Residue, volume % , max	Driveability Index,[C] max,° C (°F) Derived[D,E]
		10 volume %, max	50 volume % min	50 volume % max	90 volume %, max	End Point, max		
AA	54(7.8)	70.(158.)	77.(170.)	121.(250.)	190.(374.)	225.(437.)	2.	597. (1250.)
A	62(9.0)	70.(158.)	77.(170.)	121.(250.)	190.(374.)	225.(437.)	2.	597. (1250.)
B	69(10.0)	65.(149.)	77.(170.)	118.(245.)	190.(374.)	225.(437.)	2.	591. (1240.)
C	79(11.5)	60.(140.)	77.(170.)	116.(240.)	185.(365.)	225.(437.)	2.	586. (1230.)
D	93(13.5)	55.(131.)	66.(150.)	113.(235.)	185.(365.)	225.(437.)	2.	580. (1220.)
E	103(15.0)	50.(122.)	66.(150.)	110.(230.)	185.(365.)	225.(437.)	2.	569. (1200.)

[A] Consult EPA for approved test methods for compliance with EPA vapor pressure regulations.
[B] At 101.3 kPa pressure (760 mm Hg).
[C] Driveability Index (DI) = 1.5 T_{10} + 3.0 T_{50} + 1.0 T_{90}, where T_{10} = distillation temperature, °C (°F), at 10 % evaporated, T_{50} = distillation temperature, °C(°F), at 50 % evaporated, and T_{90} = distillation temperature, °C(°F), at 90 % evaporated.
[D] 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.
[E] 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:

$$DI_{°C} = (DI_{°F} - 176)/1.8$$

Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling[7]

D 5599 Test Method for Determination of Oxygenates in Gasoline by Gas Chromatography and Oxygen Selective Flame Ionization Detection[7]

D 5845 Test Method for Determination of MTBE, ETBE, TAME, DIPE, Methanol, Ethanol, and *tert*-Butanol in Gasoline by Infrared Spectroscopy[7]

D 6422 Test Method for Water Tolerance (Phase Separation) of Gasoline-Alcohol Blends[8]

D 6469 Guide to Microbial Contamination in Fuels and Fuel Systems[8]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[9]

2.2 *Government Standard:*

CFR 40 Code of Federal Regulations[10]

3. Terminology

3.1 *Definitions:*

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

3.1.2 *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.

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

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

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

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

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

3.1.7.1 *Discussion*—This definition is from 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 *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 mass % oxygen, or more than 0.15 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 3.2 were selected with consideration given to current oxygenate levels in the marketplace, state labeling practices, and consistency with federal legislation and regulations.

NOTE 4—Refer to Test Method D 4815 to calculate the mass oxygen content of a fuel using oxygenate concentration in mass %. Refer to Appendix X4 to calculate mass oxygen content of a fuel using oxygenate concentration in 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.

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 Method D 4815, a gas chromatographic test method, is the recommended procedure 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 and 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. Tables 5-7 show the 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).

TABLE 2 Detailed Requirements for all Volatility Classes[A]

Lead Content, max, g/L (g/U.S. gal)[B]		Copper Strip Corrosion, max	Solvent-washed Gum Content, mg/100 mL, max	Sulfur, max, mass%		Oxidation Stability, Minimum, minutes	Water Tolerance
Unleaded	Leaded			Unleaded	Leaded		
0.013(0.05)	1.1(4.2)	No. 1	5	0.10	0.15	240.	[C]

[A] See Appendix X1 for information on Antiknock Index.

[B] 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).

[C] Water tolerance limits in terms of maximum temperature for phase separation are given in Table 13.

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[8] *Annual Book of ASTM Standards*, Vol 05.04.

[9] *Annual Book of ASTM Standards*, Vol 14.02.

[10] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

TABLE 3 Vapor Lock Protection Class Requirements

Vapor Lock Protection Class	Vapor/Liquid Ratio (V/L)[AB]	
	Test Temperature, °C (°F)	V/L, max
1	60.(140.)	20
2	56.(133.)	20
3	51.(124.)	20
4	47.(116.)	20
5	41.(105.)	20
6	35.(95.)	20

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

[B] The mercury confining fluid procedure of Test Method D 2533 shall be used for gasoline-oxygenate blends. Either glycerin or mercury confining fluid may be used for gasoline. Test Method D 5188 may be used for all fuels. The procedure for estimating temperature-V/L (see Appendix X2) may only be used for gasoline.

TABLE 4 Schedule of 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 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 (available from ASTM Headquarters) 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[C]	A-3[C]	A-2[D]	A-2[D]	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:[E]													
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[F]	A-1[F]	A-1[F]	A-1[D]	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:[E,G]													
North Coast	E-5/D-4	D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[C]	A-2[D]	A-2[D]	A-2[D]	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[D,H]	A-2[D,H]	A-2[D,H]	A-2[D,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[F]	A-1[F,I]	A-1[F,I]	A-1[F,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[D,H]	A-2[D,H]	A-2[D,H]	A-2[D,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[D]	A-2[D]	A-2[D]	A-2[D]	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[I]	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[C]	A-3[C]	A-3[C]	A-3[C]	A-3/C-3	C-3	C-3/D-4	D-4
Georgia[E]	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3[C]	A-3[C]	A-2[D]	A-2[D]	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:[E]													
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	A-3	A-3	A-3	A-3/C-3	C-3/D-4	D-4	D-4/E-5
Indiana[E]	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[E]	E-5	E-5/D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-2[D]	A-2[D]	A-2[D]	A-2[D]	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[C]	A-3[C]	A-2[D]	A-2[D]	A-2/C-3	C-3	C-3/D-4	D-4
Maine[E]	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
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[E]	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[E]	E-5	E-5/D-4	D-4	D-4/A-3	A-3 (C-3)	A-3[C]	A-2[D]	A-2[D]	A-2[D]	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[D]	A-2[D]	A-2[D]	A-2[D]	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

TABLE 4 *Continued*

State	Jan.	Feb.	Mar.	Apr.	May[B]	June	July	Aug.	Sept. 1–15	Sept. 16–30	Oct.	Nov.	Dec.
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[C]	A-3[C]	A-2[D]	A-2[D]	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:													
E 122° 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	D-4/E-5
W 122° Longitude	E-5	E-5/D-4	D-4	D-4/A-4	A-4 (D-4)	A-3[C]	A-3[C]	A-3[C]	A-3[C]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Pennsylvania[E]	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	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[C]	A-3[C]	A-2[D]	A-2[D]	A-2/C-3	C-3/D-4	D-4	D-4/E-5
Texas:[E]													
E 99° Longitude	D-4	D-4	D-4/C-3	C-3/A-3	A-3 (C-3)	A-3[C,K]	A-2[D,H]	A-2[D,H]	A-2[D,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[F]	A-1[F]	A-1[F]	A-1[F]	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[D]	A-2[D]	A-2[D]	A-2[D]	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[C,K]	A-3[C,K]	A-3[C,K]	A-3[C,K]	A-3/C-3	C-3/D-4	D-4/E-5	E-5
Washington:													
E 122° 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 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 5 for specific area requirements.

[D] See Table 6 for specific area requirements.

[E] See Table 12 for specific area requirements.

[F] See Table 7 for specific area requirements.

[G] Details of State Climatological Division by county as indicated:

California, North Coast—Alameda, Contra Costa, Del Norte, Humbolt, Lake Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity.

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

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

California, Southeast—Imperial, Riverside, San Bernadino, Los Angeles (that portion 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).

[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.

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 poorer warmup driveability performance.

5.2.3 Driveability Index (DI) is intended to provide control of distillation parameters that influence cold start and warmup driveability. It is a function of the 10 %, 50 %, and 90 % evaporated distillation temperatures measured by Test Method D 86.

5.2.4 Test Method D 2533 contains procedures for measuring temperature-*V/L* of both gasoline and gasoline-oxygenate blends. For gasoline-oxygenate blends, the procedure requires that mercury be used as the confining fluid in place of glycerin. Either confining fluid may be used for gasoline. Test Method D 5188 is an alternative method for determining vapor-liquid ratio temperatures by an evacuated chamber method for gasoline-oxygenate blends, as well as gasoline. In case of dispute, Test Method D 2533 is the referee method. The method for estimating temperature-*V/L* (see Appendix X2) is only applicable for gasoline.

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 broad groups of engines and vehicles. Also discussed is the

TABLE 5 Ozone Nonattainment Areas Requiring Volatility Class AA-3

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

Alabama—Jefferson and Shelby counties
California^A—Alameda, Contra Costa, Marin, Monterey, Napa, San Francisco, San Benito, San Mateo, Santa Clara, Santa Cruz, and Solano (part) counties
Florida—Broward, Dade, Duval, Hillsborough, Palm Beach, and Pinellas counties
Georgia^A—Cherokee, Clayton, Cobb, Coweta, Dekalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Henry, Paulding, and Rockdale counties
Louisiana—Ascension, Beauregard, Calcasieu, East Baton Rough, Grant, 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
North Carolina—Davidson, Davie (part), Durham, Forsyth, Gaston, Granville (part), Guliford, Mecklenburgh, and Wake counties
Oregon—Clackamas, Marion (part), Multnomah, Polk (part), and Washington
Tennessee—Davidson, Rutherford, Shelby, Sumner, Williamson, and Wilson counties
Texas—Hardin, Jefferson, Orange, and Victoria counties
Virginia—Smyth County (part)

^{A}See Table 12 for local vapor pressure limits.

TABLE 6 Ozone Nonattainment Areas Requiring Volatility Class AA-2

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

Alabama—Jefferson and Shelby counties
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, Denver, Douglas, and Greeley counties (waived by EPA)
Georgia^A—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, Grant, 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
North Carolina—Davidson, Davie (part), Durham, Forsyth, Gaston, Granville (part), Guliford, Mecklenburgh, and Wake counties
Tennessee—Davidson, Rutherford, Shelby, Sumner, Williamson, and Wilson counties
Texas—Hardin, Jefferson, Orange, and Victoria counties
Utah—Davis and Salt Lake counties

^{A}See Table 12 for local vapor pressure limits.

TABLE 7 Ozone Nonattainment Areas Requiring Volatility Class AA-1

NOTE 1—See 40 CFR Part 81.305 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 Federal RFG Areas Requiring Volatility Class A-3

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.

Connecticut—All counties
Delaware—All counties
Illinois^A—Cook, Du Page, Grundy (part), Kane, Kendall (part), Lake, McHenry, and Will counties
Indiana^A—Lake and Porter counties
Kentucky—Boone, Bullitt (part), Campbell, Jefferson, Kenton, and Oldham (part) 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 Federal RFG Areas Requiring Volatility Class AA-3

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.

District of Columbia
Maryland—Anne Arundel, Baltimore, Calvert, Carroll, Charles, Frederick, Harford, Howard, Kent, Montgomery, Prince George's, and Queen Anne's counties
Texas—Brasoria, 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

TABLE 10 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—Brasoria, Chambers, Collin, Dallas, Denton, Fort Bend, Galveston, Harris, Liberty, Montgomery, Tarrant, and Waller counties

^{A} See Table 12 for local vapor pressure limits.

effect of altitude and weather on vehicle antiknock requirements.

5.4 Additional fuel requirements are shown in Table 2.

5.5 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 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. Water tolerance is specified in Table 13.

5.6 Depending on oxygenate type and concentration in the blend, vehicle driveability with gasoline-oxygenate blends can

TABLE 11 Federal RFG Area Requiring Volatility Class AA-1

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

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

TABLE 12 Federal 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–48.2 kPa (7.0 psi) max May 31 - 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
Georgia–Barrow, Bartow, Butts, Carroll, Cherokee, Clayton, Cobb, Coweta, Dawson, Dekalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Hall, Haralson, Henry, Jackson, Newton, Paulding, Pickens, Rockdale, Spalding, and Walton counties–48.2 kPa (7.0 psi) max June 1 - Sept 15[A] (approval pending)
Illinois–Madison, Monroe, and Saint Clair Counties area – 49.6 kPa (7.2 psi) max June 1 - Sept. 15[A]
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—49.6 kPa (7.2 psi) max June 1 - Sept. 15[A]
Maine–Androscoggin, Cumberland, Kennebec, Knox, Lincoln, Sagadahoc, and York Counties–49.6 kPa (7.2 psi) max May 1-Sept 15 (approval pending)
Michigan–Livingston, Macomb, Monroe, Oakland, Saint Clair, Washtenaw, and Wayne counties–53.8 kPa (7.8 psi) max June 1 - Sept 15
Missouri–Clay Jackson, and Platte counties–49.6 kPa (7.2 psi) max June 1 - Sept. 15[A]
Pennsylvania–Allegheny, Armstrong, Beaver, Butler, Fayette, Washington, and Westmoreland counties–53.8 kPa (7.8 psi) max June 1 - 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, Nararro, 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, VanZandt, 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 (approval pending)

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

differ significantly from that with gasolines having similar volatility characteristics.

5.7 *Water Tolerance*:

5.7.1 The term water tolerance is used to indicate the ability of a gasoline-oxygenate blend to dissolve water without phase separation. This may not be a problem with gasoline-ether blends, but it is of primary concern for alcohol-containing blends, as blends of gasoline with low-molecular weight alcohols generally will dissolve about 0.1 to 0.7 mass % of water under normal conditions, depending on the nature and amount of the alcohol(s) used, the specific hydrocarbons present, and the temperature of the blend. When blends are exposed to a greater amount of water than they can dissolve, they separate into an alcohol-rich aqueous phase, the volume of which can be significantly greater than that of the additional water, and an alcohol-poor hydrocarbon phase. As the aqueous phase can be highly corrosive to many metals and the engine cannot operate on it, such separation is very undesirable. Blends containing low-molecular weight alcohols are generally hygroscopic and can eventually absorb enough moisture from ambient air to cause separation. The problem of phase separation can usually be avoided if the fuels are sufficiently water-free initially and care is taken during distribution to prevent contact with water. To help ensure this, gasoline-alcohol blends shall be tested at the lowest temperatures to which they can be subjected, dependent on the time and place of intended use, as indicated in Table 13. The values in Table 13 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 13 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 separation of the fuel in storage tanks where temperatures may be lower than ambient.

NOTE 5—The values in Table 13 are taken from the U.S. Army Belvoir Research Development and Engineering Center's Report No. 316, entitled "A Predictive Study for Defining Limiting Temperatures and Their Application in Petroleum Product Specifications." This can be obtained as Publication AD756-420 from the National Technical Information Service, Springfield, VA 22151.

5.7.2 The water tolerance test procedure consists of cooling gasoline-alcohol blends under specified conditions to the appropriate temperature listed in Table 13. It is important to note that when cooling to a low temperature some gasoline-alcohol blends can take on a hazy appearance. This haze must be carefully distinguished from the phase separation test criterion described in Test Method D 6422 and must not be considered grounds for rejection of the fuel. This test must not be confused with that described in Section 6 (Workmanship), which is conducted at 21°C (70°F) or above, and for which the appearance of haze is proper grounds for rejection.

TABLE 13 Maximum Temperature for Phase Separation, °C[A]

	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.
[B]Alaska:												
Southern Region	−27.	−26.	−23.	−11.	1.	7.	9.	7.	1.	−9.	−19.	−23.

TABLE 13 *Continued*

State	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Temperature Conversion °F = (°C × 1.8) + 32°											
South Mainland N of 62° Latitude	−41.	−39.	−31.	−14.	−1.	7.	9.	5.	−2.	−18.	−32.	−41.
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.
[C] 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.
[D]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.
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.

TABLE 13 *Continued*

	Temperature Conversion °F = (°C × 1.8) + 32°											
State	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
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] 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.

[B] 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.

[C] The designated areas of California are divided by county as follows: *North Coast*—Alameda, Contra Costa, Del Norte, Humbolt, 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 (excepting 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 Bernadino, 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).

[D] 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.

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

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 ambient temperature or 21°C (70°F), whichever is higher.

6.2 Fuel to be used in this test shall not be cooled below about 15°C (59°F) or its temperature at the time the sample was taken, whichever is lower, as cooling of gasoline-oxygenate blends can produce changes in appearance that are not reversed on rewarming.

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

7. Test Methods

7.1 The requirements of this specification shall be determined in accordance with the methods listed below. Refer to the listed test methods to determine applicability or required modifications for use with gasoline-oxygenate blends.

7.1.1 *Distillation*—Test Method D 86.

7.1.2 *Vapor-Liquid Ratio*—Test Method D 2533 has procedures for determining vapor-liquid (*V/L*) ratios for both gasoline and gasoline-oxygenate blends. Because some oxygenates are miscible with the glycerin used in one procedure, another procedure using mercury as the confining fluid is provided for gasoline-oxygenate blends. Either procedure may be used to determine *V/L* for gasoline. Test Method D 5188 is an evacuated chamber method for determining temperatures for vapor-liquid ratios between 8 to 1 and 75 to 1. It may be used for gasoline and gasoline-oxygenate blends.

7.1.3 *Vapor Pressure*—Test Methods D 4953, D 5190, D 5191, or D 5482.

7.1.4 *Corrosion, for Copper*, Test Method D 130, 3 h at 50°C (122°F).

7.1.5 *Solvent-Washed Gum Content*—Test Method D 381, air jet apparatus.

7.1.6 *Sulfur*—Test Methods D 1266, D 2622, D 3120, or D 5453. With Test Method D 3120, fuels with sulfur content greater than 100 ppm (0.0100 mass %) must be diluted with *iso*octane. The dilution of the sample may result in a loss of precision. Test Method D 3120 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 D 3341 or D 5059 (Test Methods A or B). For lead levels below 0.03 g/L (0.1 g/U.S. gal) use Test Methods D 3237 or D 5059 (Test Method C).

7.1.8 *Oxidation Stability*—Test Method D 525.

7.1.9 *Oxygenate Detection*—Test Methods D 4815, D 5599, or D 5845. 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 D 4815 and D 5599 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 these test methods are reported in mass %. Test Method D 4815 includes procedures for calculating oxygenate concentration in volume % and mass oxygen content using the mass % oxygenate results.

7.1.10 *Water Tolerance*—See Test Method D 6422.

8. Precision and Bias [11]

8.1 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.

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

8.2.1 The following statements apply to the precision and bias of DI, which is a derived quantity not addressed in any other standard.[12]

8.2.2 The precision of DI is a function of the individual precisions of the 10 %, 50 %, and 90 % evaporated temperatures from Test Method D 86. 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.

8.2.3 *Repeatability*— The difference between two successive DI determinations using Test Method D 86 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.

8.2.4 The repeatability value was calculated using the precision data from Test Method D 86 and average distillation characteristics from the 1994 through 1998 ASTM Committee D-2 Interlaboratory Crosscheck Program for Motor Gasoline and from the 1997 and 1998 ASTM Committee D-2 Interlaboratory Crosscheck Program for Reformulated Gasoline.

8.2.5 *Reproducibility*— The difference between two single and independent DI determinations using Test Method D 86 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.

8.2.6 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 D-2 Interlaboratory Crosscheck Program for Motor Gasoline, the 1997 and 1998 ASTM Committee D-2 Interlaboratory Crosscheck Program for Reformulated Gasoline, the Auto/Oil Air Quality Improvement Research Program, the Auto/Oil AAMA Gasoline Inspections Program, and the 1995–1996 CRC volatility program.

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

9. Keywords

9.1 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; 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.

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[11] The calculations supporting the precision values shown are available from ASTM Headquarters. Request RR:D02-1468.

[12] A research report is available from ASTM Headquarters. Request D02–1468.

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 D 2699 or D 2885) and the Motor method (Test Methods D 2700 or D 2885). 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):

$$AKI = (RON + MON)/2 \tag{X1.1}$$

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."[13]

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)[14] 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 be guided also 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 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.

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[13] Details of this regulation can be found in Code of Federal Regulations Title 16, Chapter 1, Subchapter C, part 306 (16 CFR306), U.S. Government Printing Office, Superintendent of Documents, Washington DC 20402.

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

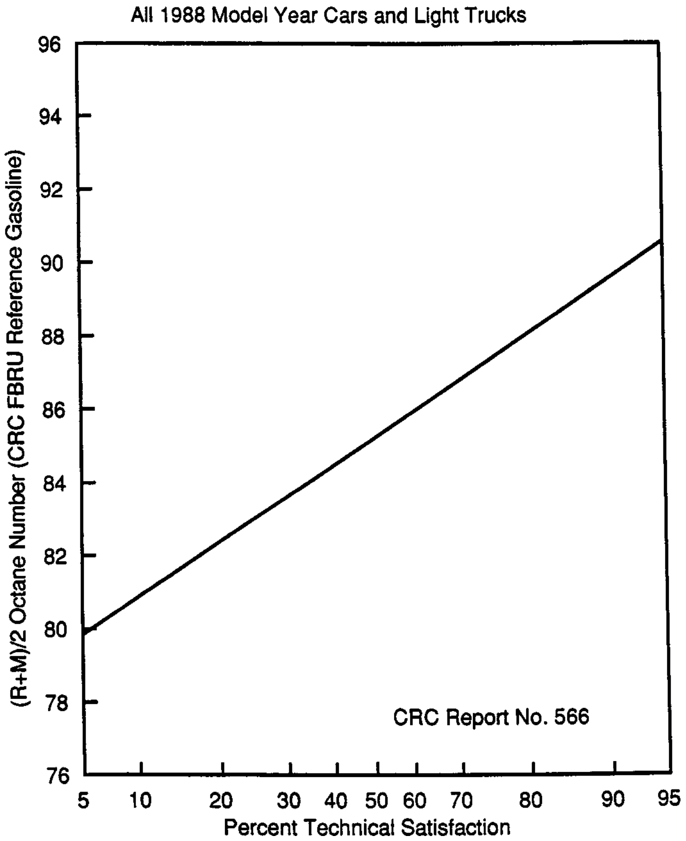

FIG. X1.1 An Example of the Statistical Distribution of Vehicle Antiknock Requirements

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.

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 D 2699) and Motor (Test Method D 2700) octane numbers. The repeatability and reproducibility variances for 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 Limits, Antiknock Index Units	Reproducibility Limits, Antiknock Index Units
83	0.2	0.7
85	0.2	0.7
87	0.2	0.7
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 limits were calculated from Research and Motor octane number results obtained by member laboratories of the ASTM National Exchange Group (NEG) participating in a cooperative testing program. The data obtained during the period 1980 through 1982 have been analyzed in accordance with RR:D02-1007, "Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants," Spring, 1973.

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 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.

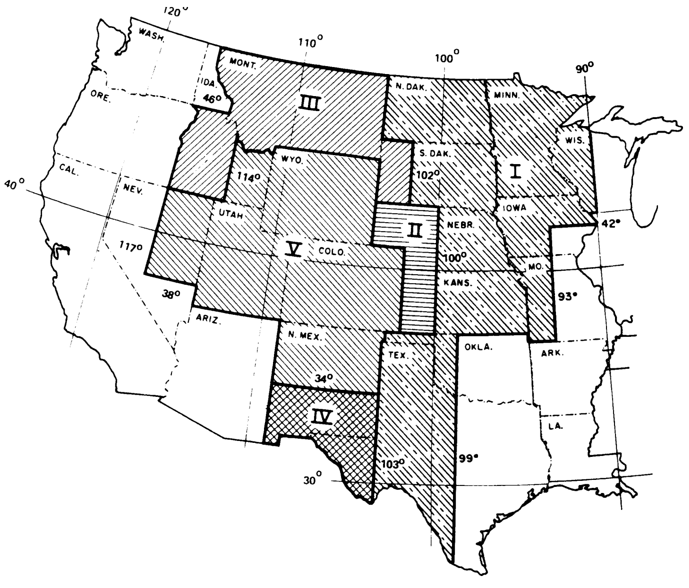

FIG. X1.2 Reduction in Vehicle Antiknock Requirements for Altitude[A,B]

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.

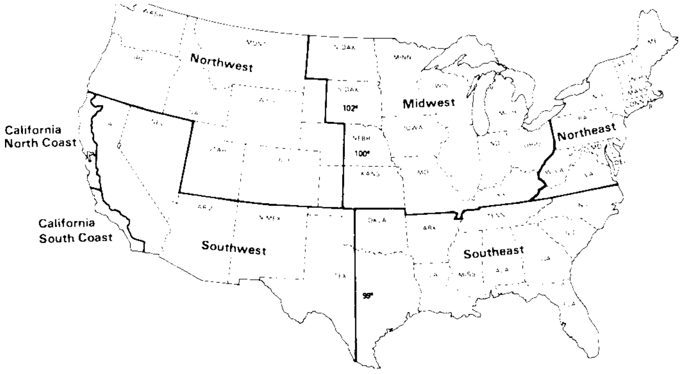

FIG. X1.3 Reduction in Vehicle Antiknock Requirements for Weather[A]

	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.

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 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 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 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.

X1.8.4 For sea-level areas outside of the United States where vapor pressure requirements are not as restrictive as those specified by EPA, 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.

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 D 4953, D 5190, D 5191, or D 5482 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 tested in Test Method D 2533. The *V/L* increases with temperature for a given fuel. Because some oxygenates are miscible with the glycerin confining fluid, Test Method D 2533 has been modified so mercury can also be used as a confining fluid. Either procedure may be used for determining *V/L* of gasoline. The mercury confining fluid shall be used for gasoline-oxygenate blends. Test Method D 5188 is an evacuated chamber method for determining temperatures for vapor-liquid ratios between 8 to 1 and 75 to 1. Test Method D 5188 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 vary from vehicle to vehicle and with operating conditions. The tendency of a fuel to cause vapor lock, as evidenced by loss of power during full-throttle accelerations, is indicated by the gasoline temperature at a *V/L* of approximately 20. A similar relationship for gasoline-oxygenate blends has also been determined. The temperature at which the maximum *V/L* 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 Three techniques for estimating temperature-*V/L* values using vapor pressure (Test Methods D 4953, D 5190, D 5191, or D 5482) and distillation (Test Method D 86) results are given in Appendix X2; they apply to gasoline only.

X1.12 Distillation

X1.12.1 Test Method D 86 for distillation provides another measure of the volatility of fuels. Table 1 designates the limits for end-point 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 end-point 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 warmup driveability performance. This relationship can be expressed by a Driveability Demerit model that can estimate vehicle driveability demerits during cold start and warmup 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 Driveability Index (DI = $1.5\ T_{10} + 3.0\ T_{50} + 1.0\ T_{90}$), as shown in Table 1, 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.[15]

X1.13 Corrosion

X1.13.1 Fuels must pass the copper strip corrosion test to minimize corrosion in fuel systems due to sulfur compounds in the fuel. Some fuels corrode fuel system metals other than copper, but there are no ASTM test methods to evaluate corrosion of these metals. Depending on the type and concentration of oxygenate, gasoline-oxygenate blends can corrode metals such as zinc, magnesium, aluminum, steel, and terne. However, at this time there is no test method with a known correlation to field performance. Consequently, additional corrosion tests are needed.

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, etc. Solvent-washed gum consists of fuel-insoluble gum and fuel-soluble gum. The fuel-insoluble portion can clog fuel filters. Both 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.

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.

X1.15 Sulfur

X1.15.1 The limit on sulfur content is included to protect against 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 Water Tolerance

X1.17.1 Water tolerance is the ability of a fuel to dissolve water without phase separation. It is not of concern for gasoline because of the very low solubility of water in hydrocarbons. Water tolerance is of some concern with gasoline-ether blends because of the limited solubility of ethers in water, but it is of great concern for gasoline-alcohol blends because of the very high solubility of alcohols in water. As such, Test Method D 6422 has been developed to determine the water tolerance (phase separation) characteristics of gasoline-alcohol blends. If the amount of water exceeds the water tolerance limit of the blend, the fuel will separate into a lower alcohol-rich aqueous phase and an upper alcohol-lean hydrocarbon phase. The resultant aqueous phase is not suitable as an automotive fuel and may be corrosive to many metals. Similarly, the hydrocarbon portion may also not be suitable as a fuel since removal of the alcohol component will change the volatility and antiknock characteristics.

X1.17.2 The most imporant factor, besides the quantity of water contacted, which governs the water tolerance of a fuel is its temperature. As the temperature of the blend decreases, water tolerance decreases. Test Method D 6422 is intended to determine the ability of gasoline-alcohol blends to retain water in solution or in a stable suspension at the lowest temperature to which they are likely to be exposed in use. Some other factors that affect water tolerance are alcohol concentration and aromatics content of the fuel.

X1.17.3 With some gasoline-oxygenate blends, formation of a haze may occur when filling a storage tank that contains water bottoms, while commingling of gasoline-oxygenate blends with gasoline, or when a sufficient decrease in temperature occurs. However, the haze may not be stable and the fuel will clear usually in a short period of time.

X1.17.4 A more critical water tolerance concern is the potential increase in storage tank water bottoms. This can occur when some gasoline-oxygenate blends and gasoline-alcohol blends in particular are added to a tank that contains

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[15] 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.

sufficient water to extract some or all of the oxygenate component from the fuel.

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

X2.1 Scope

X2.1.1 Three techniques are presented here for estimating temperature-*V/L* data from vapor pressure and distillation test results[16] on gasolines only. They are provided for use as a guideline when *V/L* data measured by Test Method D 2533 are not available. One method is designed for computer processing, one is a simpler linear technique, while the other is a nomogram form of this linear equation.

X2.1.2 These techniques are not optional procedures for measuring *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 D 2533 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 gasolines. 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; X2.2.2.6-X2.2.2.8 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 from vapor pressure (Test Methods D 4953, D 5190, D 5191, or D 5482) and distillation (Test Method D 86) 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,

$$H = G - E, °C, \tag{X2.1}$$

P = vapor pressure, kPa,

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

$$R = H/Q, \text{ except that if } H/Q \text{ is greater than 6.7, make } R = 6.7. \tag{X2.3}$$

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

$$A = 102.859 - 1.36599P + 0.009617\,P^2 - 0.000028281P^3 + 207.0097/P \tag{X2.4}$$

$$B = -5.36868 + 0.910540Q - 0.040187\,Q^2 + 0.00057774Q^3 + 0.254183/Q \tag{X2.5}$$

$$\begin{aligned} S = {} & -0.00525449 - 0.3671362/(P - 9.65) - 0.812419/(P - 9.65)^2 \\ & + 0.0009677R - 0.0000195828R^2 - 3.3502318R/P^2 \\ & + 1241.1531R/P^4 - 0.06630129R^2/P + 0.00627839R^3/P \\ & + 0.0969193R^2/P^2 \end{aligned} \tag{X2.6}$$

$$C = 0.34205P + 0.55556/S \tag{X2.7}$$

$$D = 0.62478 - 0.68964R + 0.132708R^2 - 0.0070417R^3 + 5.8485/R \tag{X2.8}$$

X2.2.2.3 If *A*, *B*, *C*, and *D*, are to be obtained from charts, read them from Fig. X2.1 through, Fig. X2.2 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:

$$T4 = A + B \tag{X2.9}$$

$$T45 = F + 0.125H + C \tag{X2.10}$$

$$T10 = T4 + 0.146341\,(T45 - T4) + D \tag{X2.11}$$

$$T20 = T4 + 0.390244\,(T45 - T4) + 1.46519D \tag{X2.12}$$

$$T30 = T4 + 0.634146\,(T45 - T4) + D \tag{X2.13}$$

where:

*T*4, *T*10, *T*20, *T*30, and *T*45 are estimated temperatures at *V/L* ratios, 4, 10, 20, 30, and 45.

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:

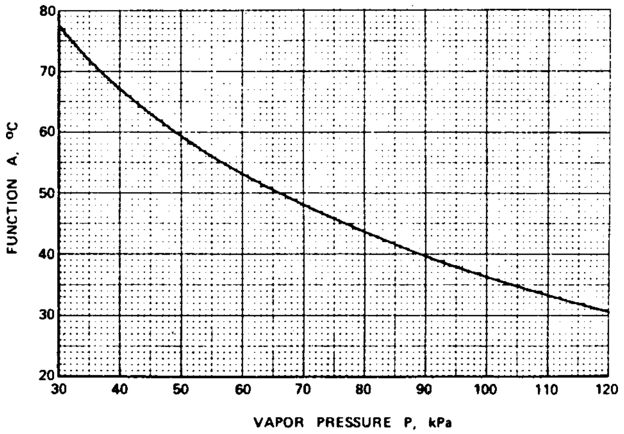

FIG. X2.1 Function *A* versus Vapor Pressure *P*

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[16] 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 D-2 to adapt it for computer processing, as well as the linear equation and the nomogram.

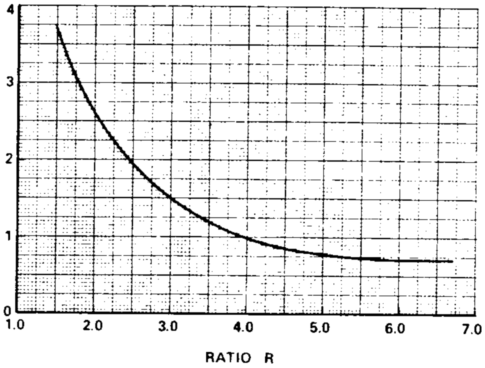


FIG. X2.2 Function *D* versus Ratio *R*

$$\begin{aligned} TX = {} & T4\left(\frac{X-10}{4-10}\times\frac{X-30}{4-30}\times\frac{X-45}{4-45}\right) \\ & + T10\left(\frac{X-4}{10-4}\times\frac{X-30}{10-30}\times\frac{X-45}{10-45}\right) \\ & + T30\left(\frac{X-4}{30-4}\times\frac{X-10}{30-10}\times\frac{X-45}{30-45}\right) \\ & + T45\left(\frac{X-4}{45-4}\times\frac{X-10}{45-10}\times\frac{X-30}{45-30}\right) \end{aligned} \quad \text{(X2.14)}$$

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 If inch-pound units are used, establish input data from vapor pressure (Test Methods D 4953, D 5190, D 5191, or D 5482) and distillation (Test Method D 86) 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,

$$H = G - E,\ ^\circ\text{F} \quad \text{(X2.15)}$$

P = vapor pressure, psi,

$$Q + F - E,\ ^\circ\text{F, and} \quad \text{(X2.16)}$$

$R = H/Q$, except that if H/Q is greater than 6.7, make R = 6.7. (X2.17)

X2.2.2.7 If *A*, *B*, *C*, and *D* are to be calculated in inch-pound units, use the following equations:

$$A = 217.147 - 16.9527P + 0.822909P^2 - 0.0166849P^3 + 54.0436/P \quad \text{(X2.18)}$$

$$B = -9.66363 + 0.910540Q - 0.0223260Q^2 + 0.000178314Q^3 + 0.823553/Q \quad \text{(X2.19)}$$

$$\begin{aligned} S = {} & -0.00525449 - 0.0532486/(P-1.4) \\ & - 0.0170900/(P-1.4)^2 + 0.0009677R - \\ & 0.0000195828R^2 - 0.0704753R/P^2 + 0.549224R/P^4 \\ & - 0.00961619R^2/P + 0.000910603R^3/P \\ & + 0.00203879R^2/P^2 \end{aligned} \quad \text{(X2.20)}$$

$$C = 4.245P + 1.0/S \quad \text{(X2.21)}$$

$$D = 1.12460 - 1.24135R + 0.238875R^2 - 0.0126750R^3 + 10.5273/R \quad \text{(X2.22)}$$

X2.2.2.8 If *A*, *B*, *C*, and *D* are to be obtained from charts in inch-pound units, read them from Fig. X2.3 through Fig. X2.4, respectively.

X2.2.2.9 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.

X2.3 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 through X2.1.4 must be kept in mind when use is made of this procedure.

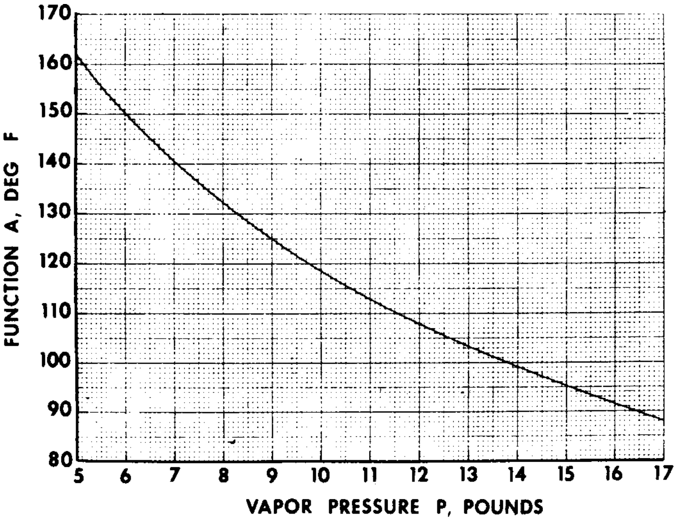


FIG. X2.3 Function *A* versus Vapor Pressure *P*

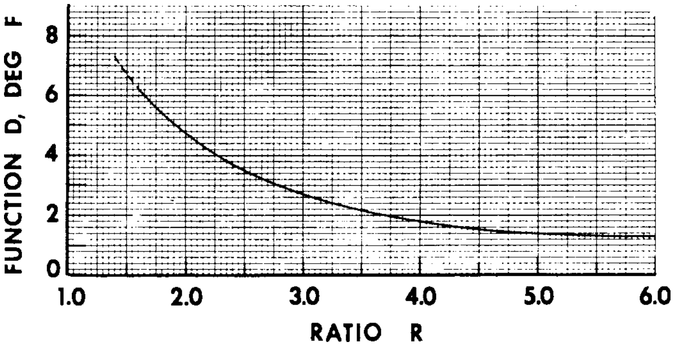


FIG. X2.4 Function *D* versus Ratio *R*

X2.3.2 *Procedure*—Obtain 10 % evaporated and 50 % evaporated points from the distillation curve (Test Method D 86) along with the vapor pressure value (Test Methods D 4953, D 5190, D 5191, or D 5482); apply these directly in the equation.

$$T_{V/L=20} = 52.47 - 0.33\,(\mathrm{VP}) + 0.20\,T_{10} + 0.17\,T_{50} \qquad \text{(X2.23)}$$

where:

$T_{V/L\ =20}$ = temperature, °C, at V/L of 20:1,
VP = vapor pressure, kPa,
T_{10} = distillation temperature, °C, at 10 % evaporated, and
T_{50} = distillation temperature, °C, at 50 % evaporated.

or in the inch-pound customary unit equation:

$$T_{V/L=20} = 114.6 - 4.1\,(\mathrm{VP}) + 0.20\,T_{10} + 0.17\,T_{50} \qquad \text{(X2.24)}$$

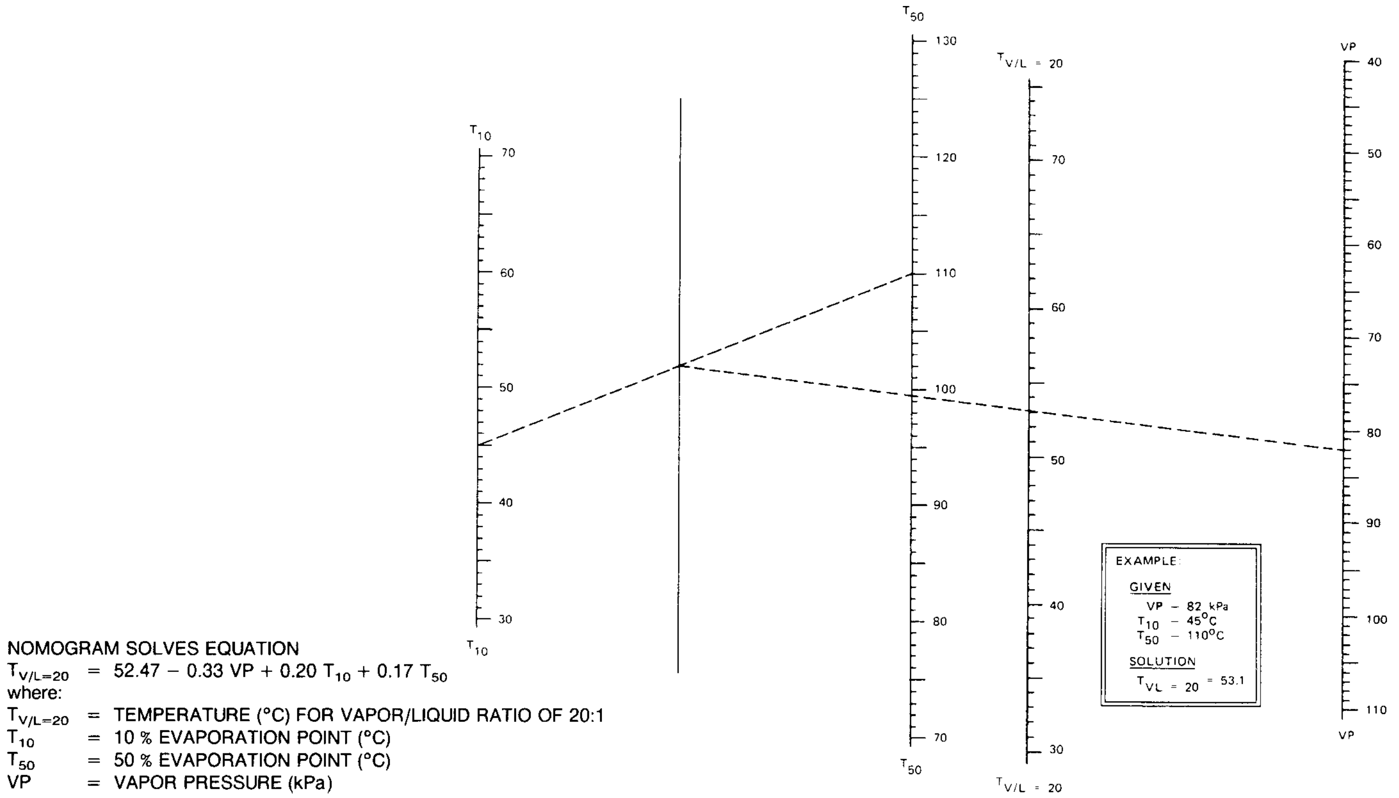
where:

$T_{V/L\ =20}$ = 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.

X2.4 Nomogram Method

X2.4.1 *Summary*—Two nomograms have been developed and are included herein (Figs. X2.5 and X2.6) to provide the same function as the linear equations procedure outlined above. Fig. X2.5 is in SI units and Fig. X2.6 is in inch-pound units. The nomograms are based on the two equations and the same limitations apply to their use in estimating *V/L* (20) temperatures.

X2.4.2 *Procedure*—Obtain 10 % evaporated and 50 % evaporated points from the distillation curve (Test Method D 86) along with the vapor pressure value (Test Methods D 4953, D 5190, D 5191, or D 5482). Select the SI unit (Fig. X2.5) or inch-pound unit (Fig. X2.6) nomogram based on the units of T_{10}, T_{50}, and VP. Using a straightedge, locate the intercept on the line between the "T_{10} and T_{50}" scales after selecting the applicable T_{10} and T_{50} values. From this intercept and the proper point on the "VP" scale, a second intercept can



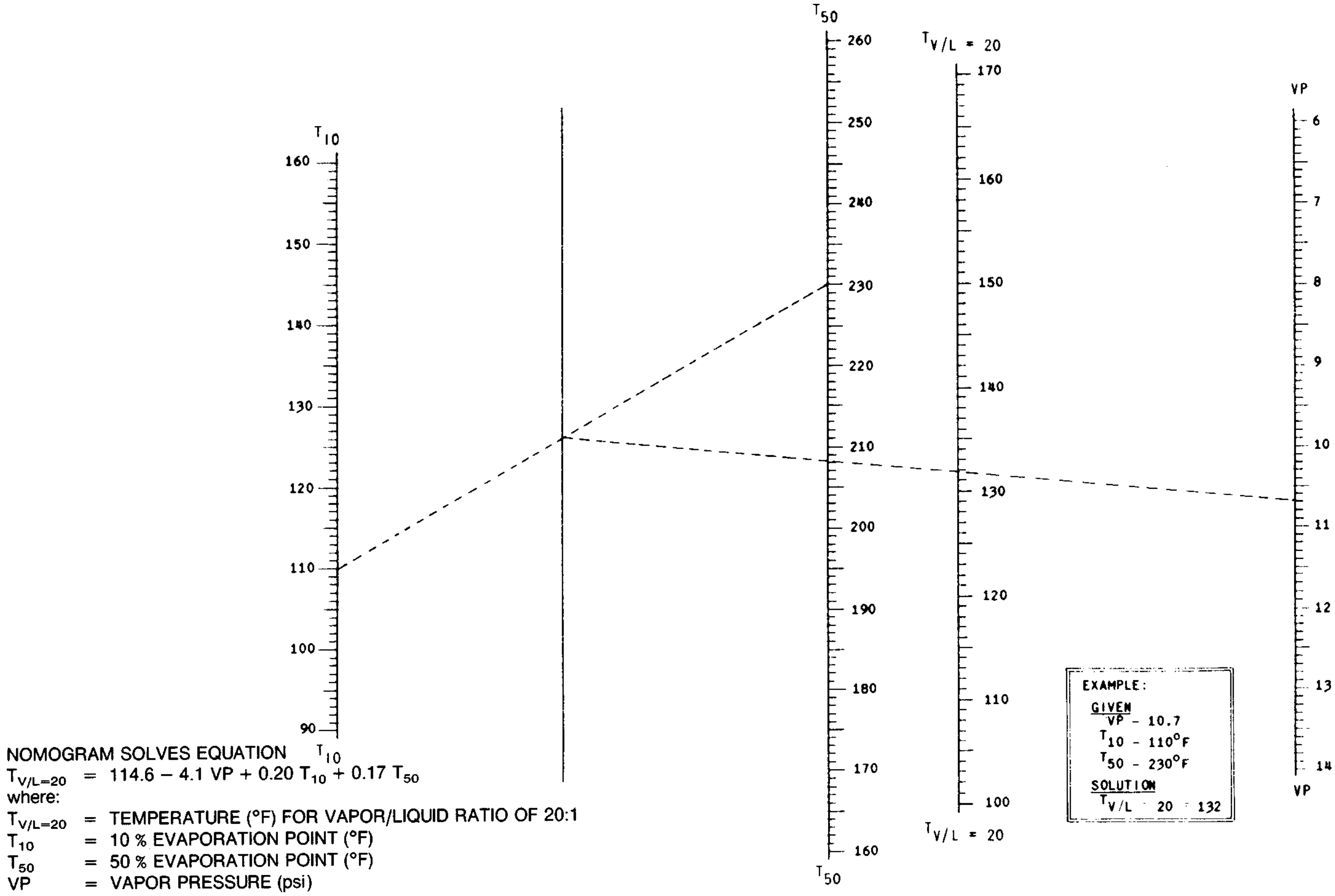
NOMOGRAM SOLVES EQUATION

$T_{V/L=20}$ = 52.47 − 0.33 VP + 0.20 T_{10} + 0.17 T_{50}

where:

$T_{V/L=20}$ = TEMPERATURE (°C) FOR VAPOR/LIQUID RATIO OF 20:1
T_{10} = 10 % EVAPORATION POINT (°C)
T_{50} = 50 % EVAPORATION POINT (°C)
VP = VAPOR PRESSURE (kPa)

FIG. X2.5 Relationship Between Gasoline Volatility and Temperature for *V/L* Ratio at Sea Level—SI Units



NOMOGRAM SOLVES EQUATION

$T_{V/L=20}$ = 114.6 − 4.1 VP + 0.20 T_{10} + 0.17 T_{50}

where:

$T_{V/L=20}$ = TEMPERATURE (°F) FOR VAPOR/LIQUID RATIO OF 20:1

T_{10} = 10 % EVAPORATION POINT (°F)

T_{50} = 50 % EVAPORATION POINT (°F)

VP = VAPOR PRESSURE (psi)

FIG. X2.6 Relationship Between Gasoline Volatility and Temperature for *V/L* Ratio of 20 at Sea Level—Inch-Pound Units

be obtained on the "$T_{V/L = 20}$" scale to provide the desired value directly.

X2.5 Precision

X2.5.1 The precision of agreement between temperature-*V/L* data estimated by any one of these three techniques and data obtained by Test Method D 2533 has not been established.

X3. SUMMARY OF 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 The EPA maximum vapor pressure limits of 7.8 psi and 9.0 psi are shown in Table 1 as Classes AA and A, respectively. 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 D through 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.

X3.1.4 EPA regulations allow 1.0 psi higher values for gasoline-ethanol blends than the EPA limits shown in Table 1 and Table 4 for the period May 1 through September 15. To qualify, the gasoline-ethanol blends must contain 9 to 10 volume % ethanol. Higher vapor pressure limits for gasoline-ethanol blends under state regulations vary for other time periods, and specific states of interest should be contacted to determine if higher limits apply.

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 EPA. EPA regulations limit their maximum concentrations to 0.05 g lead per U.S. gallon (0.013 g/L) and 0.005 g of phosphorus per U.S. gallon (0.0013 g/L) (see Test Method D 3231), 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 per U.S. gallon (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) (*a*) Hydrocarbons;

(b) (*b*) Aliphatic ethers;

(c) (*c*) Aliphatic alcohols other than methanol;

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

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

(2) The fuel must contain no more than 2.0 mass % oxygen except fuels containing aliphatic ethers and/or alcohols (excluding methanol) must contain no more than 2.7 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 D 4814 – 88 for at least one of the Seasonal and Geographical Volatility Classes specified in the standard.

NOTE X3.1—Opinion varies as to whether the EPA "substantially similar" rule requires unleaded gasolines that do not contain oxygenates to meet ASTM specifications.

X3.3.2 *Waivers*:

X3.3.2.1 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 waviers, EPA should be contacted.

X3.3.2.2 Gasoline-ethanol blends are not required by EPA to meet Specification D 4814 volatility limits (see X3.1.4 for vapor pressure limits). EPA has specified in all other waivers that the volatility of the finished gasoline-oxygenate blend must comply with Specification D 439 or D 4814 climatic and geographical limits.

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.

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, 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 D 4814-95c. For some options, the addition of 10 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 For 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 D 5500-94. 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 D 5598-94.

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

X4.1 Scope

X4.1.1 Test Method D 4815 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 D 4815 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 D 4815 or equivalent test method).

X4.2.1.2 Determine the density or relative density of the gasoline-oxygenate blend (Test Methods D 287, D 1298, or D 4052).

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.

$$\text{Oxygen, Mass \%} = \frac{V_1 \times d_1 \times O_1 + V_2 \times d_2 \times O_2 \ldots + V_n \times d_n \times O_n}{V_b \times d_b} \times 100 \qquad \text{(X4.1)}$$

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 Alchol	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.

where:

V_n = 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,
V_b = 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 volume % ethanol and 2.0 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 mass % oxygen is calculated for this gasoline-oxygenate blend.

$$\text{Oxygen, Mass \%} = \frac{9.5 \times 0.7939 \times 0.3473 + 2.0 \times 0.7460 \times 0.1815}{100 \times 0.7450} \times 100 = 3.88 \qquad \text{(X4.2)}$$

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 D 287, D 1298, or D 4052) and oxygenate analysis (Test Method D 4815 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 may cause or contribute to a variety of problems including increased corrosivity, and decreased stability, filterability, and caloric value. Microbial processes in fuel systems may also cause or contribute to system damage.

X5.2 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 may affect fuel quality.

X5.3 Guide D 6469 provides personnel with limited microbiological background an understanding of the symptoms, occurrences, and consequences of chronic microbial contamination. Guide D 6469 also suggests means for detecting and controlling microbial contamination in fuels and fuel systems.

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