Designation: D 975 – 08a

An American National Standard

Standard Specification for Diesel Fuel Oils[1]

This standard is issued under the fixed designation D 975; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This specification 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 may 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 D 4865.

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

2. Referenced Documents

2.1 *ASTM Standards:* [3]

D 56 Test Method for Flash Point by Tag Closed Cup Tester

D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure

D 93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)

D 130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D 482 Test Method for Ash from Petroleum Products

[1] This specification is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.E0.02 on Diesel Fuel Oils.

Current edition approved Oct. 1, 2008. Published October 2008. Originally approved in 1948. Last previous edition approved in 2008 as D 975–08.

[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.**

D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products
D 613 Test Method for Cetane Number of Diesel Fuel Oil
D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)
D 1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)
D 2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
D 2500 Test Method for Cloud Point of Petroleum Products
D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D 2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
D 2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
D 2880 Specification for Gas Turbine Fuel Oils
D 2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
D 3117 Test Method for Wax Appearance Point of Distillate Fuels
D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
D 3828 Test Methods for Flash Point by Small Scale Closed Cup Tester
D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products
D 4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D 4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination
D 4308 Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
D 4539 Test Method for Filterability of Diesel Fuels by Low-Temperature Flow Test (LTFT)
D 4737 Test Method for Calculated Cetane Index by Four Variable Equation
D 4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
D 5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D 5771 Test Method for Cloud Point of Petroleum Products (Optical Detection Stepped Cooling Method)
D 5772 Test Method for Cloud Point of Petroleum Products (Linear Cooling Rate Method)
D 5773 Test Method for Cloud Point of Petroleum Products (Constant Cooling Rate Method)
D 5842 Practice for Sampling and Handling of Fuels for Volatility Measurement
D 5854 Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products
D 6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
D 6079 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)
D 6217 Test Method for Particulate Contamination in Middle Distillate Fuels by Laboratory Filtration
D 6371 Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels
D 6468 Test Method for High Temperature Stability of Middle Distillate Fuels
D 6469 Guide for Microbial Contamination in Fuels and Fuel Systems
D 6751 Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
D 6890 Test Method for Determination of Ignition Delay and Derived Cetane Number (DCN) of Diesel Fuel Oils by Combustion in a Constant Volume Chamber
D 6898 Test Method for Evaluating Diesel Fuel Lubricity by an Injection Pump Rig

2.2 *Other Documents:*

26 CFR Part 48 Manufacturers and Realtors Excise Taxes[4]
40 CFR Part 80 Regulation of Fuels and Fuel Additives[4]
API RP 2003 Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents[5]
EN 14078 Liquid petroleum products - Determination of fatty acid methyl esters (FAME) in middle distillates - Infrared spectroscopy method[6]

3. Terminology

3.1 *Definitions:*

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

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

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

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

[4] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.
[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[6] Available from the National CEN members listed on the CEN website (www.cenorm.be) or from the CEN/TC 19 Secretariat (astm.@nen.nl).

TABLE 1 Detailed Requirements for Diesel Fuel Oils[A]

Property	ASTM Test Method[B]	Grade						
		No. 1-D S15	No. 1-D S500[C]	No. 1-D S5000[D]	No. 2-D S15[E]	No. 2-D S500[C,E]	No. 2-D S5000[D,E]	No. 4-D[D]
Flash Point, °C, min.	D 93	38	38	38	52[E]	52[E]	52[E]	55
Water and Sediment, % vol, max	D 2709	0.05	0.05	0.05	0.05	0.05	0.05	...
	D 1796	...	...	...	...	...	...	0.50
Distillation Temperature, °C 90 %, % vol recovered	D 86							
min		...	...	...	282[E]	282[E]	282[E]	...
max		288	288	288	338	338	338	...
Kinematic Viscosity, mm^2/S at 40°C	D 445							
min		1.3	1.3	1.3	1.9[E]	1.9[E]	1.9[E]	5.5
max	...	2.4	2.4	2.4	4.1	4.1	4.1	24.0
Ash % mass, max	D 482	0.01	0.01	0.01	0.01	0.01	0.01	0.10
Sulfur, ppm (μg/g)[F] max	D 5453	15	...	...	15	...	...	...
% mass, max	D 2622[G]	...	0.05	...	...	0.05	...	...
% mass, max	D 129	...	...	0.50	...	...	0.50	2.00
Copper strip corrosion rating, max (3 h at a minimum control temperature of 50°C)	D 130	No. 3	No. 3	No. 3	No. 3	No. 3	No. 3	...
Cetane number, min[H]	D 613	40[I]	40[I]	40[I]	40[I]	40[I]	40[I]	30[I]
One of the following properties must be met:								
(1) Cetane index, min.	D 976–80[G]	40	40	...	40	40	...	...
(2) Aromaticity, % vol, max	D 1319[G]	35	35	...	35	35	...	...
Operability Requirements								
Cloud point, °C, max	D 2500	[J]	[J]	[J]	[J]	[J]	[J]	...
or								
LTFT/CFPP, °C, max	D 4539/ D 6371							
Ramsbottom carbon residue on 10 % distillation residue, % mass, max	D 524	0.15	0.15	0.15	0.35	0.35	0.35	...
Lubricity, HFRR @ 60°C, micron, max	D 6079	520	520	520	520	520	520	...
Conductivity, pS/m or Conductivity Units (C.U.), min	D 2624/D 4308	25[K]	25[K]	25[K]	25[K]	25[K]	25[K]	...

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

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

[C] 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 per thousand barrels of the solid dye standard Solvent Red 26, or the tax must be collected.

[D] 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 per thousand barrels of the solid dye standard Solvent Red 26.

[E] 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.

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

[G] These test methods are specified in 40 CFR Part 80.

[H] Where cetane number by Test Method D 613 is not available, Test Method D 4737 can be used as an approximation.

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

[J] 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 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 D 4539 and D 6371 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 may be used to estimate expected regional target temperatures for use with Test Methods D 2500, D 4539, and D 6371. Refer to X5.1.3 for further general guidance on test application.

[K] 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 8.2 for detailed requirements) into mobile transport (for example, tanker trucks, rail cars, and barges). The conductivity specification becomes effective on 11/12/08.

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 D 93, except where other methods are prescribed by law. For all grades, Test Method D 3828 may be used as an alternate 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 D 56

may be used as an alternate 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 D 93 shall be used as the referee method. Test Method D 56 can not be used as the alternate 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 D 2500. For all fuel grades in Table 1, the automatic Test Methods D 5771, D 5772, or D 5773 can be used as alternates with the same limits. Test Method D 3117 can also be used since it is closely related to Test Method D 2500. In case of dispute, Test Method D 2500 shall be the referee method.

5.1.3 *Water and Sediment*—Test Method D 2709 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 D 1796 is used for Grade No. 4-D.

5.1.4 *Carbon Residue*—Test Method D 524 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 D 482 is used for all grades in Table 1.

5.1.6 *Distillation*—Test Method D 86 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 D 2887 can be used as an alternate. Results from Test Method D 2887 shall be reported as "Predicted D86" results by application of the correlation in Appendix X5 of Test Method D 2887 to convert the values. In case of dispute, Test Method D 86 shall be the referee method. Grade No. 4-D does not have distillation requirements.

5.1.7 *Viscosity*—Test Method D 445 is used for all fuel grades in Table 1.

5.1.8 *Sulfur*—The following list shows the referee test methods and alternate test methods for sulfur, the range over which each test method applies and the corresponding fuel grades.

Sulfur Test Method	Range	Grades
D 129 (referee)	>0.1 mass %	No. 1-D S5000, No. 2-D S5000, No. 4-D
D 1266	0.0005 to 0.4 mass % 5 to 4000 mg/kg (wt ppm)	No. 1-D S500, No. 2-D S500
D 1552	>0.06 mass %	No. 1- D S5000, No. 2-D S5000, No. 4-D
D 2622 (referee for S500 Grades)	0.0003 to 5.3 mass % 3 to 53 000 mg/kg (wt ppm)	All Grades
D 3120	3.0 to 100 mg/kg (wt ppm)	No. 1-D S15, No. 2-D S15 No. 1-D S500, No. 2-D S500 (S500 grades must be diluted before testing)
D 4294	0.0150 to 5.00 mass % 150 to 50 000 mg/kg (wt ppm)	No. 1- D S5000, No. 2-D S5000, No. 4-D
D 5453 (referee for S15 grades)	0.0001 to 0.8 mass % 1.0 to 8000 mg/kg (wt ppm)	All Grades

NOTE 4—The units used to report results in the above test methods are:

D 129	mass %
D 1266	mass %
D 1552	mass %
D 2622	mass %
D 3120	ppm (µg/g)
D 4294	mass %
D 5453	ppm (µg/g)

Results reported in mg/kg and in ppm (µg/g) are numerically the same. The units used in Table 1 for the sulfur requirements are the units in which results for the referee test are reported.

5.1.9 *Copper Corrosion*—Test Method D 130, 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.

5.1.10 *Cetane Number*—Test Method D 613 is used for all fuel grades in Table 1. Test Method D 6890 is 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 D 613 shall be the referee method.

5.1.11 *Cetane Index*—Test Methods D 976–80 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 D 1319. 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. 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 D 6079.

5.1.14 *Conductivity*—Both conductivity test methods, Test Methods D 2624 and D 4308 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 D 4308 is preferred.

6. Workmanship

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

7. Requirements

7.1 The grades of diesel fuel oils herein specified shall be hydrocarbon based oils conforming to the detailed requirements shown in Table 1.

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

7.3.1 *Biodiesel for Blending*—If biodiesel is a component of any diesel fuel, the biodiesel shall meet the requirements of Specification D 6751.

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

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

7.3.3 Test Method EN 14078 shall be used for determination of the vol% biodiesel in a biodiesel blend.

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

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

8. Precautionary Notes on Conductivity

8.1 Due to the normal depletion of fuel conductivity during commingling, storage, and distribution, or 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 may 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 D 4865 and Test Method D 2624.

8.2 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.

8.3 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 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.

8.4 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.

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, may be produced within the boiling range of 150 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 may 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.

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

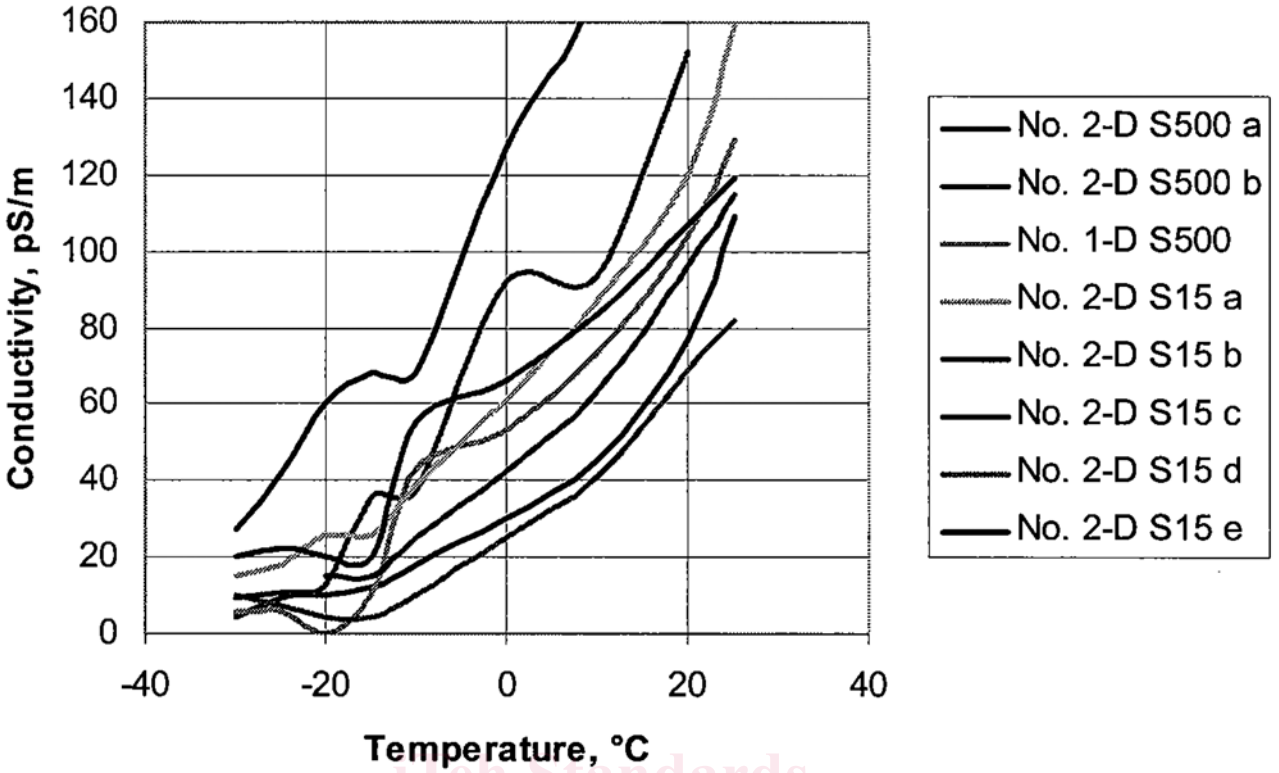

FIG. X1.1 Conductivity Varies with Temperature

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 may 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 may 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 may 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 D 6469 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 may 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 may 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 D 4865 as well as API RP 2003 and ISGOTT.[7]

X1.16.2 Conductivity is know 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.

[7] *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 D 4057 and automatic method sampling is covered in Practice D 4177.

X2.2.2 The correct sample volume and appropriate container selection are also important decisions that can impact test results. Practice D 4306 for aviation fuel container selection for tests sensitive to trace contamination may be useful. Practice D 5854 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 D 6079, "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 D 4306."

X2.2.3 For volatility determination of a sample, Practice D 5842 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 distillate fuel equipment manufacturer or by federal, state, or local government regulations. Although they cannot replace a 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.

X3.2 Definitions

X3.2.1 *bulk fuel*—fuel in the storage facility.

X3.2.2 *fuel contaminants*—foreign materials that make fuel less suitable or unsuitable for the intended use.

X3.2.2.1 *Discussion*—Fuel contaminants include materials introduced subsequent to the manufacture of fuel and fuel degradation products.

X3.2.3 *fuel-degradation products*—those materials that are formed in fuel during extended storage or exposure to high temperatures.

X3.2.3.1 *Discussion*—Insoluble degradation products may combine with other fuel contaminants to reinforce deleterious effects. Soluble degradation products (soluble gums) are less volatile than fuel and may 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 may be catalyzed by dissolved metals, especially copper salts. When dissolved copper is present it can be deactivated with metal deactivator additives.

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

X3.2.5 *severe use*—use of the fuel in applications which may result in engines operating under high load conditions that may cause the fuel to be exposed to excessive heat.

X3.3 Fuel Selection

X3.3.1 Certain distilled refinery products are generally more suitable for long-term storage and severe service than others. 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 specific refineries may be different. 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 fuels from various sources may interact to give stability properties worse than expected based on the characteristics of the individual fuels.

X3.4 Fuel Additives

X3.4.1 Available fuel additives can improve the suitability of marginal fuels for long-term storage and thermal stability, but may be unsuccessful for fuels with markedly poor stability properties. Most additives should be added at the refinery or during the early weeks of storage to obtain maximum benefits.

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

X3.5 Tests for Fuel Quality

X3.5.1 At the time of manufacture, the storage stability of fuel may be assessed using Test Method D 2274 or D 5304. However, these accelerated stability tests may not correlate well with field storage stability due to varying field conditions and to fuel composition.

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 D 6468, provides an indication of thermal oxidative stability of middle distillate fuels when heated to temperatures near 150°C.

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 program. A plan to replace aged fuel with fresh product at established intervals is also desirable.

X3.6.2 Stored fuel should be periodically sampled and its quality assessed. Practice D 4057 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 D 4057, 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 D 6217.

X3.6.4 Test Method D 6468, can be used for investigation of operational problems that might be related to fuel thermal stability. 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 operation may be on fuels from multiple sources.

X3.6.5 Some additives exhibit effects on fuels tested in accordance with Test Method D 6468 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.

X3.7 Fuel Storage Conditions

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

X3.7.2 Copper and copper-containing alloys should be avoided. Copper can promote fuel degradation and may 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 D 2880 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.

X3.8.2 Inadequate high temperature stability may 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 can often be consumed in a normal way, depending on the fuel system requirements. Filters and other cleanup equipment can require special attention and increased maintenance. Burner nozzle or injector fouling can occur more rapidly.

X3.9.2 Fuels containing very large quantities of fuel degradation products and other contaminants or with runaway microbiological growth require special attention. Consultation with experts in this area is desirable. It can be possible to drain the sediment or draw off most of the fuel above the sediment layer and use it with the precautions described in X3.9.1. However, very high soluble gum levels or corrosion products from microbiological contamination can cause severe operational problems.

X3.10 Thermal Stability Guidelines

X3.10.1 Results from truck fleet experience suggests that Test Method D 6468 can be used to qualitatively indicate whether diesel fuels have satisfactory thermal stability performance properties.[8,9]

X3.10.2 Performance in engines has not been sufficiently correlated with results from Test Method D 6468 to provide definitive specification requirements. However, the following guidelines are suggested.

[8] 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.

[9] 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.

X3.10.2.1 Fuels giving a Test Method D 6468 reflectance value of 70 % or more in a 90 minute test at the time of manufacture should give satisfactory performance in normal use.

X3.10.2.2 Fuels giving a Test Method D 6468 reflectance value of 80 % or more in a 180 minute test at the time of manufacture should give satisfactory performance in severe use.

X3.10.3 Thermal stability as determined by Test Method D 6468 is known to degrade during storage.[10] The guidance above is for fuels used within six months of manufacture.

[10] Henry, C. P., "The DuPont F21 149°C (300°F) Accelerated Stability Test," *Distillate Fuel Stability and Cleanliness, ASTM STP 751*, 1981, pp. 22-33.

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 D 975. Two test methods were proposed and approved. These are Test Method D 6078, a scuffing load ball-on-cylinder lubricity evaluator method, SLBOCLE, and Test Method D 6079, 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 microns has been placed in Specification D 975.[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 microns might not prevent excessive wear,[14] while fuels with values below 450 microns should provide sufficient lubricity in all cases.[13] More accurately, an industry-accepted long-term durability pump test, such as Test Method D 6898, 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.

[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.