**Designation: D975 − 17**

# Standard Specification for Diesel Fuel Oils[1]

This standard is issued under the fixed designation D975; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

## 1. Scope*

1.1 This specification covers seven grades of diesel fuel oils suitable for various types of diesel engines. These grades are described as follows:

1.1.1 *Grade No. 1-D S15*—A special-purpose, light middle distillate fuel for use in diesel engine applications requiring a fuel with 15 ppm sulfur (maximum) and higher volatility than that provided by Grade No. 2-D S15 fuel.[2]

1.1.2 *Grade No. 1-D S500*—A special-purpose, light middle distillate fuel for use in diesel engine applications requiring a fuel with 500 ppm sulfur (maximum) and higher volatility than that provided by Grade No. 2-D S500 fuel.[2]

1.1.3 *Grade No. 1-D S5000*—A special-purpose, light middle distillate fuel for use in diesel engine applications requiring a fuel with 5000 ppm sulfur (maximum) and higher volatility than that provided by Grade No. 2-D S5000 fuels.

1.1.4 *Grade No. 2-D S15*—A general purpose, middle distillate fuel for use in diesel engine applications requiring a fuel with 15 ppm sulfur (maximum). It is especially suitable for use in applications with conditions of varying speed and load.[2]

1.1.5 *Grade No. 2-D S500*—A general-purpose, middle distillate fuel for use in diesel engine applications requiring a fuel with 500 ppm sulfur (maximum). It is especially suitable for use in applications with conditions of varying speed and load.[2]

1.1.6 *Grade No. 2-D S5000*—A general-purpose, middle distillate fuel for use in diesel engine applications requiring a fuel with 5000 ppm sulfur (maximum), especially in conditions of varying speed and load.

1.1.7 *Grade No. 4-D*—A heavy distillate fuel, or a blend of distillate and residual oil, for use in low- and medium-speed diesel engines in applications involving predominantly constant speed and load.

NOTE 1—A more detailed description of the grades of diesel fuel oils is given in X1.2.

NOTE 2—The Sxxx designation has been adopted to distinguish grades by sulfur rather than using words such as "Low Sulfur" as previously because the number of sulfur grades is growing and the word descriptions were thought to be not precise. S5000 grades correspond to the so-called "regular" sulfur grades, the previous No. 1-D and No. 2-D. S500 grades correspond to the previous "Low Sulfur" grades. S15 grades were not in the previous grade system and are commonly referred to as "Ultra-Low Sulfur" grades or ULSD.

1.2 This specification, unless otherwise provided by agreement between the purchaser and the supplier, prescribes the required properties of diesel fuels at the time and place of delivery.

1.2.1 Nothing in this specification shall preclude observance of federal, state, or local regulations which can be more restrictive.

NOTE 3—The generation and dissipation of static electricity can create problems in the handling of distillate diesel fuel oils. For more information on the subject, see Guide D4865.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

D56 Test Method for Flash Point by Tag Closed Cup Tester
D86 Test Method for Distillation of Petroleum Products and

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[1] This specification is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.E0 on Burner, Diesel, Non-Aviation Gas Turbine, and Marine Fuels.

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[2] This fuel complies with 40 CFR Part 80—Control of Air Pollution from New Motor Vehicles: Heavy–Duty Engines and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements: Final Rule. Regulation of Fuels and Fuel Additives: Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

Liquid Fuels at Atmospheric Pressure
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D482 Test Method for Ash from Petroleum Products
D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products
D613 Test Method for Cetane Number of Diesel Fuel Oil
D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D1552 Test Method for Sulfur in Petroleum Products by High Temperature Combustion and Infrared (IR) Detection or Thermal Conductivity Detection (TCD)
D1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)
D2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
D2500 Test Method for Cloud Point of Petroleum Products and Liquid Fuels
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
D2880 Specification for Gas Turbine Fuel Oils
D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
D3117 Test Method for Wax Appearance Point of Distillate Fuels (Withdrawn 2010)[4]
D3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
D3828 Test Methods for Flash Point by Small Scale Closed Cup Tester
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination
D4308 Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
D4539 Test Method for Filterability of Diesel Fuels by Low-Temperature Flow Test (LTFT)
D4737 Test Method for Calculated Cetane Index by Four Variable Equation
D4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
D5304 Test Method for Assessing Middle Distillate Fuel Storage Stability by Oxygen Overpressure
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D5771 Test Method for Cloud Point of Petroleum Products and Liquid Fuels (Optical Detection Stepped Cooling Method)
D5772 Test Method for Cloud Point of Petroleum Products and Liquid Fuels (Linear Cooling Rate Method)
D5773 Test Method for Cloud Point of Petroleum Products and Liquid Fuels (Constant Cooling Rate Method)
D5842 Practice for Sampling and Handling of Fuels for Volatility Measurement
D5854 Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products
D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
D6079 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)
D6217 Test Method for Particulate Contamination in Middle Distillate Fuels by Laboratory Filtration
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6371 Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels
D6468 Test Method for High Temperature Stability of Middle Distillate Fuels
D6469 Guide for Microbial Contamination in Fuels and Fuel Systems
D6751 Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
D6890 Test Method for Determination of Ignition Delay and Derived Cetane Number (DCN) of Diesel Fuel Oils by Combustion in a Constant Volume Chamber
D6898 Test Method for Evaluating Diesel Fuel Lubricity by an Injection Pump Rig
D7039 Test Method for Sulfur in Gasoline, Diesel Fuel, Jet Fuel, Kerosine, Biodiesel, Biodiesel Blends, and Gasoline-Ethanol Blends by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry
D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
D7094 Test Method for Flash Point by Modified Continuously Closed Cup (MCCCFP) Tester
D7170 Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Fixed Range Injection Period, Constant Volume Combustion Chamber Method

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

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

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

D7371 Test Method for Determination of Biodiesel (Fatty Acid Methyl Esters) Content in Diesel Fuel Oil Using Mid Infrared Spectroscopy (FTIR-ATR-PLS Method)

D7467 Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)

D7545 Test Method for Oxidation Stability of Middle Distillate Fuels—Rapid Small Scale Oxidation Test (RSSOT)

D7619 Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter

D7668 Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Ignition Delay and Combustion Delay Using a Constant Volume Combustion Chamber Method

D7688 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR) by Visual Observation

D7689 Test Method for Cloud Point of Petroleum Products and Liquid Fuels (Mini Method)

D7861 Test Method for Determination of Fatty Acid Methyl Esters (FAME) in Diesel Fuel by Linear Variable Filter (LVF) Array Based Mid-Infrared Spectroscopy

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

E1064 Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration

2.2 *Other Documents:*

26 CFR Part 48 Manufacturers and Realtors Excise Taxes[5]

40 CFR Part 80 Regulation of Fuels and Fuel Additives[5]

API RP 2003 Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents[6]

EN 14078 Liquid petroleum products—Determination of fatty acid methyl esters (FAME) in middle distillates—Infrared spectroscopy method[7]

EN 15751 Automotive fuels - Fatty acid methyl ester (FAME) fuel and blends with diesel fuel - Determination of oxidation stability by accelerated oxidation method[7]

ISO 4406 Hydraulic Fluid Power—Fluids—Method for Coding the Level of Contamination by Solid Particles[6]

ISO 16889 Hydraulic Fluid Power—Filters—Multi-pass Method for Evaluating Filtration Performance of a Filter Element

## 3. Terminology

3.1 *Definitions:*

3.1.1 *additive, n—in fuel oils,* a substance added to fuel oil at a blend level not greater than 1 % by volume of the finished fuel.

3.1.1.1 *Discussion*—Additives are generally included in finished fuel oil to enhance performance properties (for example, cetane number, lubricity, cold flow, etc.).

3.1.1.2 *Discussion*—Additives that contain hydrocarbon oil blended with other substances may exclude the hydrocarbon oil portion for determination of the volume percent of the additive in the finished fuel.

3.1.2 *alternative blendstock, n—in fuel oils,* a non-hydrocarbon oil substance added to fuel oil at blend levels greater than 1 % by volume of the finished fuel.

3.1.2.1 *Discussion*—An alternative blendstock should normally have an industry consensus standard or an annex in this specification that defines its physical and chemical properties.

3.1.2.2 *Discussion*—See Appendix X7 for guidance regarding new materials for #1-D and #2-D grades of diesel fuels.

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

3.1.4 *biodiesel blend (BXX), n*—blend of biodiesel fuel with diesel fuel oils.

3.1.4.1 *Discussion*—In the abbreviation, BXX, the XX represents the volume percentage of biodiesel fuel in the blend.

3.1.5 *hydrocarbon oil, n*—a homogeneous mixture with elemental composition primarily of carbon and hydrogen that may also contain sulfur, oxygen, or nitrogen from residual impurities and contaminants associated with the fuel's raw materials and manufacturing processes and excluding added oxygenated materials.

3.1.5.1 *Discussion*—Neither macro nor micro emulsions are included in this definition since neither are homogeneous mixtures.

3.1.5.2 *Discussion*—Examples of excluded oxygenated materials are alcohols, esters, ethers, and triglycerides.

3.1.5.3 *Discussion*—The hydrocarbon oil may be manufactured from a variety of raw materials, for example petroleum (crude oil), oil sands, natural gas, coal, and biomass. Appendix X7 discusses some matters for consideration regarding the use of diesel fuels from feedstocks other than petroleum.

3.1.6 *switch loading, n—of liquid fuels*, the practice of loading low vapor pressure product (for example, diesel fuel) into an empty or near-empty fixed or portable container that previously held a high or intermediate vapor pressure product (such as gasoline or solvent) without prior compartment cleaning treatment and inert gas purging; and the reverse procedure where a high vapor pressure product is added to a container that previously held a low vapor pressure product.

3.1.6.1 *Discussion*—Since middle distillate fuels have flash points above 38 °C, during normal distribution of these fuels, the atmosphere above the fuels in a container such as a tanker truck, rail car, or barge, is normally below the lower explosive limit, so there is low risk of fire or explosion should an electrostatic discharge (spark) occur. However, when the previous load in the compartment was a volatile, flammable fuel such as gasoline, and if some residual fuel vapor or mist

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

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[7] Available from the National CEN members listed on the CEN website (www.cenorm.be) or from the CEN/TC 19 Secretariat (astm.@nen.nl).

remains in the compartment, and the container has a mixture of air and fuel vapor or mist (that is, not purged with an inert gas), then there is a risk that the atmosphere in the container being filled could be in the explosive range creating a hazard should an electrostatic discharge occur.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *S(numerical specification maximum)*—indicates the maximum sulfur content, in weight ppm (µg/g), allowed by this specification in a diesel fuel grade.

3.2.1.1 *Discussion*—Of the seven diesel fuel grades specified in this standard, six have important distinguishing maximum sulfur regulatory requirements. These are Grades No. 1-D S15, No. 1-D S500, No. 1-D S5000, No. 2-D S15, No. 2-D S500 and No. 2-D S5000. The seventh grade, No. 4-D, is distinguished from these other grades by many major properties in addition to sulfur (unregulated maximum), and therefore is not included in this designation system. Thus, Grade No. 4-D does not have the designation S20000 as part of its grade name.

## 4. Sampling, Containers, and Sample Handling

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

4.2 Correct sampling procedures are critical to obtaining a representative sample of the diesel fuel oil to be tested. Refer to Appendix X2 for recommendations. The recommended procedures or practices provide techniques useful in the proper sampling or handling of diesel fuels.

## 5. Test Methods

5.1 The requirements enumerated in this specification shall be determined in accordance with the following methods:

5.1.1 *Flash Point*—Test Methods D93, except where other methods are prescribed by law. For all grades, Test Methods D3828 and D7094 may be used as alternatives with the same limits. For Grades No. 1-D S15, No. 1-D S500 , No. 1-D S5000, No. 2-D S15, No. 2-D S500, and No. 2-D S5000, Test Method D56 may be used as an alternative with the same limits, provided the flash point is below 93 °C and the viscosity is below 5.5 mm$^2$/s at 40 °C. This test method will give slightly lower values. In cases of dispute, Test Methods D93 shall be used as the referee method. Test Method D56 may not be used as the alternative method for Grade No. 4-D because its minimum viscosity limit is 5.5 mm$^2$/s at 40 °C.

5.1.2 *Cloud Point*—Test Method D2500. For all fuel grades in Table 1, the automatic Test Methods D5771, D5772, D5773, or D7689 may be used as alternatives with the same limits. Test Method D3117 can also be used since it is closely related to Test Method D2500. In case of dispute, Test Method D2500 shall be the referee method.

5.1.3 *Water and Sediment*—Test Method D2709 is used for fuel Grades No. 1-D S15, No. 1-D S500, No. 1-D S5000, No. 2-D S15, No. 2-D S500, and No. 2-D S5000. Test Method D1796 is used for Grade No. 4-D. See Appendix X8 for additional guidance on water and sediment in Grades No. 1-D and 2-D diesel fuels.

5.1.4 *Carbon Residue*—Test Method D524 is used for fuel Grades No. 1-D S15, No. 1-D S500, No. 1-D S5000, No. 2-D S15, No. 2-D S500 and No. 2-D S5000. Grade No. 4-D does not have a limit for carbon residue.

5.1.5 *Ash*—Test Method D482 is used for all grades in Table 1.

5.1.6 *Distillation*—Test Method D86 is used for Grades No. 1-D S15, No. 1-D S500, No. 1-D S5000, No. 2-D S15, No. 2-D S500, and No. 2-D S5000. For all grades, Test Method D2887 or Test Method D7345 can be used as an alternative. Results from Test Method D2887 shall be reported as “Predicted D86” results by application of the correlation in Appendix X4 of Test Method D2887 to convert the values. Results from Test Method D7345 shall be reported as “Predicted D86” results by application of the corrections described in Test Method D7345 to convert to D86 equivalent values. In case of dispute, Test Method D86 shall be the referee method. Grade No. 4-D does not have distillation requirements.

5.1.7 *Viscosity*—Test Method D445 is used for all fuel grades in Table 1. Bias-corrected values from Test Method D7042 may be used as alternative results for Test Method D445 on Grades No. 1-D and No. 2-D with the same limits. Section 15, Precision and Bias, of Test Method D7042 contains bias-correction information. In case of dispute, Test Method D445 shall be used as the referee method.

5.1.8 *Sulfur*—The following list shows the referee test methods and alternative test methods for sulfur and the corresponding fuel grades to which each applies.

| Sulfur Test Method | Grades |
|---|---|
| D129 | No. 1-D S5000, No. 2-D S5000,<br>No. 4-D |
| D1266 | No. 1-D S500, No. 2-D S500 |
| D1552 | No. 1- D S5000, No. 2-D S5000,<br>No. 4-D |
| D2622 (referee for S500, S5000, and No. 4 Grades) | All Grades |
| D3120 | No. 1-D S15, No. 2-D S15<br>No. 1-D S500, No. 2-D S500<br>(If the fuel contains biodiesel, this method may not be applicable as it is limited to oxygenates with a boiling range of 26 °C to 274 °C) |
| D4294 | No. 1-D S500, No. 2-D S500<br>No. 1- D S5000, No. 2-D S5000,<br>No. 4-D |
| D5453 (referee for S15 grades) | All Grades |
| D7039 | No. 1–D S15, No. 2–D S15<br>No. 1-D S500, No. 2-D S500 |
| D7220 | No. 1–D S15, No. 1–D S500<br>No. 2–D S15, No. 2–D S500 |

5.1.9 *Copper Corrosion*—Test Method D130, 3 h test at a minimum control temperature of 50 °C. This test method is used for fuel Grades No. 1-D S15, No. 1-D S500, No. 1-D S5000, No. 2-D S15, No. 2-D S500 and No. 2-D S5000. Grade No. 4-D does not have a copper corrosion requirement.

**TABLE 1 Detailed Requirements for Diesel Fuel Oils[A,B]**

| Property | ASTM Test Method[C] | Grade | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | No. 1-D S15 | No. 1-D S500[D] | No. 1-D S5000[E] | No. 2-D S15[F] | No. 2-D S500[D,F] | No. 2-D S5000[E,F] | No. 4-D[E] |
| Flash Point, °C, min. | D93 | 38 | 38 | 38 | 52[F] | 52[F] | 52[F] | 55 |
| Water and Sediment, percent volume, max | D2709 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | ... |
| | D1796 | ... | ... | ... | ... | ... | ... | 0.50 |
| Distillation Temperature, °C 90 %, percent volume recovered | D86 | | | | | | | |
| min | | ... | ... | ... | 282[F] | 282[F] | 282[F] | ... |
| max | | 288 | 288 | 288 | 338 | 338 | 338 | ... |
| Kinematic Viscosity, mm$^2$/S at 40 °C | D445 | | | | | | | |
| min | | 1.3 | 1.3 | 1.3 | 1.9[F] | 1.9[F] | 1.9[F] | 5.5 |
| max | ... | 2.4 | 2.4 | 2.4 | 4.1 | 4.1 | 4.1 | 24.0 |
| Ash percent mass, max | D482 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.10 |
| Sulfur, ppm (µg/g)[G] max | D5453 | 15 | ... | ... | 15 | ... | ... | ... |
| percent mass, max | D2622[H] | ... | 0.05 | 0.50 | ... | 0.05 | 0.50 | 2.00 |
| Copper strip corrosion rating, max (3 h at a minimum control temperature of 50 °C) | D130 | No. 3 | No. 3 | No. 3 | No. 3 | No. 3 | No. 3 | ... |
| Cetane number, min[I] | D613 | 40.[J] | 40.[J] | 40.[J] | 40.[J] | 40.[J] | 40.[J] | 30.[J] |
| One of the following properties must be met: | | | | | | | | |
| (1) Cetane index, min. | D976–80[H] | 40 | 40 | ... | 40 | 40 | ... | ... |
| (2) Aromaticity, percent volume, max | D1319[H] | 35 | 35 | ... | 35 | 35 | ... | ... |
| Operability Requirements | | | | | | | | |
| Cloud point, °C, max | D2500 | [K] | [K] | [K] | [K] | [K] | [K] | ... |
| or | | | | | | | | |
| LTFT/CFPP, °C, max | D4539/D6371 | | | | | | | |
| Ramsbottom carbon residue on 10 % distillation residue, percent mass, max | D524 | 0.15 | 0.15 | 0.15 | 0.35 | 0.35 | 0.35 | ... |
| Lubricity, HFRR @ 60 °C, micron, max | D6079/D7688 | 520 | 520 | 520 | 520 | 520 | 520 | ... |
| Conductivity, pS/m or Conductivity Units (C.U.), min | D2624/D4308 | 25[L] | 25[L] | 25[L] | 25[L] | 25[L] | 25[L] | ... |

[A] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.

[B] See Sections 6 and 7 for further statements on diesel fuel requirements.

[C] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 5.1.

[D] Under United States regulations, if Grades No. 1–D S500 or No. 2–D S500 are sold for tax exempt purposes then, at or beyond terminal storage tanks, they are required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb of the solid dye standard Solvent Red 26 per thousand barrels of diesel fuel or kerosine, or the tax must be collected.

[E] Under United States regulations, Grades No.1–D S5000, No. 2–D S5000, and No. 4–D are required by 40 CFR Part 80 to contain a sufficient amount of the dye Solvent Red 164 so its presence is visually apparent. At or beyond terminal storage tanks, they are required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb of the solid dye standard Solvent Red 26 per thousand barrels of diesel fuel or kerosine.

[F] When a cloud point less than −12 °C is specified, as can occur during cold months, it is permitted and normal blending practice to combine Grades No. 1 and No. 2 to meet the low temperature requirements. In that case, the minimum flash point shall be 38 °C, the minimum viscosity at 40 °C shall be 1.7 mm$^2$/s, and the minimum 90 % recovered temperature shall be waived.

[G] Other sulfur limits can apply in selected areas in the United States and in other countries.

[H] These test methods are specified in 40 CFR Part 80 for S500 grades.

[I] Where cetane number by Test Method D613 is not available, Test Method D4737 can be used as an approximation. Although biodiesel blends are excluded from the scope of Test Method D4737, the results of Test Method D4737 for up to B5 blends can be used as an approximation.

[J] Low ambient temperatures as well as engine operation at high altitudes may require the use of fuels with higher cetane ratings.

[K] It is unrealistic to specify low temperature properties that will ensure satisfactory operation at all ambient conditions. In general, cloud point (or wax appearance point) Low Temperature Flow Test, and Cold Filter Plugging Point Test may be used as an estimate of operating temperature limits for Grades No. 1–D S15; No. 2–D S15; No. 1–D S500; No. 2–D S500; and No. 1–D S5000 and No. 2–D S5000 diesel fuel oils. However, satisfactory operation below the cloud point (or wax appearance point) may be achieved depending on equipment design, operating conditions, and the use of flow-improver additives as described in X5.1.2. Appropriate low temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures. Test Methods D4539 and D6371 may be especially useful to estimate vehicle low temperature operability limits when flow improvers are used. Due to fuel delivery system, engine design, and test method differences, low temperature operability tests may not provide the same degree of protection in various vehicle operating classes. Tenth percentile minimum air temperatures for U.S. locations are provided in Appendix X5 as a means of estimating expected regional temperatures. The tenth percentile minimum air temperatures can be used to estimate expected regional target temperatures for use with Test Methods D2500, D4539, and D6371. Refer to X5.1.3 for further general guidance on test application.

[L] The electrical conductivity of the diesel fuel is measured at the time and temperature of the fuel at delivery. The 25 pS/m minimum conductivity requirement applies at all instances of high velocity transfer (7 m/s) but sometimes lower velocities, see 8.1 for detailed requirements) into mobile transport (for example, tanker trucks, rail cars, and barges).

5.1.10 *Cetane Number*—Test Method D613 is used for all fuel grades in Table 1. Test Method D6890, Test Method D7170, or Test Method D7668 (see Note 4) may be used for all No. 1-D and No. 2-D grades with the DCN result being compared to the cetane number specification requirement of 40. Test Method D613 shall be the referee method.

NOTE 4—Precision from Test Method D7668 were obtained from results produced by laboratories using externally obtained pre-blended calibration reference material.

5.1.11 *Cetane Index*—Test Methods D976–80 is used for fuel Grades No. 1-D S15, No. 1-D S500, No. 2-D S15 and No. 2-D S500. Grades No. 1-D S5000, No. 2-D S5000 and No. 4-D do not have an aromatics content requirement, so do not use this test method as a surrogate for aromatics content.

5.1.12 *Aromaticity*—Test Method D1319. This test method provides an indication of the aromatics content of fuels. For fuels with a maximum final boiling point of 315 °C, this method is a measurement of the aromatic content of the fuel.

TABLE 2 Transfer Conditions

| Maximum Pipe Diameter (for a distance of 30 s upstream of delivery nozzle) | When Filling Tank Truck Compartments | When Filling Undivided Rail Car Compartments | When Filling Marine Vessels |
|---|---|---|---|
| 0.1023 m | fuel velocity ≥ 4.9 m/s | fuel velocity ≥ 7.0 m/s | fuel velocity ≥ 7.0 m/s |
| 0.1541 m | fuel velocity ≥ 3.24 m/s | fuel velocity ≥ 5.20 m/s | fuel velocity ≥ 7.0 m/s |
| 0.2027 m | fuel velocity ≥ 2.47 m/s | fuel velocity ≥ 3.90 m/s | fuel velocity ≥ 7.0 m/s |
| 0.2545 m | fuel velocity ≥ 1.96 m/s | fuel velocity ≥ 3.14 m/s | fuel velocity ≥ 7.0 m/s |

This test method is used for fuel Grades No. 1-D S15, No. 1-D S500, No. 2-D S15 and No. 2-D S500. Grades No. 1-D S5000, No. 2-D S5000 and No. 4-D do not have an aromatics content requirement.

5.1.13 *Lubricity*—Test Method D6079 or D7688. Test Method D6079 shall be the referee method.

5.1.14 *Conductivity*—Both conductivity test methods, Test Methods D2624 and D4308 are allowed for all grades of No. 1 and No. 2 diesel fuels. There is no conductivity requirement for No. 4 diesel fuel. For conductivities below 1 pS/m, Test Method D4308 is preferred.

## 6. Workmanship

6.1 The diesel fuel shall be visually free of undissolved water, sediment, and suspended matter.

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

## 7. Requirements

7.1 The grades of diesel fuel oils herein specified shall be hydrocarbon oils, except as provided in 7.3, with the inclusion of additives to enhance performance, if required, conforming to the detailed requirements shown in Table 1.

NOTE 5—Additives are generally included in finished diesel fuel to improve performance properties (cetane number, lubricity, cold flow, and so forth).

7.2 *Grades No. 2-D S15, No. 2-D S500 and No. 2–D S5000*—When a cloud point less than −12 °C is specified, as can occur during cold months, it is permitted and normal blending practice to combine Grades No. 1 and No. 2 to meet the low temperature requirements. In that case, the minimum flash point shall be 38 °C, the minimum viscosity at 40 °C shall be 1.7 mm$^2$/s, and the minimum 90 % recovered temperature shall be waived.

7.3 *Alternative Blendstocks:*

7.3.1 *Fuels Blended with Biodiesel*—The detailed requirements for fuels blended with biodiesel shall be as follows:

7.3.1.1 *Biodiesel for Blending*—If biodiesel is a component of any diesel fuel, the biodiesel shall meet the requirements of Specification D6751.

7.3.1.2 Diesel fuel oil containing up to 5 % volume biodiesel shall meet the requirements for the appropriate grade No. 1-D or No. 2-D fuel, as listed in Table 1.

7.3.1.3 Test Method D7371 shall be used for determination of the volume percent biodiesel in a biodiesel blend. Test Method EN 14078 or Test Method D7861 may also be used. In cases of dispute, Test Method D7371 shall be the referee test method. See Practice E29 for guidance on significant digits.

7.3.1.4 Diesel fuels containing more than 5 % volume biodiesel component are not included in this specification.

7.3.1.5 Biodiesel blends with No. 4–D fuel are not covered by this specification.

## 8. Precautionary Notes on Conductivity

8.1 Accumulation of static charge occurs when a hydrocarbon liquid flows with respect to another surface. The electrical conductivity requirement of 25 pS/m minimum at temperature of delivery shall apply when the transfer conditions in Table 2 exist for the delivery into a mobile transport container (for example, tanker trucks, railcars, and barges).

## 9. Keywords

9.1 biodiesel; biodiesel blend; diesel; fuel oil; petroleum and petroleum products

# APPENDIXES

## (Nonmandatory Information)

## X1. SIGNIFICANCE OF ASTM SPECIFICATION FOR DIESEL FUEL OILS

### X1.1 Introduction

X1.1.1 The properties of commercial fuel oils depend on the refining practices employed and the nature of the crude oils from which they are produced. Distillate fuel oils, for example, can be produced within the boiling range of 150 °C and 400 °C having many possible combinations of various properties, such as volatility, ignition quality, viscosity, and other characteristics.

### X1.2 Grades

X1.2.1 This specification is intended as a statement of permissible limits of significant fuel properties used for specifying the wide variety of commercially available diesel fuel oils. Limiting values of significant properties are prescribed for seven grades of diesel fuel oils. These grades and their general applicability for use in diesel engines are broadly indicated as follows:

X1.2.2 *Grade No. 1-D S15*—Grade No. 1-D S15 comprises the class of very low sulfur, volatile fuel oils from kerosine to the intermediate middle distillates. Fuels within this grade are applicable for use in *(1)* high-speed diesel engines and diesel engine applications that require ultra-low sulfur fuels, *(2)* applications necessitating frequent and relatively wide variations in loads and speeds, and *(3)* applications where abnormally low operating temperatures are encountered.

X1.2.3 *Grade No. 1-D S500*—Grade No. 1-D S500 comprises the class of low-sulfur, volatile fuel oils from kerosine to the intermediate middle distillates. Fuels within this grade are applicable for use in *(1)* high-speed diesel engines that require low sulfur fuels, *(2)* in applications necessitating frequent and relatively wide variations in loads and speeds, and *(3)* in applications where abnormally low operating temperatures are encountered.

X1.2.4 *Grade No. 1-D S5000*—Grade No. 1-D S5000 comprises the class of volatile fuel oils from kerosine to the intermediate middle distillates. Fuels within this grade are applicable for use in high-speed diesel engines applications necessitating frequent and relatively wide variations in loads and speeds, and also for use in cases where abnormally low operating temperatures are encountered.

X1.2.5 *Grade No. 2-D S15*—Grade No. 2-D S15 includes the class of very low sulfur, middle distillate gas oils of lower volatility than Grade No. 1-D S15. These fuels are applicable for use in *(1)* high speed diesel engines and diesel engine applications that require ultra-low sulfur fuels, *(2)* applications necessitating relatively high loads and uniform speeds, or *(3)* diesel engines not requiring fuels having higher volatility or other properties specified in Grade No. 1-D S15.

X1.2.6 *Grade No. 2-D S500*—Grade No. 2-D S500 includes the class of low-sulfur, middle distillate gas oils of lower volatility than Grade No. 1-D S500. These fuels are applicable for use in *(1)* high-speed diesel engine applications that require low sulfur fuels, *(2)* applications necessitating relatively high loads and uniform speeds, or *(3)* diesel engines not requiring fuels having higher volatility or other properties specified for Grade No. 1-D S500.

X1.2.7 *Grade No. 2-D S5000*—Grade No. 2-D S5000 includes the class of middle distillate gas oils of lower volatility than Grade No. 1-D S5000. These fuels are applicable for use in *(1)* high-speed diesel engines in applications necessitating relatively high loads and uniform speeds, or *(2)* in diesel engines not requiring fuels having higher volatility or other properties specified for Grade No. 1-D S5000.

X1.2.8 *Grade No. 4-D*—Grade No. 4-D comprises the class of more viscous middle distillates and blends of these middle distillates with residual fuel oils. Fuels within this grade are applicable for use in low- and medium-speed diesel engines in applications necessitating sustained loads at substantially constant speed.

### X1.3 Selection of Particular Grade

X1.3.1 The selection of a particular diesel fuel oil from one of these seven ASTM grades for use in a given engine requires consideration of the following factors:

X1.3.1.1 Fuel price and availability,
X1.3.1.2 Maintenance considerations,
X1.3.1.3 Engine size and design,
X1.3.1.4 Emission control systems,
X1.3.1.5 Speed and load ranges,
X1.3.1.6 Frequency of speed and load changes, and
X1.3.1.7 Atmospheric conditions. Some of these factors can influence the required fuel properties outlined as follows:

### X1.4 Cetane Number

X1.4.1 Cetane number is a measure of the ignition quality of the fuel and influences combustion roughness. The cetane number requirements depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. Increase in cetane number over values actually required does not materially improve engine performance. Accordingly, the cetane number specified should be as low as possible to assure maximum fuel availability.

### X1.5 Distillation

X1.5.1 The fuel volatility requirements depend on engine design, size, nature of speed and load variations, and starting and atmospheric conditions. For engines in services involving rapidly fluctuating loads and speeds as in bus and truck operation, the more volatile fuels can provide best performance, particularly with respect to smoke and odor. However, best fuel economy is generally obtained from the heavier types of fuels because of their higher heat content.

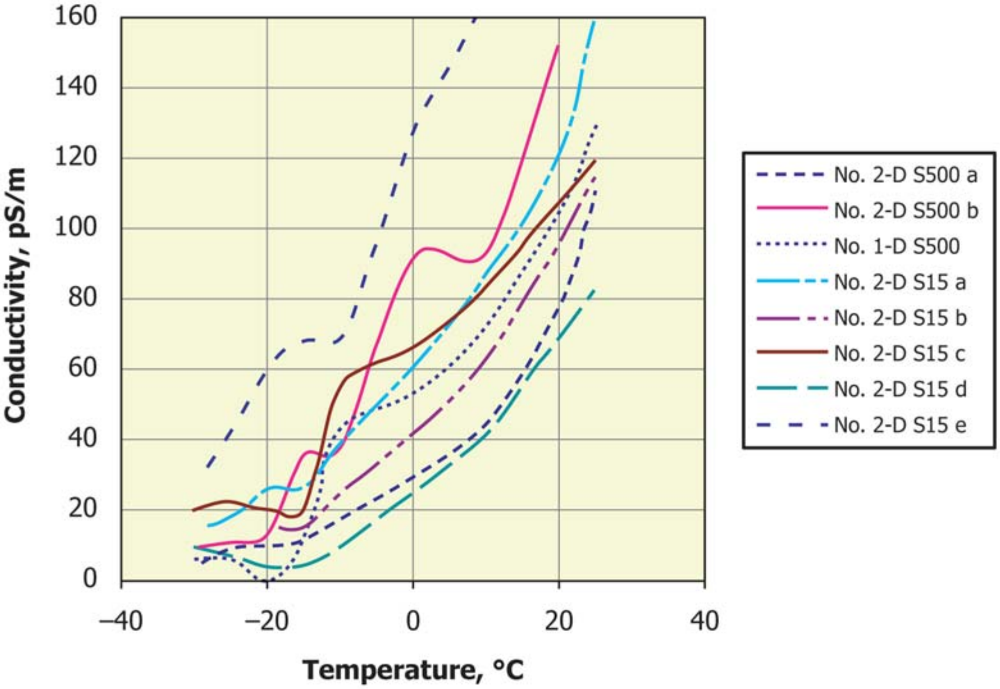

FIG. X1.1 Conductivity Varies with Temperature

## X1.6 Viscosity

X1.6.1 For some engines it is advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage. Maximum viscosity, on the other hand, is limited by considerations involved in engine design and size, and the characteristics of the injection system.

## X1.7 Carbon Residue

X1.7.1 Carbon residue gives a measure of the carbon depositing tendencies of a fuel oil when heated in a bulb under prescribed conditions. While not directly correlating with engine deposits, this property is considered an approximation.

## X1.8 Sulfur

X1.8.1 The effect of sulfur content on engine wear and deposits appears to vary considerably in importance and depends largely on operating conditions. Fuel sulfur can affect emission control systems performance. To assure maximum availability of fuels, the permissible sulfur content should be specified as high as is practicable, consistent with maintenance considerations.

## X1.9 Flash Point

X1.9.1 The flash point as specified is not directly related to engine performance. It is, however, of importance in connection with legal requirements and safety precautions involved in fuel handling and storage, and is normally specified to meet insurance and fire regulations.

## X1.10 Cloud Point

X1.10.1 Cloud point is of importance in that it defines the temperature at which a cloud or haze of wax crystals appears in the oil under prescribed test conditions which generally relates to the temperature at which wax crystals begin to precipitate from the oil in use.

## X1.11 Ash

X1.11.1 Ash-forming materials can be present in fuel oil in two forms: *(1)* abrasive solids, and *(2)* soluble metallic soaps. Abrasive solids contribute to injector, fuel pump, piston and ring wear, and also to engine deposits. Soluble metallic soaps have little effect on wear but can contribute to engine deposits.

## X1.12 Copper Strip Corrosion

X1.12.1 This test serves as a measure of possible difficulties with copper and brass or bronze parts of the fuel system.

## X1.13 Aromaticity

X1.13.1 This test is used as an indication of the aromatics content of diesel fuel. Aromatics content is specified to prevent an increase in the average aromatics content in Grades No. 1-D S15, No. 1-D S500, No. 2-D S15 and No. 2-D S500 fuels and is required by 40 CFR Part 80. Increases in aromatics content of fuels over current levels can have a negative impact on emissions.

## X1.14 Cetane Index

X1.14.1 Cetane Index is specified as a limitation on the amount of high aromatic components in Grades No. 1-D S15, No. 1-D S500, No. 2-D S15 and No. 2-D S500.

## X1.15 Other

X1.15.1 *Microbial Contamination*—Refer to Guide D6469 for a discussion of this form of contamination.

### X1.16 Conductivity

X1.16.1 Electrical conductivity of fuels is an important consideration in the safe handling characteristics of any fuel. The risk associated with explosions due to static electrical discharge depends on the amount of hydrocarbon and oxygen in the vapor space and the energy and duration of a static discharge. There are many factors that can contribute to the high risk of explosion. For Ultra Low Sulfur Diesel (ULSD) fuels in particular, electrical conductivity can likely be very low before the addition of static dissipater additive (SDA). The intent of this requirement is to reduce the risk of electrostatic ignitions while filling tank trucks, barges, ship compartments, and rail cars, where flammable vapors from the past cargo can be present. Generally, it does not apply at the retail level where flammable vapors are usually absent. Those parties handling any fuel are advised to review Guide D4865 as well as API RP 2003 and ISGOTT.[8]

X1.16.2 Conductivity is known to be highly dependent on temperature. The conductivity requirement in Table 1 will decrease the risk, but it will not eliminate it.

X1.16.3 Fig. X1.1 presents the response of conductivity to temperature for some typical diesel fuels.

X1.16.4 Due to the normal depletion of fuel conductivity additive during commingling, storage, distribution, or reduction of conductivity, or a combination thereof, at low temperatures, the fuel should be sufficiently treated, if needed with conductivity improver additives (also called static dissipater additives (SDA)) to ensure that the electrical conductivity requirement is met. The method of fuel distribution and temperature at the point of delivery into mobile transport can require a substantially greater conductivity level than 25 pS/m at the point of additive treatment. If a static dissipater additive is needed to meet the minimum conductivity requirement, then initial additive treatment should allow for temperature, commingling, distribution, and adequate mixing effects to ensure the minimum conductivity is attained at the point of delivery into mobile transport. For more information on this subject, please refer to Guide D4865 and Test Method D2624.

X1.16.5 Fuel handlers should not be lulled into a false sense of security if the fuel meets or exceeds the minimum conductivity requirement. Improved fuel conductivity will accelerate the dissipation of electric charge but not eliminate the risks associated with handling combustible or flammable fuels. Fuel handlers should be aware of the increased static electricity production when diesel fuels are filtered through fine-mesh strainers and filters. Fuel handlers are encouraged to use industry-recommended safety practices to minimize the risk associated with handling fuel. One such safe operating practice recommends lower maximum flowrates upon initial loading procedures. Loading operations involving "switch-loading" of tanker trucks and other vessels pose increased risks.

X1.16.6 There is some concern over excessive additization of diesel fuel with static dissipater additives. A potential concern includes failure of exposed electrical equipment immersed in over-additized fuel. Another concern is potential interference with the properties of adjacent products in pipeline. Fuel handlers using static dissipater additives should employ effective controls to prevent over-additizing diesel fuel. Fuel handlers adding SDA or other additives should be aware of possible antagonistic or synergistic effects between additives used simultaneously in diesel fuel. Consultation with the appropriate SDA additive supplier or other experts, or both, as well as conducting appropriate additive interaction studies is recommended.

X1.16.7 For those fuel transporters that practice switch loading of fuels without container cleaning and purging after hauling high or intermediate fuels or solvents, risks are involved with that practice. Switch loading should be discouraged because of the difficulty in ensuring removal of all residual vapor-producing materials. Accidental electrostatic discharge ignition requires three elements:

*(1)* Presence of a flammable atmosphere from a previous volatile cargo,

*(2)* The ability of the low volatility material being loaded to accumulate an electrostatic charge because of low conductivity, and

*(3)* Operating conditions during loading, which encourage charge generation and reduce charge relaxation—especially the velocity of the loading stream. Switch loading also refers to the reverse situation when light product (for example, gasoline) is loaded into a container that previously held middle distillate fuel (for example, diesel), although this mode of switch loading is generally not considered a static ignition hazard (but may be a product contamination concern).

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[8] *ISGOTT (International Safety Guide for Oil Tankers and Terminals)* , 5th edition, Oil Companies International Marine Forum (OCIMF), London, England, www.ocimf.com.

## X2. SAMPLING, CONTAINERS AND SAMPLE HANDLING

### X2.1 Introduction

X2.1.1 This appendix provides guidance on methods and techniques for the proper sampling of diesel fuel oils. As diesel fuel oil specifications become more stringent and contaminants and impurities become more tightly controlled, even greater care needs to be taken in collecting and storing samples for quality assessment.

### X2.2 Sampling, Containers and Sample Handling Recommendations

X2.2.1 Appropriate manual method sampling procedures can be found in Practice D4057 and automatic method sampling is covered in Practice D4177.

X2.2.2 The correct sample volume and appropriate container selection are also important decisions that can impact test results. Practice D4306 for aviation fuel container selection for tests sensitive to trace contamination can be useful. Practice D5854 for procedures on container selection and sample mixing and handling is recommended. For cetane number determination protection from light is important. Collection and storage of diesel fuel oil samples in an opaque container, such as a dark brown glass bottle, metal can, or a minimally reactive plastic container to minimize exposure to UV emissions from sources such as sunlight or fluorescent lamps, is recommended. According to Paragraph 8.2 of Test Method D6079, "Because of sensitivity of lubricity measurements to trace materials, sample containers shall be only fully epoxy-lined metal, amber borosilicate glass, or polytetrafluoroethylene as specified in Practice D4306."

X2.2.3 For volatility determination of a sample, Practice D5842 for special precautions recommended for representative sampling and handling techniques may be appropriate.

## X3. STORAGE AND THERMAL STABILITY OF DIESEL FUELS

### X3.1 Scope

X3.1.1 This appendix provides guidance for consumers of diesel fuels who may wish to store quantities of fuels for extended periods or use the fuel in severe service or high temperature applications. Fuels containing residual components are excluded. Consistently successful long-term fuel storage or use in severe applications requires attention to fuel selection, storage conditions, handling and monitoring of properties during storage and prior to use.

X3.1.2 Normally produced fuels have adequate stability properties to withstand normal storage and use without the formation of troublesome amounts of insoluble degradation products. Fuels that are to be stored for prolonged periods or used in severe applications should be selected to avoid formation of sediments or gums, which can overload filters or plug injectors. Selection of these fuels should result from supplier-user discussions.

X3.1.3 These suggested practices are general in nature and should not be considered substitutes for any requirements imposed by the warranty of the equipment manufacturer or by federal, state, or local government regulations. Although they cannot replace knowledge of local conditions or good engineering and scientific judgment, these suggested practices do provide guidance in developing an individual fuel management system for the middle distillate fuel user. They include suggestions in the operation and maintenance of existing fuel storage and handling facilities and for identifying where, when, and how fuel quality should be monitored or selected for storage or severe use.

X3.1.4 Thermal stability test method, Test Method D6468, was established and successfully used for many years to evaluate Grade No. 2-D S5000 and S500 diesel fuels. Reflectance levels of 70 % at 90 min and 80 % at 180 min were suggested by studies and experience for acceptable and premium performance. The National Conference on Weights and Measures (NCWM) adopted 80 % reflectance at 180 min as one requirement for the definition of premium diesel.

X3.1.5 Nearly all S15 fuel samples, when tested, result in reflectance levels greater than 90 %. Some experts were concerned about the formation of peroxides as the next category of stability concern for S15. If formed, peroxides could affect certain elastomers in equipment adversely.

X3.1.6 Despite high thermal stability as defined by Test Method D6468 and a lack of incidents regarding peroxide formation, the stability of diesel fuel remains a concern because a number of elements have changed. A high reflectance from the Test Method D6468 test may no longer be a clear indication of sufficiently high diesel stability.

X3.1.6.1 Diesel common-rail fuel injection systems with high pressure and high temperature were introduced.

X3.1.6.2 Fuels may be stressed more severely than before in production and usage.

X3.1.6.3 Finer filters are required in some applications to remove particulates from fuel.

X3.1.6.4 Fuel characteristics have changed and new fuel blends, such as with biodiesel, were introduced.

X3.1.7 Therefore, it has been shown that the existing test methods, suggested levels, and practices may not be compatible or adequate to describe diesel fuel stability and its effect in current and future diesel injection equipment. New test methods such as Rancimat (EN 15751) and PetroOxy (D7545) have been introduced and are used, if appropriate for the fuel type.

### X3.2 Definitions

X3.2.1 *bulk fuel, n*—fuel in a vessel exceeding 400 L.

X3.2.2 *fuel contaminants, n*—material not intended to be present in a fuel, whether introduced during or subsequent to manufacture, handling, distribution or storage, that makes the fuel less suitable for the intended use.

X3.2.2.1 *Discussion*—Fuel contaminants include materials introduced subsequent to the manufacture of fuel and fuel degradation products. Contaminants, which can be soluble in the fuel or insoluble (suspended liquid droplets or solid or semisolid particles), can be the result of improper processing or contamination by a wide range of materials including water, rust, airblown dust, deterioration of internal protective coatings on pipes or vessels and products of fuel degradation and biological growth. Solid or semisolid contaminants can be referred to as silt or sediment.

X3.2.3 *fuel-degradation products, n*—those materials that are formed in fuel during storage, usage, or exposure to high temperatures and pressures.

X3.2.3.1 *Discussion*—Insoluble degradation products can combine with other fuel contaminants to enhance deleterious effects. Soluble degradation products (soluble gums) are less volatile than fuel and can carbonize to form deposits due to complex interactions and oxidation of small amounts of olefinic or sulfur-, oxygen-, or nitrogen-containing compounds present in fuels. The formation of degradation products can be catalyzed by dissolved metals, especially copper and zinc. When dissolved copper and zinc are present it can be deactivated with metal deactivator additives.

X3.2.4 *long-term storage, n*—storage of fuel for longer than 12 months after it is received by the user.

X3.2.5 *severe use, n*—use of the fuel in applications where engines operating under high load conditions can cause the fuel to be exposed to excessive heat and pressure.

## X3.3 Fuel Selection

X3.3.1 The stability properties of middle distillates are highly dependent on the crude oil sources, severity of processing, use of additives, and whether additional refinery treatment has been carried out.

X3.3.2 The composition and stability properties of middle distillate fuels produced at different refineries can vary. Any special requirements of the user, such as long-term storage or severe service, should be discussed with the supplier.

X3.3.3 Blends of S15, S500, and S5000 diesel fuels from various sources can interact to give stability properties worse than expected based on the characteristics of the individual fuels.

## X3.4 Fuel Additives

X3.4.1 Fuel additives can improve the suitability of marginal fuels for long-term storage and thermal stability, but can be unsuccessful for fuels with markedly poor stability properties. Most stability additives should be added at the refinery or as soon after manufacture as possible (no more than a few weeks) to obtain maximum benefits.

X3.4.2 Biocides or biostats kill or inhibit, respectively, the growth of fungi and bacteria, which can grow at fuel-water interfaces to give high particulate concentrations in the fuel. Most available biocides and biostats are soluble in both the fuel and water or in the water phase only.

## X3.5 Tests for Fuel Quality

X3.5.1 The storage stability of fuel may be assessed using Test Method D2274 or D5304. However, these accelerated stability tests may not correlate well with field storage stability due to varying field conditions and to fuel composition. Also, these test methods were developed for S5000 and S500 fuels and may not show potential instability of S15 fuels and biodiesel blends of S15 fuels. More recently developed accelerated stability Test Method D7545 has been shown to be suitable for assessing the potential instability of S15 fuels and biodiesel blends of S15 fuels. EN 15751 is used in Specification D7467 for B6-B20 Biodiesel blends and has been shown to be suitable for assessing the potential instability of S15 biodiesel blends of 2 % biodiesel or greater. The presence of cetane improver (2-ethylhexyl nitrate) in diesel fuel can degrade Test Method D7545 performance. While Test Method D7545 can be used to assess the potential instability of fuels, there is no current limit for its use within a specification.

X3.5.2 Performance criteria for accelerated stability tests that assure satisfactory long-term storage of fuels have not been established.

X3.5.3 Test Method D6468, developed for S5000 and S500 fuels, does not show potential thermal instability of S15 fuels and biodiesel blends of S15 fuels very well. Typical S15 diesel fuel almost always results in greater than 90 % reflectance.

## X3.6 Fuel Monitoring

X3.6.1 A plan for monitoring the quality of bulk fuel during prolonged storage is an integral part of a successful fuel quality program. A plan to replace aged fuel with fresh product is also desirable.

X3.6.2 Stored fuel should be periodically sampled and its quality assessed. Practice D4057 provides guidance for sampling. Fuel contaminants and degradation products will usually settle to the bottom of a quiescent tank. A "Bottom" or "Clearance" sample, as defined in Practice D4057, should be included in the evaluation along with an "All Level" sample.

X3.6.3 The quantity of insoluble fuel contaminants present in fuel can be determined using Test Method D6217.

X3.6.4 Test Method D6468, can be used for investigation of operational problems that might be related to fuel thermal stability of S500 and S5000 fuels. Test Method D6468 does not show potential thermal stability of S15 fuels and biodiesel blends of S15 fuels very well. Use EN 15751 or Test Method D7545 for oxidative stability assessment instead. Testing samples from the fuel tank or from bulk storage may give an indication as to the cause of filter plugging. It is more difficult to monitor the quality of fuels in vehicle tanks since they may contain fuels from multiple sources.

X3.6.5 Some additives exhibit effects on S5000 and S500 fuels tested in accordance with Test Method D6468 that may or may not be observed in the field. Data have not been developed that correlate results from the test method for various engine types and levels of operating severity.

X3.6.6 Test Method D7619 can be used to assess the number and size of particulates in Grades 1-D and 2-D diesel fuels. However, with this test method, water droplets are counted as particles unless a co-solvent such as isopropyl alcohol or "Resolver" is used. Agglomerated particles can also be detected and counted as a single larger particle. While Test Method D7619 can be used to assess the particulate content of fuels, there is no current limit for its use within a specification. Data have not been developed to determine acceptable levels of particulates. Obtaining a representative sample and following the recommended sampling procedures is particularly important with particle counting test methods. Sampling a static tank for cleanliness by particle counting is very difficult and potentially very misleading. Fuel samples collected from more than a foot or two above the bottom in a static tank will almost always give very clean results. Testing a true bottom sample for cleanliness has little value beyond the identification of significant dirt or debris on the bottom of the tank. If such dirt or debris is stirred up, then very dirty fuel will be dispensed. Depending on frequency of product delivery sampling shortly after delivery of product has stirred the tank may be appropriate.

### X3.7 Fuel Storage Conditions

X3.7.1 Contamination levels in fuel can be reduced by keeping storage tanks free of water. Tankage should also have provisions for water draining on a scheduled basis. Water promotes corrosion, and microbiological growth can occur at a fuelwater interface. Underground storage is preferred to avoid temperature extremes; above-ground storage tanks should be sheltered or painted with reflective paint as high storage temperatures may accelerate fuel degradation. While underground tankage is preferred to minimize diurnal temperature swings, there can be a greater risk of water contamination in underground tanks. Fixed roof tanks should be kept full to limit oxygen supply and tank breathing.

X3.7.2 Copper, copper-containing alloys, and zinc-coated or galvanized equipment should be avoided. Copper can promote fuel degradation and can produce mercaptide gels. Zinc coatings can react with water or organic acids in the fuel to form gels that rapidly plug filters.

X3.7.3 Appendix X2 of Specification D2880 discusses fuel contaminants as a general topic.

### X3.8 Fuel Use Conditions

X3.8.1 Many diesel engines are designed so that the diesel fuel is used for heat transfer. In modern heavy-duty diesel engines, for example, only a portion of the fuel that is circulated to the fuel injectors is actually delivered to the combustion chamber. The remainder of the fuel is circulated back to the fuel tank, carrying heat with it. Thus adequate high temperature stability can be a necessary requirement in some severe applications or types of service. Recirculation rates vary depending on fuel injection system design.

X3.8.2 Inadequate high temperature stability can result in the formation of insoluble degradation products.

### X3.9 Use of Degraded Fuels

X3.9.1 Fuels that have undergone mild-to-moderate degradation are not fit for purpose in modern diesel engine fuel systems. Use of such degraded fuels pose the risk of polymeric deposits and resin formation affecting high pressure pump and injector performance, up to catastrophic fuel system damage.

X3.9.2 Fuels containing very large quantities of fuel degradation products and other contaminants or with runaway microbiological growth are even less appropriate for use in fuel injection systems. Drainage of sediments or fuel drawn off above the sediment layer does not remove dissolved polymers and aging acids present. Very high soluble gum levels or corrosion products from microbiological contamination will likely cause severe operational problems. Precautions for avoiding negative fuel system impacts from use of severely degraded fuels are not presently available.

### X3.10 Thermal Stability Guidelines

X3.10.1 Results from truck fleet experience suggests that Test Method D6468 can be used to qualitatively indicate whether diesel fuels have satisfactory thermal stability performance properties.[9,10] However, this test method was developed for S5000 and S500 fuels and may not be useful for S15 fuels that always perform well in this test. Today's current S15 fuels and biodiesel blends can still have stability problems, but Test Method D6468 is not the appropriate method of evaluation.

X3.10.2 Performance in engines has not been sufficiently correlated with results from Test Method D6468 for S5000, and S500, and S15 diesel fuel, to provide definitive specification requirements.

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[9] Bacha, John D., and Lesnini, David G., "Diesel Fuel Thermal Stability at 300°F," *Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels*, Vancouver, B.C., October 1997.

[10] Schwab, Scott D., Henly, Timothy J., Moxley, Joel F., and Miller, Keith, "Thermal Stability of Diesel Fuel," *Proceedings of the 7th International Conference on Stability and Handling of Liquid Fuels*, Graz, Austria, September 2000.

## X4. DIESEL FUEL LUBRICITY

### X4.1 Introduction

X4.1.1 Diesel fuel functions as a lubricant in most components of fuel injection equipment such as pumps and injectors. In limited cases, fuel with specific properties will have insufficient lubricating properties which will lead to a reduction in the normal service life and functional performance of diesel fuel injection systems.

### X4.2 Fuel Characteristics Affecting Equipment Wear

X4.2.1 Currently, two fuel characteristics affect equipment wear. These are low viscosity and lack of sufficient quantities of trace components that have an affinity for surfaces. If fuel viscosity meets the requirements of a particular engine, a fuel film is maintained between the moving surfaces of the fuel system components. This prevents excessive metal-to-metal contact and avoids premature failure due to wear. Similarly, certain surface active molecules in the fuel adhere to, or combine with, surfaces to produce a protective film which also can protect surfaces against excessive wear.

### X4.3 Fuel Lubricity

X4.3.1 The concern about fuel lubricity is limited to situations in which fuels with lower viscosities than those specified for a particular engine are used or in which fuels that have been processed in a manner that results in severe reduction of the trace levels of the surface active species that act as surface protecting agents. Presently the only fuels of the latter type shown to have lubricity problems resulted from sufficiently severe processing to reduce aromatics or sulfur.

X4.3.2 Work in the area of diesel fuel lubricity is ongoing by several organizations, such as the International Organization for Standardization (ISO), the ASTM Diesel Fuel Lubricity Task Force, and the Coordinating Research Council (CRC) Diesel Performance Group. These groups include representatives from the fuel injection equipment manufacturers, fuel producers, and additive suppliers. The charge of the ASTM task force has been the recommendation of test methods and fuel lubricity requirements for Specification D975. Two test methods were proposed and approved. These are Test Method D6078, a scuffing load ball-on-cylinder lubricity evaluator method, SLBOCLE, and Test Method D6079, a high frequency reciprocating rig (HFRR) method. Use of these tests raises three issues: 1) The correlation of the data among the two test methods and the fuel injection equipment is not perfect, 2) Both methods in their current form do not apply to all fuel-additive combinations, and 3) The reproducibility values for both test methods are large. In order to protect diesel fuel injection equipment, an HFRR Wear Scar Diameter (WSD) of 520 µm has been placed in Specification D975.[11]

X4.3.3 Most experts agree that fuels having a SLBOCLE lubricity value below 2000 g might not prevent excessive wear in injection equipment[12] while fuels with values above 3100 g should provide sufficient lubricity in all cases.[13] Experts also agree that if HFFR test at 60 °C is used, fuels with values above 600 µm might not prevent excessive wear,[14] while fuels with values below 450 µm should provide sufficient lubricity in all cases.[13] More accurately, an industry-accepted long-term durability pump test, such as Test Method D6898, can be used to evaluate the lubricity of a diesel fuel. A poor result in such a test indicates that the fuel has low lubricity and may not be able to provide sufficient protection.

NOTE X4.1—Some injection equipment can be fitted with special components that can tolerate low lubricity fuels.

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[11] Mitchell, K., "Diesel Fuel Lubricity—Base Fuel Effects," SAE Technical Paper 2001–01–1928, 2001.

[12] Westbrook, S. R., "Survey of Low Sulfur Diesel Fuels and Aviation Kerosenes from U.S. Military Installations," SAE Technical Paper 952369, 1995.

[13] Nikanjam, M., "ISO Diesel Fuel Lubricity Round Robin Program," SAE Technical Paper 952372, 1995.

[14] Nikanjam, M., "Diesel Fuel Lubricity: On the Path to Specifications ," SAE Technical Paper 1999-01-1479, 1999.

## X5. TENTH PERCENTILE MINIMUM AMBIENT AIR TEMPERATURES FOR THE UNITED STATES (EXCEPT HAWAII)

### X5.1 Introduction

X5.1.1 The tenth percentile minimum ambient air temperatures shown on the following maps (Figs. X5.1-X5.12) and in Table X5.1 were derived from an analysis of historical hourly temperature readings recorded over a period of 15 years to 21 years from 345 weather stations in the United States. This study was conducted by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, Aberdeen Proving Ground, MD 21005. The tenth percentile minimum ambient air temperature is defined as the lowest ambient air temperature which will not go lower on average more than 10 % of the time. In other words, the daily minimum ambient air temperature would on average not be expected to go below the monthly tenth percentile minimum ambient air temperature more than 3 days for a 30 day month. See Table X5.1.

X5.1.2 These data can be used to estimate low temperature operability requirements. In establishing low temperature operability requirements, consideration should be given to the following. These factors, or any combination, can make low temperature operability more or less severe than normal. As X5.1.2.1 through X5.1.2.12 indicate, field work suggests that cloud point (or wax appearance point) is a fair indication of the low temperature operability limit of fuels without cold flow additives in most vehicles.

X5.1.2.1 Long term weather patterns (Average winter low temperatures will be exceeded on occasion).

X5.1.2.2 Short term local weather conditions (Unusual cold periods do occur).

X5.1.2.3 Elevation (High locations are usually colder than surrounding lower areas).

X5.1.2.4 Specific engine design.

X5.1.2.5 Fuel system design (Recycle rate, filter location, filter capacity, filter porosity, and so forth.)

X5.1.2.6 Fuel viscosity at low temperatures

X5.1.2.7 Equipment add-ons (Engine heaters, radiator covers, fuel line and fuel filter heaters and so forth.)

X5.1.2.8 Types of operation (Extensive idling, engine shutdown, or unusual operation).

X5.1.2.9 Low temperature flow improver additives in fuel.

X5.1.2.10 Geographic area for fuel use and movement between geographical areas.

X5.1.2.11 General housekeeping (Dirt or water, or both, in fuel or fuel supply system).

X5.1.2.12 Impact failure for engine to start or run (Critical vs. non-critical application).

X5.1.3 *Historical Background*—Three test methods have been widely used to estimate or correlate with low temperature vehicle operability. Cloud point, Test Method D2500, is the oldest of the three and most conservative of the tests. The cloud point test indicates the earliest appearance of wax precipitation that might result in plugging of fuel filters or fuel lines under prescribed cooling conditions. Although not 100 % failsafe, it is the most appropriate test for applications that can not tolerate much risk. The Cold Filter Plugging Point (CFPP) test, Test Method D6371, was introduced in Europe in 1965. The CFPP was designed to correlate with the majority of European vehicles. Under rapid cooling conditions, 20 cc fuel is drawn through a 45 µm screen then allowed to flow back through the screen for further cooling. This process is continued every 1 °C until either the 20 cc fuel fails to be drawn through the screen in 60 s or it fails to return through the screen in 60 s. It was field tested many times in Europe[15] before being widely accepted as a European specification. Field tests have also shown CFPP results more than 10 °C below the cloud point should be viewed with caution because those results did not necessarily reflect the true vehicle low temperature operability limits.[16] CFPP has been applied to many areas of the world where similar vehicle designs are used. The Low Temperature Flow Test (LTFT), Test Method D4539, was designed to correlate with the most severe and one of the most common fuel delivery systems used in North American Heavy Duty trucks. Under prescribed slow cool conditions (1 °C ⁄h), similar to typical field conditions, several 200 cc fuel specimens in glass containers fitted with 17 µm screen assemblies are cooled. At 1 °C intervals one specimen is drawn through the screen under a 20 kPa vacuum. Approximately 90 % of the fuel must come over in 60 s or less for the result to be a pass. This process is continued at lower temperatures (1 °C increments) until the fuel fails to come over in the allotted 60 s. The lowest passing temperature is defined as the LTFT for that fuel. In 1981, a CRC program was conducted to evaluate the efficacy of cloud point, CFPP, pour point, and LTFT for protecting the diesel vehicle population in North America and to determine what benefit flow-improvers could provide. The field test consisted of 3 non-flow improved diesel fuels, 5 flow improved diesel fuels, 4 light-duty passenger cars, and 3 heavy-duty trucks. The field trial resulted in two documents[17],[18] that provide insight into correlating laboratory tests to North American vehicle performance in the field. The general conclusions of the study were:

*(1)* In overnight cool down, 30 % of the vehicles tested had a final fuel tank temperature within 2 °C of the overnight minimum ambient temperature.

*(2)* The use of flow-improved diesel fuel permits some vehicles to operate well below the fuel cloud point.

*(3)* Significant differences exist in the severity of diesel vehicles in terms of low temperature operation.

*(4)* No single laboratory test was found that adequately predicts the performance of all fuels in all vehicles.

*(5)* CFPP was a better predictor than pour point, but both methods over-predicted, minimum operating temperatures in many vehicles. For this reason, these tests were judged inadequate predictors of low-temperature performance and dismissed from further consideration.

*(6)* Cloud point and LTFT showed varying degrees of predictive capability, and offered distinctively different advantages. Both predicted the performance of the base fuels well, but LTFT more accurately predicted the performance of the flow-improved fuels. On the other hand, cloud point came closest to a fail-safe predictor of vehicle performance for all vehicles.

Since the 1981 field test, non-independent studies[19] using newer vehicles verified the suitability of the LTFT for North American heavy-duty trucks. Users are advised to review these and any more recent publications when establishing low temperature operability requirements and deciding upon test methods.

X5.1.3.1 *Current Practices*—It is recognized that fuel distributors, producers, and end users in the United States use cloud point, wax appearance point, CFPP, and LTFT to estimate vehicle low temperature operability limits for diesel fuel. No independent data has been published in recent years to determine test applicability for today's fuels and vehicles.

## X5.2 Maps

X5.2.1 The maps in the following figures were derived from CCL Report No. 316, "A Predictive Study for Defining

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[15] "Low Temperature Operability of Diesels. A Report by CEC Investigation Group IGF-3," CEC P-171–82.

[16] "SFPP-A New Laboratory Test for Assessment of Low Temperature Operability of Modern Diesel Fuels," CEC/93/EF 15, 5–7, May 1993.

[17] CRC Report No. 537, "The Relationship Between Vehicle Fuel Temperature and Ambient Temperature, 1981 CRC Kapuskasing Field Test," December 1983.

[18] CRC Report No. 528, "1981 CRC Diesel Fuel Low-Temperature Operability Field Test," September 1983.

[19] SAE 962197, SAE 982576, SAE 2000-01-2883.

Limiting Temperatures and Their Application in Petroleum Product Specifications," by John P. Doner. This report was published by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, and it is available from the National Technical Information Service, Springfield, VA 22151, by requesting Publication No. AD756-420.

X5.2.2 Where states are divided the divisions are noted on the maps and table with the exception of California, which is divided by counties as follows:

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 the Los Angeles County Aqueduct), Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada.

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 Bernardino, 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).

X5.2.3 The temperatures in CCL Report No. 316 were in degrees Fahrenheit. The degree Celsius temperatures in Appendix X5 were obtained by converting the original degree Fahrenheit temperatures.

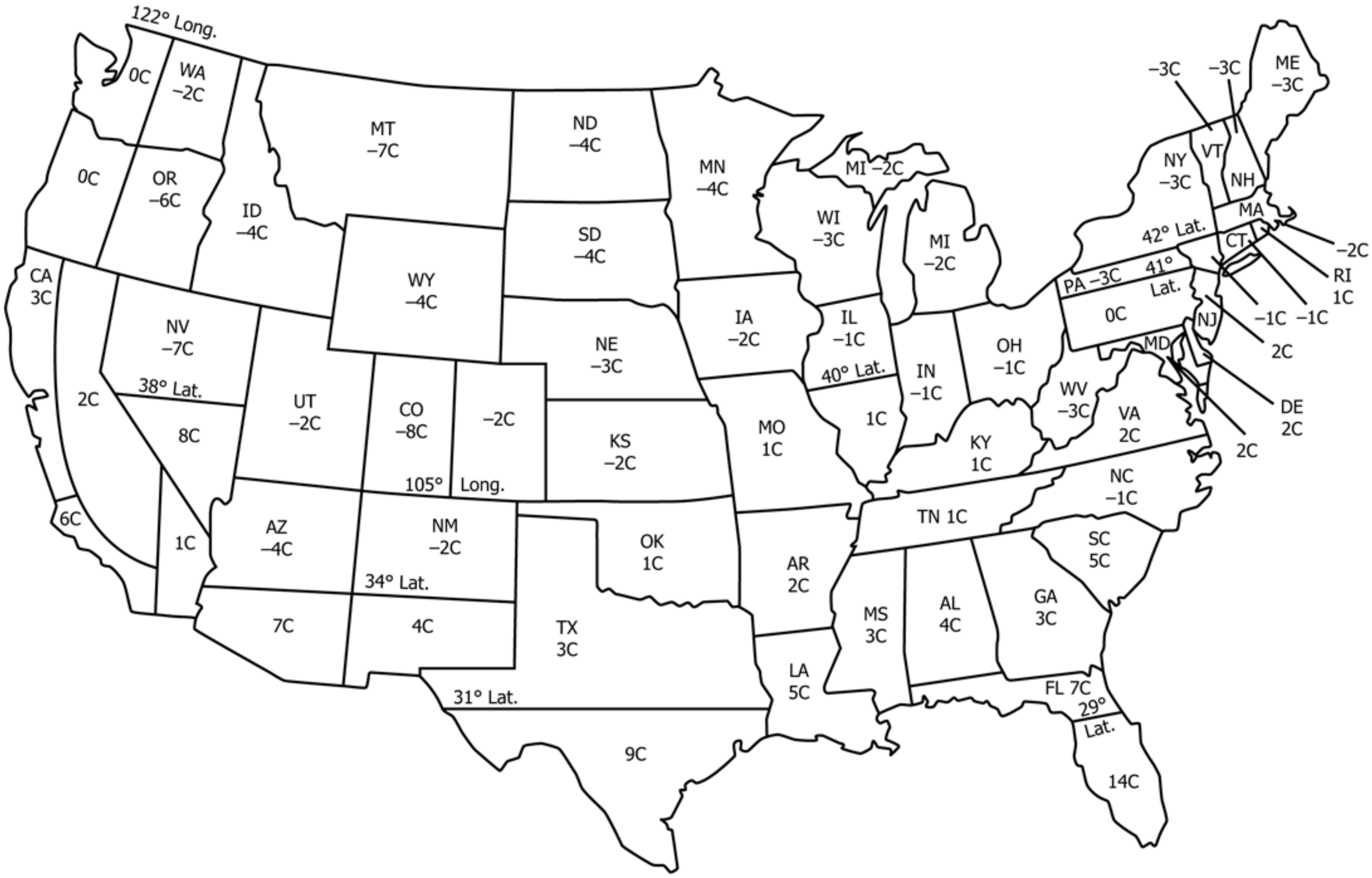

FIG. X5.1 October—10th Percentile Minimum Temperatures

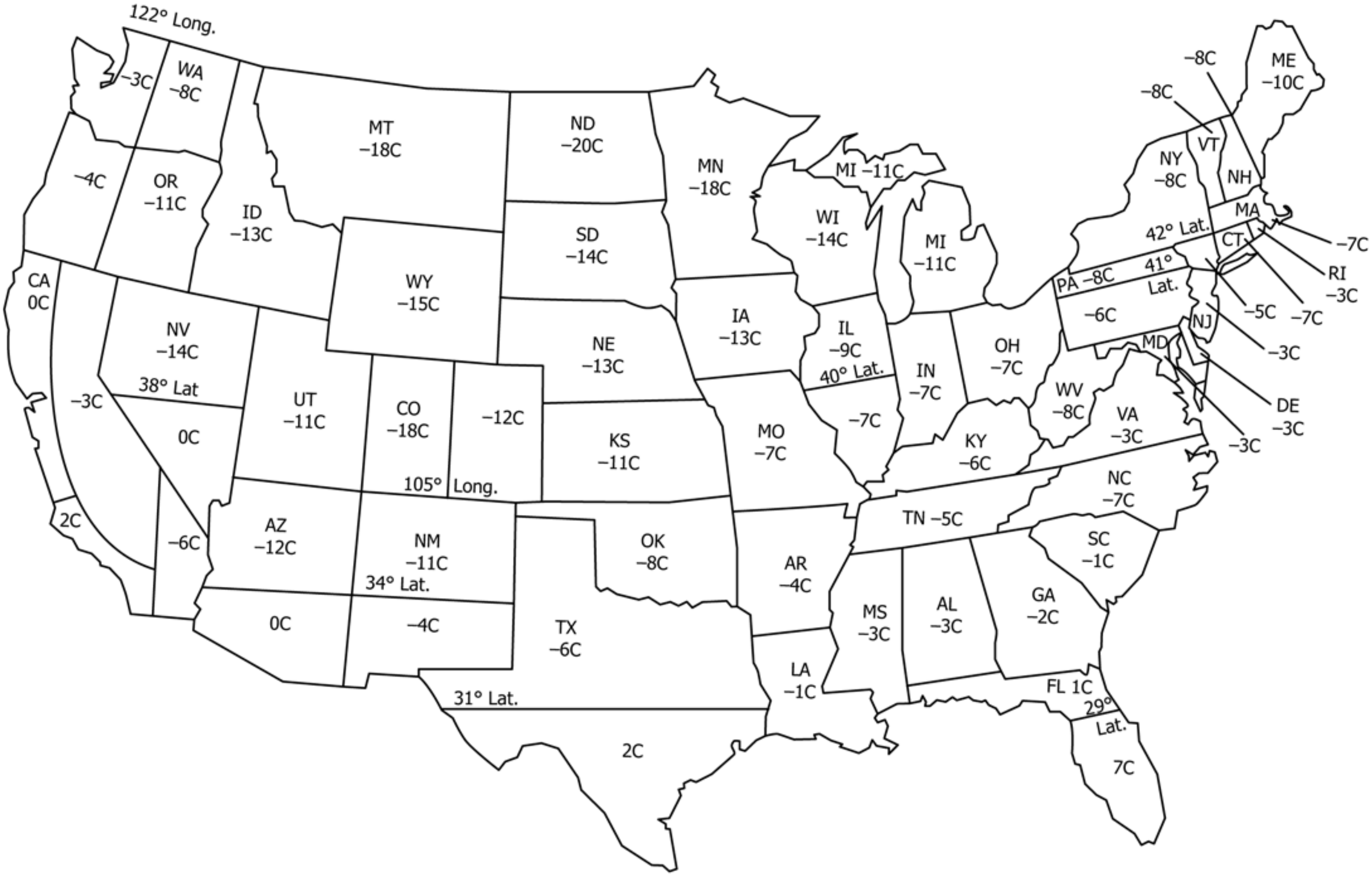

FIG. X5.2 November—10th Percentile Minimum Ambient Air Temperatures

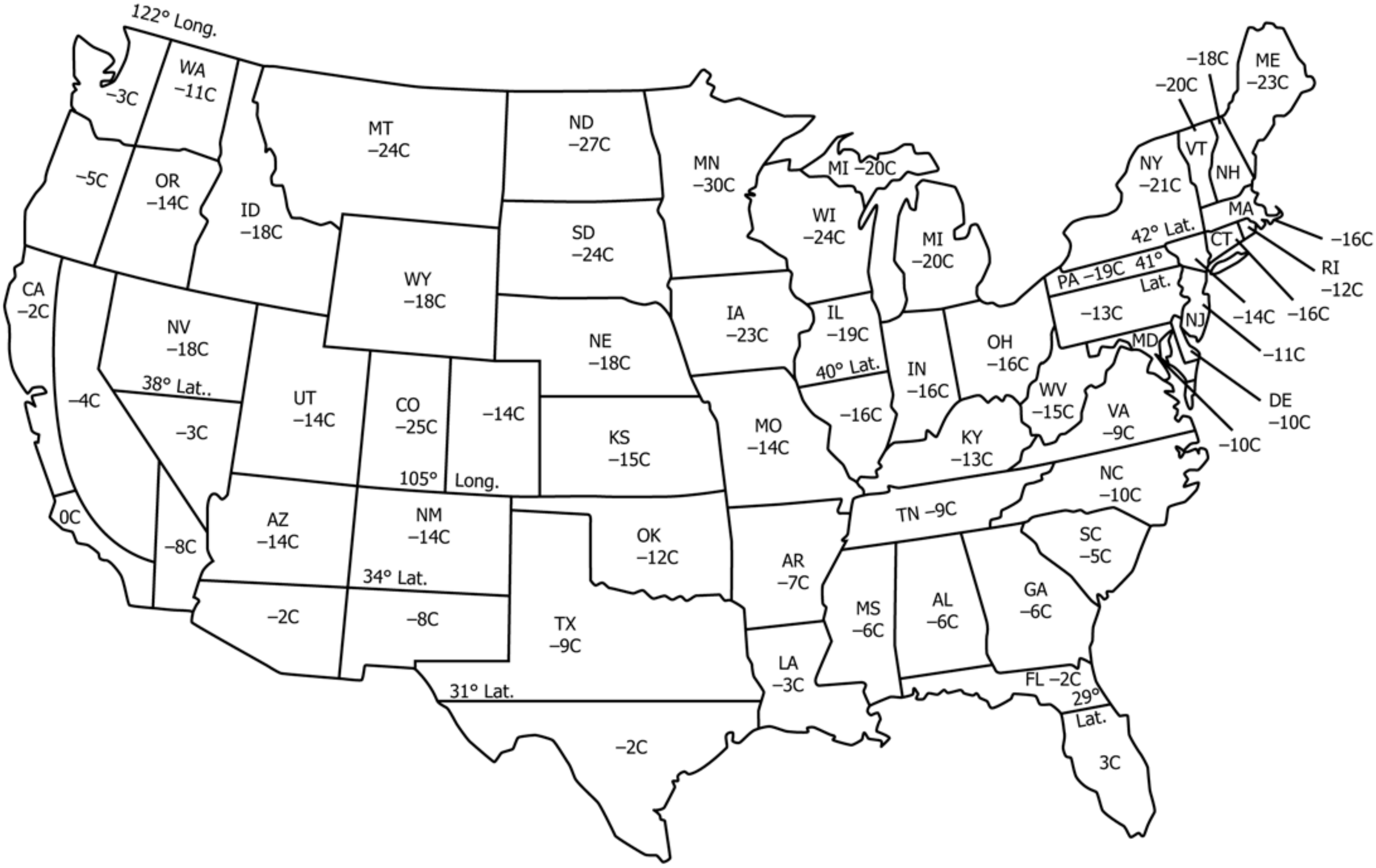

FIG. X5.3 December—10th Percentile Minimum Ambient Air Temperatures

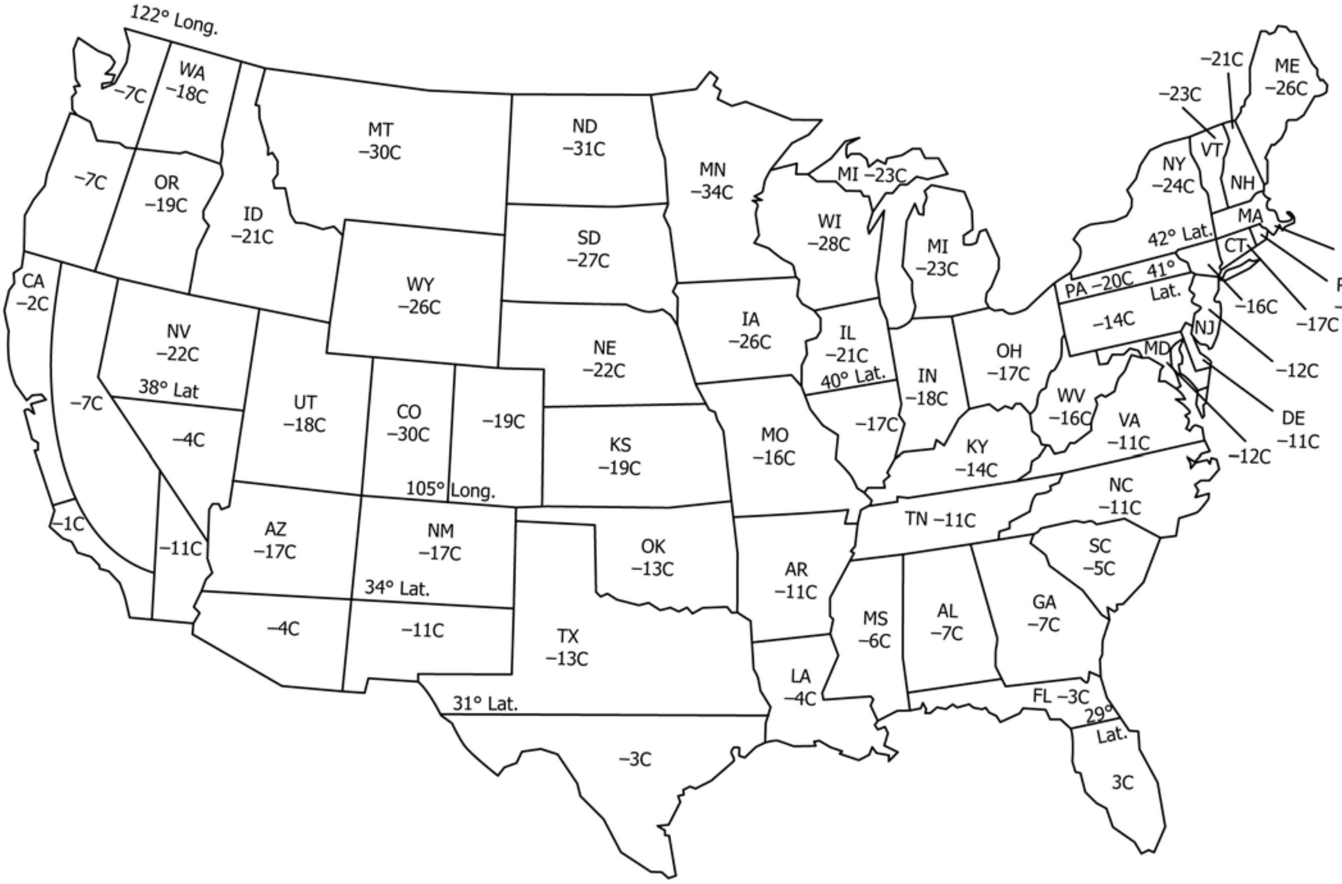

FIG. X5.4 January—10th Percentile Minimum Ambient Air Temperatures

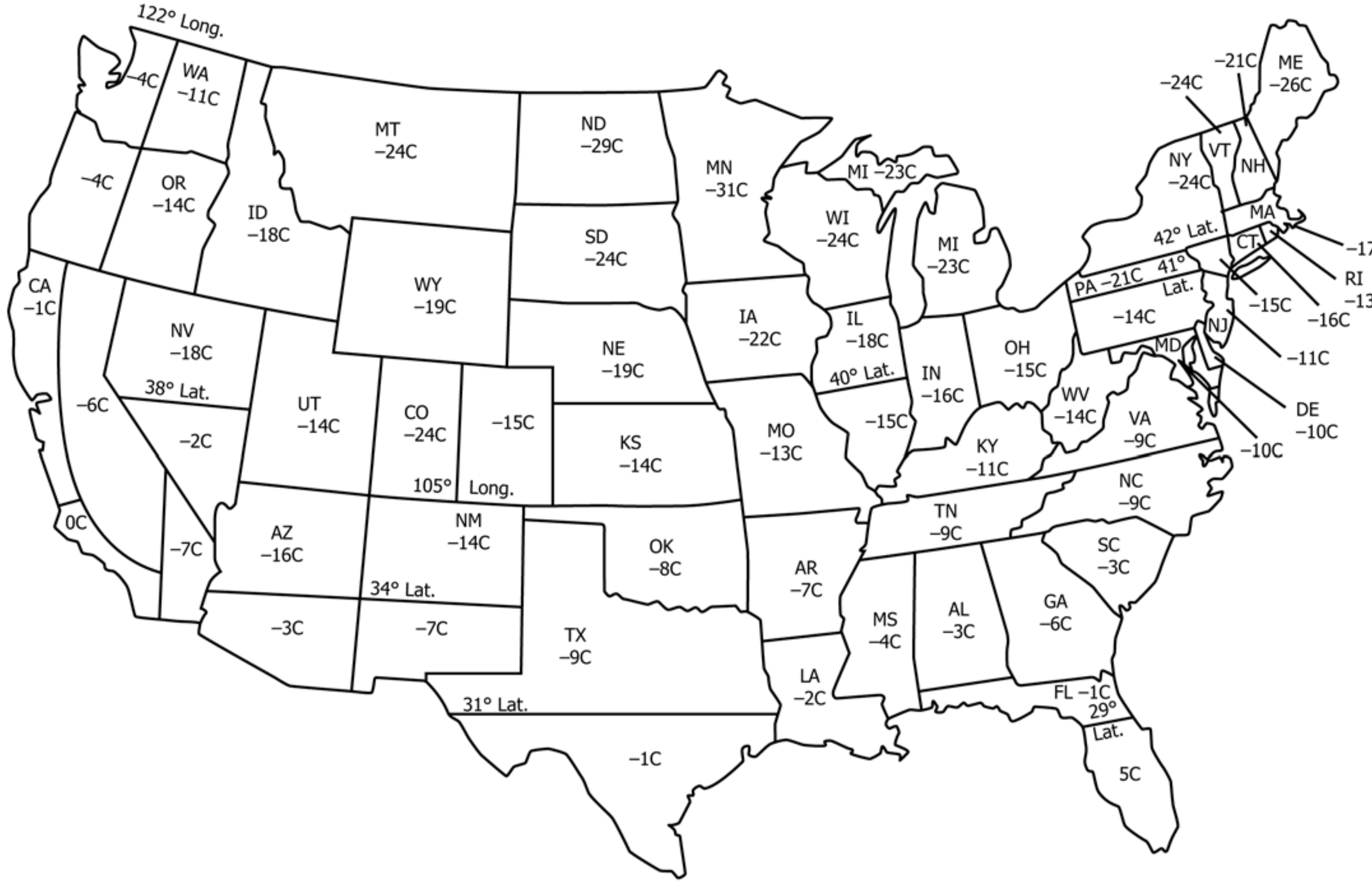

FIG. X5.5 February—10th Percentile Minimum Ambient Air Temperatures

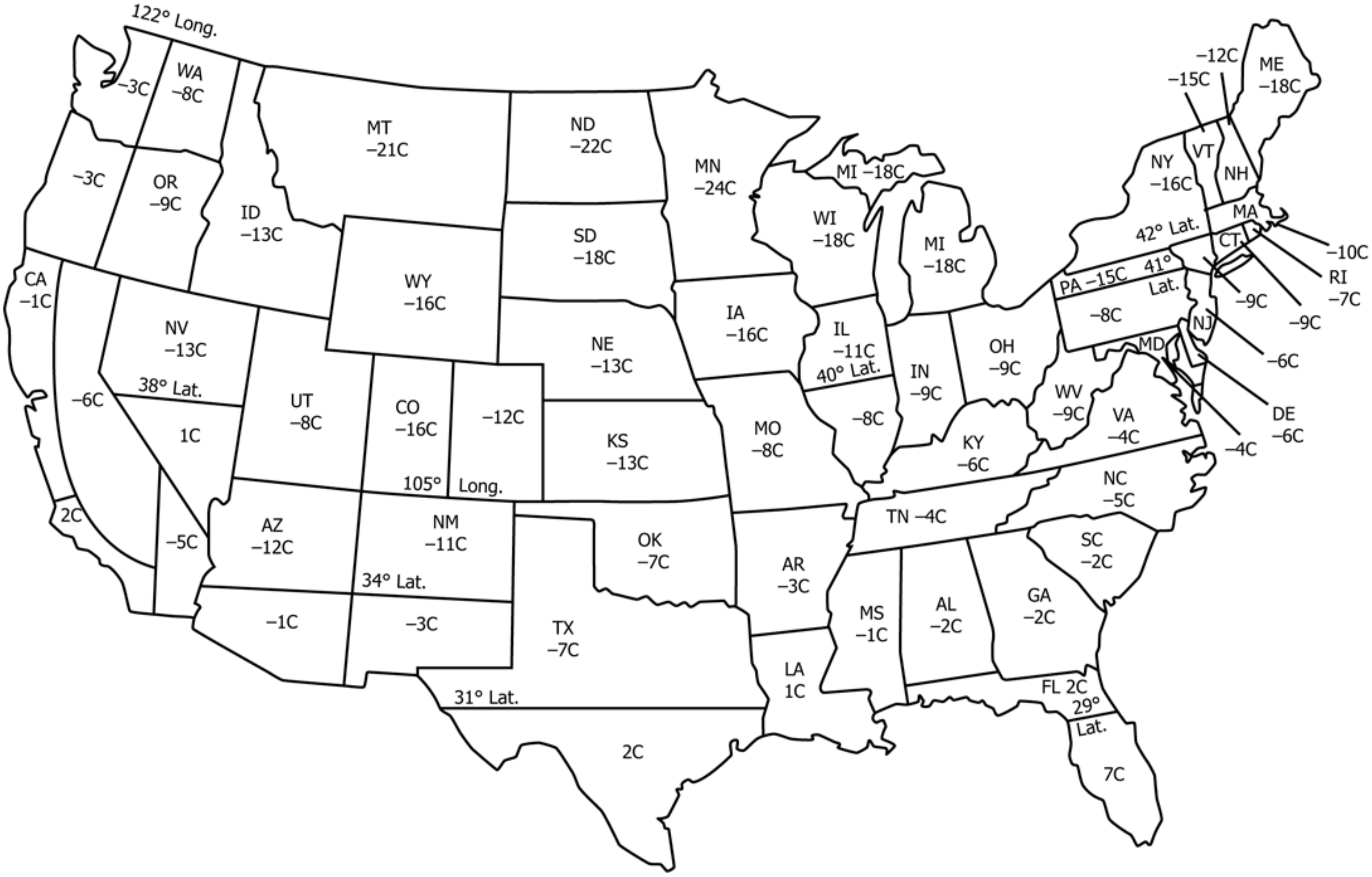

FIG. X5.6 March—10th Percentile Minimum Ambient Air Temperatures

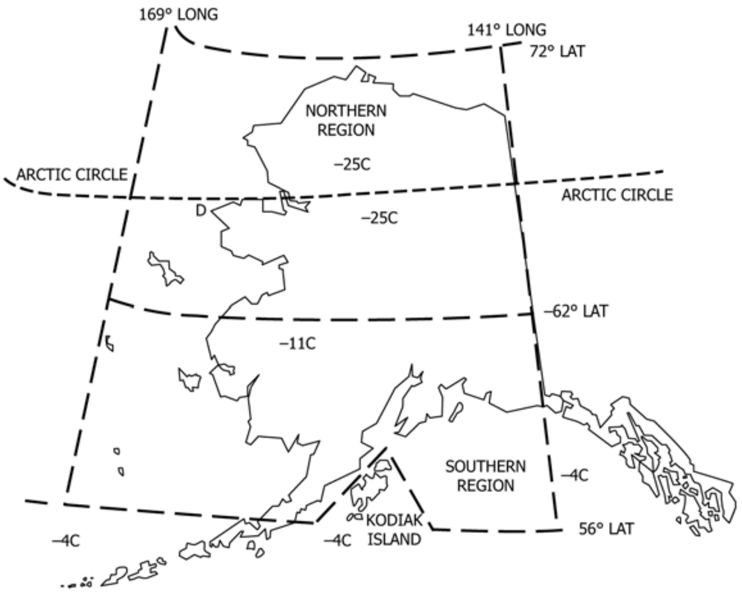

FIG. X5.7 October—10th Percentile Minimum Ambient Air Temperatures

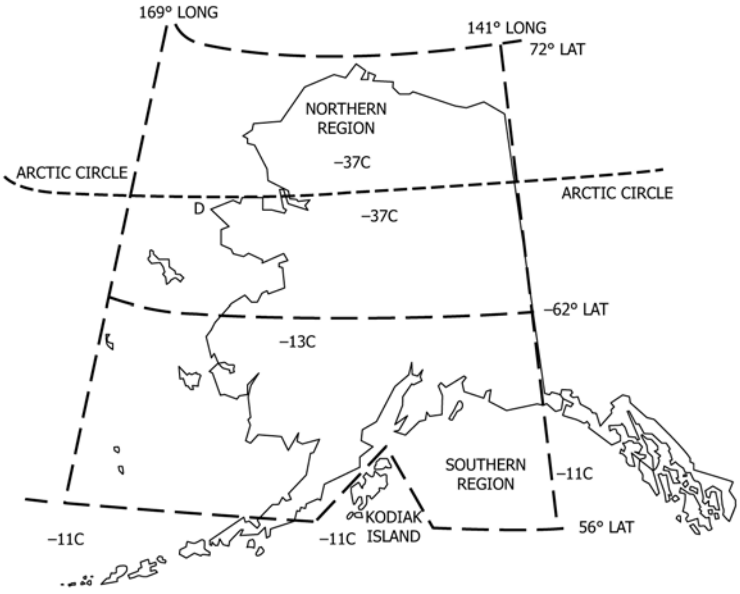

FIG. X5.8 November—10th Percentile Minimum Ambient Air Temperatures

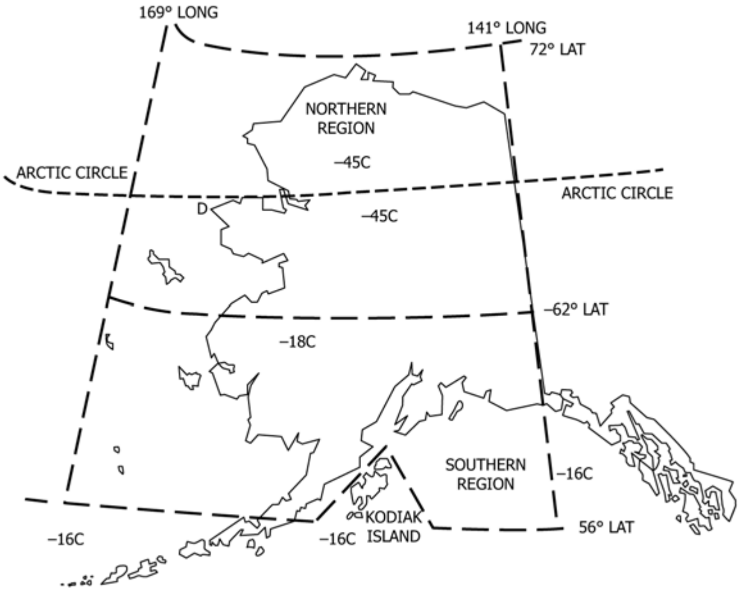

FIG. X5.9 December—10th Percentile Minimum Ambient Air Temperatures

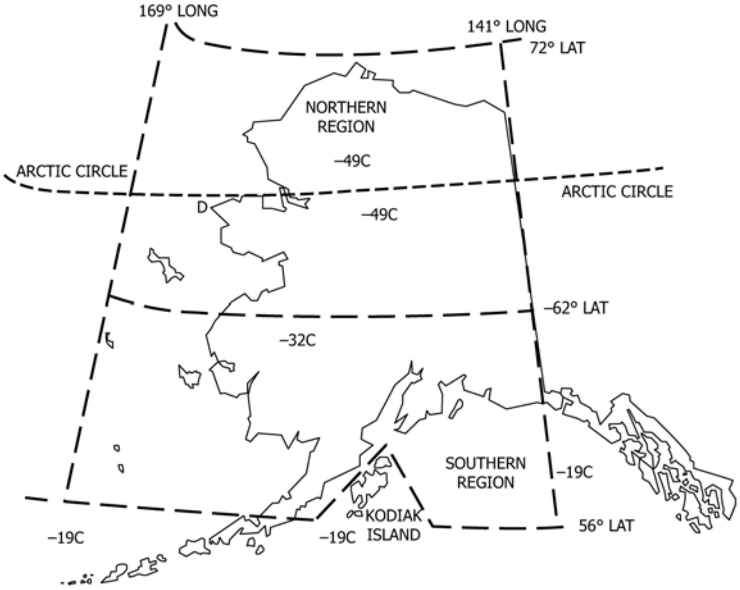

FIG. X5.10 January—10th Percentile Minimum Ambient Air Temperatures

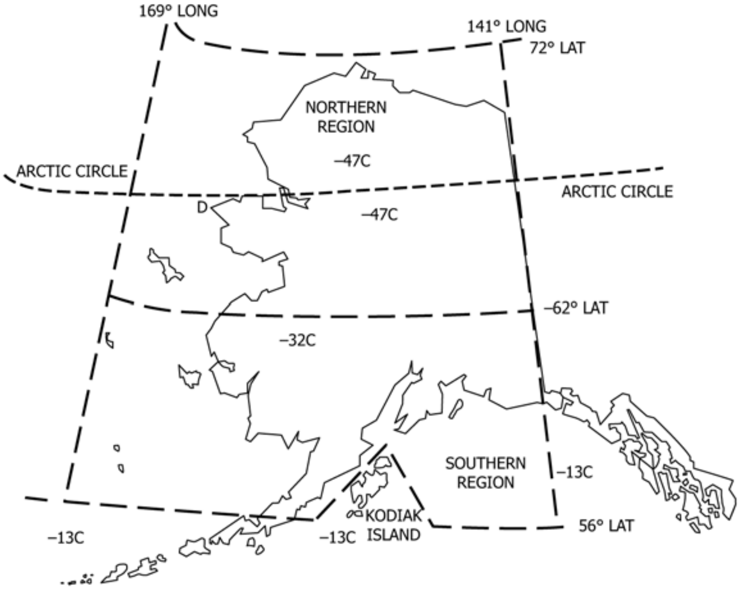

FIG. X5.11 February—10th Percentile Minimum Ambient Air Temperatures

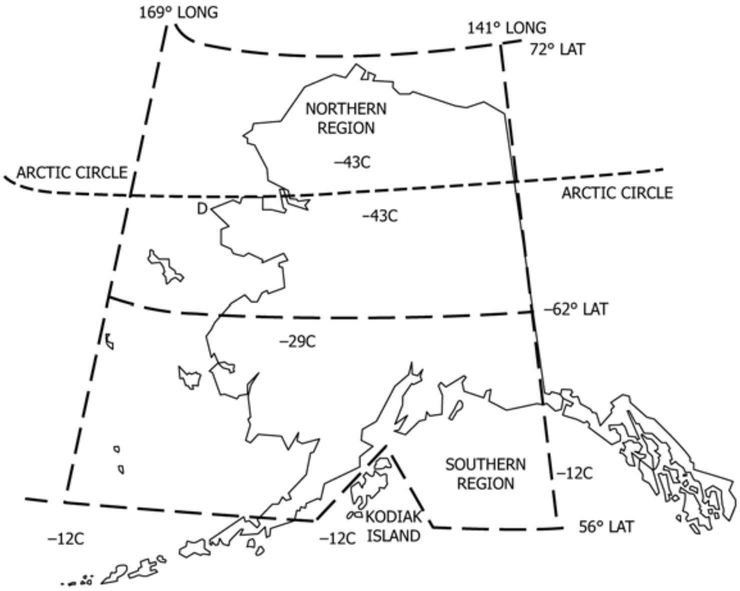

FIG. X5.12 March—10th Percentile Minimum Ambient Air Temperatures

**TABLE X5.1 Tenth Percentile Minimum Ambient Air Temperatures for the United States (except Hawaii)**

| State | | 10th Percentile Temperature°C, min | | | | | |
|---|---|---|---|---|---|---|---|
| | | Oct. | Nov. | Dec. | Jan. | Feb. | March |
| Alabama | | 4 | –3 | –6 | –7 | –3 | –2 |
| Alaska | Northern | –25 | –37 | –45 | –49 | –47 | –43 |
| | Southern | –11 | –13 | –18 | –32 | –32 | –29 |
| | South East | –4 | –11 | –16 | –19 | –13 | –12 |
| Arizona | North 34° latitude | –4 | –12 | –14 | –17 | –16 | –12 |
| | South 34° latitude | 7 | 0 | –2 | –4 | –3 | –1 |
| Arkansas | | 2 | –4 | –7 | –11 | –7 | –3 |
| California | North Coast | 3 | 0 | –2 | –2 | –1 | –1 |
| | Interior | 2 | –3 | –4 | –7 | –6 | –6 |
| | South Coast | 6 | 2 | 0 | –1 | 0 | 2 |
| | Southeast | 1 | –6 | –8 | –11 | –7 | –5 |
| Colorado | East 105° long | –2 | –12 | –14 | –19 | –15 | –12 |
| | West 105° long | –8 | –18 | –25 | –30 | –24 | –16 |
| Connecticut | | –1 | –7 | –16 | –17 | –16 | –9 |
| Delaware | | 2 | –3 | –10 | –11 | –10 | –6 |
| Florida | North 29° latitude | 7 | 1 | –2 | –3 | –1 | 2 |
| | South 29° latitude | 14 | 7 | 3 | 3 | 5 | 7 |
| Georgia | | 3 | –2 | –6 | –7 | –6 | –2 |
| Idaho | | –4 | –13 | –18 | –21 | –18 | –13 |
| Illinois | North 40° latitude | –1 | –9 | –19 | –21 | –18 | –11 |
| | South 40° latitude | 1 | –7 | –16 | –17 | –15 | –8 |
| Indiana | | –1 | –7 | –16 | –18 | –16 | –9 |
| Iowa | | –2 | –13 | –23 | –26 | –22 | –16 |
| Kansas | | –2 | –11 | –15 | –19 | –14 | –13 |
| Kentucky | | 1 | –6 | –13 | –14 | –11 | –6 |
| Louisiana | | 5 | –1 | –3 | –4 | –2 | 1 |
| Maine | | –3 | –10 | –23 | –26 | –26 | –18 |
| Maryland | | 2 | –3 | –10 | –12 | –10 | –4 |
| Massachusetts | | –2 | –7 | –16 | –18 | –17 | –10 |
| Michigan | | –2 | –11 | –20 | –23 | –23 | –18 |
| Minnesota | | –4 | –18 | –30 | –34 | –31 | –24 |
| Mississippi | | 3 | –3 | –6 | –6 | –4 | –1 |
| Missouri | | 1 | –7 | –14 | –16 | –13 | –8 |
| Montana | | –7 | –18 | –24 | –30 | –24 | –21 |
| Nebraska | | –3 | –13 | –18 | –22 | –19 | –13 |
| Nevada | North 38° latitude | –7 | –14 | –18 | –22 | –18 | –13 |
| | South 38° latitude | 8 | 0 | –3 | –4 | –2 | 1 |
| New Hampshire | | –3 | –8 | –18 | –21 | –21 | –12 |
| New Jersey | | 2 | –3 | –11 | –12 | –11 | –6 |
| New Mexico | North 34° latitude | –2 | –11 | –14 | –17 | –14 | –11 |
| | South 34° latitude | 4 | –4 | –8 | –11 | –7 | –3 |
| New York | North 42° latitude | –3 | –8 | –21 | –24 | –24 | –16 |
| | South 42° latitude | –1 | –5 | –14 | –16 | –15 | –9 |
| North Carolina | | –1 | –7 | –10 | –11 | –9 | –5 |
| North Dakota | | –4 | –20 | –27 | –31 | –29 | –22 |
| Ohio | | –1 | –7 | –16 | –17 | –15 | –9 |
| Oklahoma | | 1 | –8 | –12 | –13 | –8 | –7 |
| Oregon | East 122° long | –6 | –11 | –14 | –19 | –14 | –9 |
| | West 122° long | 0 | –4 | –5 | –7 | –4 | –3 |
| Pennsylvania | North 41° latitude | –3 | –8 | –19 | –20 | –21 | –15 |
| | South 41° latitude | 0 | –6 | –13 | –14 | –14 | –8 |
| Rhode Island | | 1 | –3 | –12 | –13 | –13 | –7 |
| South Carolina | | 5 | –1 | –5 | –5 | –3 | –2 |
| South Dakota | | –4 | –14 | –24 | –27 | –24 | –18 |
| Tennessee | | 1 | –5 | –9 | –11 | –9 | –4 |
| Texas | North 31° latitude | 3 | –6 | –9 | –13 | –9 | –7 |
| | South 31° latitude | 9 | 2 | –2 | –3 | –1 | 2 |
| Utah | | –2 | –11 | –14 | –18 | –14 | –8 |
| Vermont | | –3 | –8 | –20 | –23 | –24 | –15 |
| Virginia | | 2 | –3 | –9 | –11 | –9 | –4 |
| Washington | East 122° long | –2 | –8 | –11 | –18 | –11 | –8 |
| | West 122° long | 0 | –3 | –3 | –7 | –4 | –3 |
| West Virginia | | –3 | –8 | –15 | –16 | –14 | –9 |
| Wisconsin | | –3 | –14 | –24 | –28 | –24 | –18 |
| Wyoming | | –4 | –15 | –18 | –26 | –19 | –16 |

## X6. MICROBIAL CONTAMINATION

X6.1 Uncontrolled microbial contamination in fuel systems can cause or contribute to a variety of problems, including increased corrosivity and decreased stability, filterability, and caloric value. Microbial processes in fuel systems can also cause or contribute to system damage.

X6.2 Because the microbes contributing to the problems listed in X6.1 are not necessarily present in the fuel itself, no microbial quality criterion for fuels is recommended. However, it is important that personnel responsible for fuel quality understand how uncontrolled microbial contamination can affect fuel quality.

X6.3 Guide D6469 provides personnel with limited microbiological background an understanding of the symptoms, occurrences, and consequences of microbial contamination. Guide D6469 also suggests means for detecting and controlling microbial contamination in fuels and fuel systems. Good housekeeping, especially keeping fuel dry, is critical.

## X7. GUIDANCE ON EVALUATION OF NEW MATERIALS FOR #1D AND #2D GRADES OF DIESEL FUELS

X7.1 The purpose of this Appendix is to give some general guidance from Subcommittee D02.E0 on evaluation of new materials for blends in or replacements for Specification D975, Grades #1-D and #2-D type fuels.

X7.2 ASTM International is an organization made up of volunteers and open to all stakeholders and interested entities including users of fuels, producers of fuels, and general interests, including members of the public, and governmental and nongovernmental organizations. Technical committees and subcommittees of ASTM International do not certify, approve, reject, or endorse specific fuels. Rather, ASTM International Committee D02 on Petroleum Products and Lubricants and its Subcommittee D02.E0 on Burner, Diesel, Non-Aviation Gas Turbine, and Marine Fuels develop fuel specifications and with other subcommittees, test methods for diesel fuels. These fuel specifications and test methods provide minimum requirements for properties of fuels covered by these documents in commerce and address the concerns of stakeholders, including that fuels perform appropriately in the specified application.

X7.3 Historically, diesel fuel has been hydrocarbon molecules refined from petroleum. As a result, Specification D975 has evolved to define performance requirements (and tests to determine if those requirements were met) for diesel (compression ignition) engine fuels composed of conventional hydrocarbon oils refined from petroleum. Because the specification evolved to describe this type of fuel, some of the properties necessary for use in a compression ignition engine which are inherent in petroleum derived oils may not be addressed in Specification D975.

X7.4 Specification D975, however, does not require that fuels be derived from petroleum. Section 7.1reads, "The grades of diesel fuel oils herein specified shall be hydrocarbon oils, except as provided in 7.3, with the addition of chemicals to enhance performance, if required, conforming to the detailed requirements shown in Table 1." "Hydrocarbon oils, except as provided in 7.3," provides a path to include other fuels and blendstocks appropriate for inclusion in Specification D975. To date, this path has been used by biodiesel, which is not refined from petroleum and is not hydrocarbon oil.

X7.5 It should be noted that fuel specifications other than Specification D975 have been and are being developed for fuel for compression ignition engines. Specification D6751 sets specifications for fatty acid alkyl esters (B100) to be used as an alternative blendstock. Specification D7467 sets specifications for diesel blends containing biodiesel in the range of 6 % to 20 %. Other new specifications are currently under development. Some new materials may require additional new standard specifications if they are significantly different than current diesel fuels and require different parameters to be controlled or different test methods to properly measure required parameters.

X7.6 Because the composition and properties of new fuels may vary, the particular path to a specification for a new fuel may vary. Some current alternative fuels are similar to traditional petroleum-refined diesel fuel while others are chemically and physically different. Future fuels may vary even more.

X7.7 Three areas for consideration when reviewing new fuels alignment with existing standards or developing new standards are: test methods, chemical and physical limitations of fuels in existing specifications, and chemical and physical limitations appropriate for new fuels. The test methods that have been developed for existing compression ignition engine fuels may or may not be appropriate for a new fuel. Guidance on materials used to develop a test method, and it's applicability, can generally be found in a test method's scope and precision statements. The test method may also work for other materials.

X7.8 Applicability of the test method to materials outside its scope may be established by the subcommittee responsible for the method. Also, Subcommittee D02.E0, during the specification development process, may determine that a test method is applicable for specification purposes, even if the material is not in the test method's scope. Chemical and physical limits set in existing standards may or may not be appropriate to the new fuel or components. The new material may also require chemical or physical limits that are not appropriate to fuels in existing standards. These along with other considerations may indicate the need for separate new specifications. Although each case will require a separate evaluation, logic suggests that the fewer chemical and physical differences there are between the new fuel and traditional petroleum-based diesel fuel, the fewer differences in test methods and chemical or physical limits will be needed.

X7.9 If the proponent of the new fuel desires to move forward via the consensus process as described by ASTM bylaws and as implemented in Committee D02, then the proponent or a task force including the fuel manufacturer or proponent will bring forward ballot revisions to Specification D975 or a new specification appropriate for use of the new fuel or blendstock. Because D02 specifications are established based on technical data, such data should exist before the specification process moves forward. If such data does not exist, it needs to be developed.

X7.10 This guidance is not all-encompassing and cannot replace the judgment and process of a task force and subcommittee charged with evaluating a new fuel or blendstock. However it may give some guidance to proponents or fuel manufacturers who are considering participation in ASTM Committee D02 and its subcommittees to promote the inclusion of their new fuel or blendstock in ASTM standards.

## X8. WATER AND SEDIMENT GUIDELINES

### X8.1 Introduction

X8.1.1 This appendix provides guidance regarding the control of water and sediment (particulate) in the distribution and use of diesel fuel oils in modern compression ignition engines. The information in this appendix is intended to provide additional information beyond the control of water and sediment in D975 as prescribed in Table 1 utilizing test methods defined in 5.1.3.

X8.1.2 All parties involved in the production, distribution, and use of fuels are advised that the engine requirements are changing and everyone involved should take appropriate steps to assure that clean and dry fuel is being delivered.

X8.1.3 All parties involved in the design, manufacture, and use of engines and/or equipment that use fuels are advised that on-board filtration and water removal systems should be installed and properly maintained such that clean, dry fuel delivered to the engine and/or equipment is maintained.

### X8.2 Water

X8.2.1 Water can be found at some concentration in all marketplace fuels. Water can either be a separate phase (that is, free water) or dissolved in the fuel. The amount of water that will dissolve in fuel is dependent on the temperature and chemical composition (including all blend components, additives, and impurities) of the fuel. For example, fuel stored at very cold temperatures, that is, –20 °C, can have very little dissolved water, whereas fuel stored at high temperatures and high ambient humidity conditions, that is, 35 °C and 95 % relative humidity, can have a significantly higher concentration of dissolved water. As another example, a highly aromatic fuel can hold more dissolved water than a highly paraffinic fuel, while both fuels still meet all of the requirements of D975. The Test Method D2709 centrifuge test method for determination of free water and sediment provides a cost effective screening procedure to determine relatively high levels of free water and sediment, but cannot measure dissolved water. In contrast, the Test Method D6304 and Test Method E1064 test methods measure total water content (the sum of dissolved and free water). Diesel fuel should never contain free water at the time it is introduced into a vehicle or equipment fuel tank, but such a result can be difficult to achieve when 'warm' fuel, saturated with dissolved water cools. Under those circumstances, free water (or ice at temperatures below 0 °C) separates from the fuel. A good industry practice is to drain any free water from a storage tank before the fuel is moved further through the distribution system. Fuel tanks utilized for process flow control without sufficient settling time cannot be utilized for water separation. For those tanks, water removal may be required downstream prior to the delivery to the retail outlet or distributor. Options for water removal include the addition of settling time in tankage with water draw off, using appropriate water-absorption techniques, or adding water coalescing facilities at point of fuelling equipment to ensure that only fuel with no free water ("dry fuel") goes into the equipment's fuel tank. Water-absorbing cartridge filters, which are designed to stop flowing on exposure to water, can be used as an alert mechanism for the presence of free water in a fuel tank.

### X8.3 Sediment

X8.3.1 Sediment, otherwise known as particulates, can be found in virtually all marketplace fuels. These particulates come from a variety of sources including piping, storage tanks, microbial contamination, fuel degradation products, and exposure to airborne particles during fuel transportation and handling. Engine/vehicle filtration systems are designed based on the expectation that fuel introduced to the engine's fuel tank will meet certain cleanliness levels. Sediment or particulates in fuel can be measured in two fundamentally different ways: *(1)* mass of the total sediment or particulates per unit volume; or *(2)* particle size and count per unit volume. Filtration can be put in place at various points in the fuel production and distribution system to limit the amount of sediment or particulate that is introduced to the vehicle or equipment fuel tank. Filtration at the point of fuel delivery into equipment is particularly important. Historically, sediment or particulate control by measurement of total mass or volume has been sufficient to determine fuel cleanliness. However, as fuel injection system pressures and event precision requirements [including timing of injection events and multiple injections per power stroke] have increased, the fuel injection systems have become far more sensitive to particle size and amounts. ASTM has developed a particle size rating procedure that describes particle size and related count information (Test Method D7619). Utilizing the particle size and count

**TABLE X8.1 Particle Number Range Codes**

| Range Code Chart | | |
|---|---|---|
| Range Code | Particles per millilitre | |
| | More than | Less than or Equal to |
| 21 | 10 000 | 20 000 |
| 20 | 5000 | 10 000 |
| 19 | 2500 | 5000 |
| 18 | 1300 | 2500 |
| 17 | 640 | 1300 |
| 16 | 320 | 640 |
| 15 | 160 | 320 |
| 14 | 80 | 160 |
| 13 | 40 | 80 |

information, fuel can be characterized by range numbers as described below (reference ISO 4406). As shown in Table X8.1, the number of particles counted per milliliter of fuel defines a "Range Code". Particles are counted per particle size such that the number of particles is determined that are greater than 4, 6, and 14 micrometers respectively.

X8.3.1.1 For example a fuel particle characterization of 18/16/13 would describe relatively cleaner fuel containing:

18: 1300 to 2500 particles greater than or equal to 4 µm ⁄mL
16: 320 to 640 particles greater than or equal to 6 µm ⁄mL
13: 40 to 80 particles greater than or equal to 14 µm ⁄mL

X8.3.1.2 Whereas a fuel particle characterization of 21/19/17 would describe a relatively dirtier fuel containing:

21: 10 000 to 20 000 particles greater or equal to than 4 µm ⁄mL
19: 2500 to 5000 particles greater than or equal to 6 µm ⁄mL
17: 640 to 1300 particles greater than or equal to 14 µm ⁄mL

X8.3.2 Filtration specifications should include both a micron rating and a beta rating. The absolute micron rating gives the size of the largest particle that will pass through openings in the filter, although no standardized test method to determine its value exists. In contrast, the nominal micron rating describes the size of a typical particle that the filter will remove. The beta rating comes from the Multipass Method for Evaluating Filtration Performance of a Fine Filter Element (ISO 16889). The ratio is defined as the particle count upstream divided by the particle count downstream at the rated particle size. The efficiency of the filter can be calculated directly from the beta ratio because the percent capture efficiency is ((beta-1)/beta) × 100. However, caution must be exercised when using beta ratios to compare filters because such ratios do not take into account actual operating conditions like flow surges, mounting orientation, vibration, and changes in temperature. As in all filtration system designs, the flow capacity and the expected contamination level are critical to achieve an acceptable result. Table X8.2 provides an example of filter beta ratings, particulate removal and percent efficiency.

**TABLE X8.2 Filter Beta Ratio**

| Incoming Contaminant Level (particles/mL) | Outgoing Contaminant Level (particles/mL) | Beta Ratio | Percent Efficiency |
|---|---|---|---|
| 1 000 000 | 500 000 | 2 | 50 |
| | 50 000 | 20 | 95 |
| | 13 000 | 75 | 98.7 |
| | 5000 | 200 | 99.5 |
| | 1000 | 1000 | 99.9 |
| | 100 | 10 000 | 99.99 |

## X8.4 Water and Sediment Controls

X8.4.1 Several strategies may be used separately or in combination to control the amount of water and sediment that are ultimately delivered to the end user's fuel tank.

X8.4.2 One potential method for ensuring that clean and dry fuel is delivered to the vehicle or equipment is to use high volume particulate filtration, combined with either water coalescing or water absorbing capability. Such a system should be designed based upon expected local fuel quality, operating conditions and the customer's needs. Factors to be considered may include:

X8.4.2.1 The flow rating for the filtration, coalescer, or absorber being at least as high as the maximum expected fuel transfer rate;

X8.4.2.2 Selection of particulate filtration including both the micron and beta ratings based upon the application;

X8.4.2.3 Selection of coalescer or water absorber capable of removing visible free water in the fuel;

X8.4.2.4 An automatic water drain system to remove separated water.

X8.4.3 Water separation through the use of a coalescer can be adversely affected by polar substances either inherent in the fuel chemistry or added to the fuel. In fuel storage and delivery systems in which such materials are anticipated:

X8.4.3.1 A water absorber may be preferable (see caution in Section X8.2.1), or

X8.4.3.2 If a coalescer is utilized, the water content in the fuel should periodically be monitored downstream of the coalescer to assure dry fuel delivery to downstream users.

## SUMMARY OF CHANGES

Subcommittee D02.E0 has identified the location of selected changes to this standard since the last issue (D975 – 16a) that may impact the use of this standard. (Approved May 1, 2017.)

*(1)* Revised subsection 7.3 to remove reference to undefined alternative fuels and repeated definition of alternative blendstocks.

Subcommittee D02.E0 has identified the location of selected changes to this standard since the last issue (D975 – 16) that may impact the use of this standard. (Approved Oct. 1, 2016.)

*(1)* Added new definition of "additive" and "alternative blendstock" and discussions of the new terms.
*(2)* Revised Appendix X3 completely.
*(3)* Added new subsection 6.2.
*(4)* Revised subsections 7.3 and X7.5.

Subcommittee D02.E0 has identified the location of selected changes to this standard since the last issue (D975 – 15c) that may impact the use of this standard. (Approved Sept. 1, 2016.)

*(1)* Revised footnote I of Table 1.

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