Designation: D2880 – 23

Standard Specification for Gas Turbine Fuel Oils[1]

This standard is issued under the fixed designation D2880; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This specification covers the grades of fuels for gas turbines, excepting gas turbines used in aircraft, for the guidance of interested parties such as turbine manufacturers and the suppliers and purchasers of fuel oils. These grades are described as follows:

1.1.1 Grades No. 0-GT S5000, No. 0-GT S500, and No. 0-GT S15 includes naphtha, Jet B, and other light hydrocarbon liquids that characteristically have low flash point and low viscosity as compared with kerosine and fuel oils.

1.1.2 Grades No. 1-GT S5000, No. 1-GT S500, and No. 1-GT S15 are a light distillate fuel oil suitable for use in nearly all gas turbines.

1.1.3 Grades No. 2-GT S5000, No. 2-GT S500, and No. 2-GT S15, which is a heavier distillate than Grade No. 1-GT, can be used by gas turbines not requiring the clean burning characteristics of Grade No. 1-GT. Fuel heating equipment may be required by the gas turbine depending on the fuel system design or ambient temperature conditions, or both.

1.1.4 Grade No. 3-GT may be a heavier distillate than Grade No. 2-GT, a residual fuel oil that meets the low ash requirements, or a blend of distillate with a residual fuel oil. Fuel heating will be required by the gas turbine in almost every installation.

1.1.5 Grade No. 4-GT includes most residuals and some topped crudes. Because of the wide variation and lack of control of properties, the gas turbine manufacturer should be consulted with regard to acceptable limits on properties.

1.2 Three appendixes are provided for informational purposes only and do not constitute a requirement of this specification unless mutually agreed upon between the interested parties.

1.2.1 Appendix X1 describes the five grades of gas turbine fuels covered by this specification. Further, it states the significance of various test methods used in inspecting the fuels.

1.2.2 Appendix X2 discusses the sources of fuel contaminants and notes the significance of such contaminants in the operation of gas turbines and gas turbine fuel systems. The particular significance of trace metals in gas turbine fuels is noted. Upper limits of trace metals are recommended for the various grades of gas turbine fuels, but these recommended limits do not constitute a requirement of the specification unless mutually agreed upon by the interested parties. Limitations due to the use of used or recycled oil are also noted.

NOTE 1—The gas turbine operator should consult Practice D4418 for methods of ensuring fuels of adequate cleanliness and for guidance on long-term storage of distillate fuels and on liquids from non-petroleum sources as gas turbine.

NOTE 2—The generation and dissipation of static electricity can create problems in the handling of distillate gas turbine fuel oils. For more information on the subject, see Guide D4865.

1.3 This specification, unless otherwise provided by agreement between the purchaser and the supplier, prescribes the required properties of gas turbine fuel oils at the time and place of delivery.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D56 Test Method for Flash Point by Tag Closed Cup Tester

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

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D97 Test Method for Pour Point of Petroleum Products

[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 and Non-Aviation Gas Turbine Fuels.

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[2] 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**

D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)
D396 Specification for Fuel Oils
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
D975 Specification for Diesel Fuel
D1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
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)
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
D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
D3605 Test Method for Trace Metals in Gas Turbine Fuels by Atomic Absorption and Flame Emission Spectroscopy
D3828 Test Methods for Flash Point by Small Scale Closed Cup Tester
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
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
D4418 Practice for Receipt, Storage, and Handling of Fuels for Gas Turbines
D4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D5854 Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products
D5949 Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method)
D5950 Test Method for Pour Point of Petroleum Products (Automatic Tilt Method)
D5985 Test Method for Pour Point of Petroleum Products (Rotational Method)
D6079 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)
D6469 Guide for Microbial Contamination in Fuels and Fuel Systems
D6728 Test Method for Determination of Contaminants in Gas Turbine and Diesel Engine Fuel by Rotating Disc Electrode Atomic Emission Spectrometry
D6749 Test Method for Pour Point of Petroleum Products (Automatic Air Pressure Method)
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
D7220 Test Method for Sulfur in Automotive, Heating, and Jet Fuels by Monochromatic Energy Dispersive X-ray Fluorescence Spectrometry
D7344 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure (Mini Method)
D7345 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure (Micro Distillation Method)
D7346 Test Method for No Flow Point and Pour Point of Petroleum Products and Liquid Fuels
D7688 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR) by Visual Observation
D7945 Test Method for Determination of Dynamic Viscosity and Derived Kinematic Viscosity of Liquids by Constant Pressure Viscometer
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *Other Documents:*[3]

26 CFR Part 48 Diesel Fuel Excise Tax; Dye Color and Concentration
40 CFR Part 80 Regulation of Fuels and Fuel Additives

3. Terminology

3.1 *Definitions:*

3.1.1 *contamination, n*—any process which introduces contaminants into the fuel.

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

3.1.2.1 *Discussion*—Contaminants, which can be soluble in the fuel or insoluble (suspended liquid droplets or solid or semi-solid particles), can be the result of improper processing or contamination by a wide range of materials including water,

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

rust, airblown dust, deterioration of internal protective coatings on pipes or vessels and products of fuel degradation and microbial growth.

3.1.2.2 *Discussion*—Solid or semisolid contaminants can be referred to as silt or sediment.

3.1.3 *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.

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

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

3.1.3.3 *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 X3 discusses some matters for consideration regarding the use of fuel oils from feedstocks other than petroleum.

3.1.4 *S(numerical specification maximum), n*—a part of the grade name that states the maximum sulfur content in ppm by mass (mg/kg) allowed by this specification and formatted as S followed with no space by the numerical sulfur maximum.

3.1.4.1 *Discussion*—Of the eleven fuel grades specified in this specification, nine have important distinguishing maximum sulfur regulatory requirements: Grades 0-GT S5000, 0-GT S500, 0-GT S15; No. 1-GT S5000, No. 1-GT S500, No. 1-GT S15; No. 2-GT S5000, No. 2-GT S500, and No. 2-GT S15. The remaining grades are distinguished from these grades by other major properties in addition to sulfur (unregulated levels), and therefore are not included in this designation system.

3.1.4.2 *Discussion*—mg/kg is equivalent to μg/g, 1×10^{-4} % by mass, and mass fraction 0.000001.

3.1.4.3 *Discussion*—Most, but not all, test methods to determine sulfur content mentioned in this specification produce results in units of mg/kg. Consult the test method in use to determine units for a particular result.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fuel entering the combustor(s), n*—the fuel that is actually burned in the gas turbine. Fuel may be sampled at a point upstream from the point of entry into the combustor(s), provided the sample is representative of the fuel actually entering the combustor(s).

4. General Requirements

4.1 The grades of gas turbine fuels herein specified shall be hydrocarbon oils with the use of additives to enhance performance properties, if required. The hydrocarbon oils shall be free of inorganic acid, and free of excessive amounts of solid or fibrous foreign matter likely to make frequent cleaning of suitable strainers necessary.

NOTE 3—Additives are generally included in finished gas turbine fuel oil to improve performance properties (corrosion and anti-corrosion, and so forth).

4.2 All grades containing residual components shall remain homogeneous in normal storage and not separated by gravity into light and heavy oil components outside the viscosity limits for the grade.

5. Detailed Requirements

5.1 The various grades of gas turbine fuel oil shall conform to the limiting requirements shown in Tables 1 and 2. As noted in the supplementary footnotes to Table 1, the requirements for Grade Nos. 1-GT and 2-GT conform in most respects to corresponding Grade Nos. 1 and 2 fuels in Specification D396, and to Grade Nos. 1-D and 2-D in Specification D975. The viscosity range of Grade Nos. 3-GT and 4-GT fuel brackets the Grade Nos. 4, 5, and 6 of Specification D396 and Grade No. 4-D of Specification D975. It is the intent that fuels meeting Specification D396 and D975 requirements may also be supplied under these specifications provided they meet the requirements listed in Tables 1 and 2.

5.2 Modifications of limiting requirements and the inclusion of fuel additives to meet special operating conditions may be agreed upon between the interested parties.

5.3 The properties listed in this specification are those of greatest significance in obtaining acceptable performance of the turbine. However, trace metals, even in fractional parts per million, are detrimental to gas turbine service life. Information on the maximum concentration of critical metallic elements in the fuel as it enters the turbine combustor(s) is provided in Appendix X2. Distillate fuels are usually of satisfactory purity as refined, but suppliers rarely have control over possible contamination by trace metals in distribution and storage. The limits in Appendix X2, although required as the fuel enters the combustor(s), do not apply to the fuel as delivered unless mutually agreed upon by the interested parties. Fuels may, therefore, require on-site clean-up, quality control procedures, special handling, or other arrangements.

6. Test Methods

6.1 The requirements enumerated in this specification shall be determined in accordance with the following ASTM methods except as noted:

6.1.1 *Flash Point*—Test Methods D93, except where other methods are prescribed by law. For all grades, Test Method D3828 and D7094 may be used as an alternative with the same limits. For Grades No. 1-GT and No. 2-GT, Test Method D56[4] 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 case of dispute, Test Method D93 shall be used as the referee method.

6.1.2 *Pour Point*—Test Method D97. For all grades, the automatic Test Methods D5949, D5950, D5985, or D7346 may be used as alternates with the same limits. In case of dispute, Test Method D97 shall be used as the referee method.

6.1.3 *Water and Sediment*—Test Method D2709 is used for Grades 0-GT, 1-GT, and 2-GT. Test Method D1796 is used for Grades 3-GT and 4-GT.

[4] Other mutually acceptable methods may be used.

TABLE 1 Detailed Requirements for Gas Turbine Fuel Oils Conforming to Grades 0-GT, 1-GT, or 2-GT[A, B, C, D]

Property	ASTM Test Method[E]	No. 0-GT S15, S500, or S5000	No. 1-GT S15, S500, or S5000[F]	No. 2-GT S15, S500, or S5000[F]
Flash Point, °C, min	D93	[G]	38	38
Distillation Temperature, °C	D86			
90 % volume recovered, min		...	282	282
90 % volume recovered, max		...	338	338
Kinematic viscosity at 40 °C, mm^2/s	D445			
min		[G]	1.3	1.9
max			2.4	4.1
Sulfur, percent by mass, max[H]				
Grade S15	D5453	0.0015	0.0015	0.0015
Grade S500	D2622	0.05	0.05	0.05
Grade S5000	D2622	0.5	0.5	0.5
Pour Point °C, max[I]	D97	...	–18	–6
Ramsbottom carbon residue on 10 % distillation residue percent by mass, max	D524	0.15	0.15	0.15
Density at 15 °C, kg/m^3 max	D1298	...	850	876
Lubricity, HFRR at 60 °C, micron, max	D6079	...	520	520
Requirements for all grades				
Ash, percent by mass, max	D482		0.01	
Water and sediment, percent by volume, max	D2709		0.05	
Conductivity (pS/m) or Conductivity Units (C.U.), min	D2624/D4308		25[J]	

[A] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.
[B] Gas turbines with waste heat recovery equipment may require fuel sulfur limits to prevent cold end corrosion. Environmental limits may also apply to fuel sulfur in selected areas in the United States and in other countries.
[C] See Sections 4 and 5 for further statements on gas turbine fuel oil requirements.
[D] No. 0-GT includes naphtha, Jet B fuel and other volatile hydrocarbon liquids. No. 1-GT corresponds in general to Specification D396 Grade No. 1 fuel and D975 Grade 1-D diesel fuel in physical properties. No. 2-GT corresponds in general to Specification D396 No. 2 fuel and D975 Grade 2-D diesel fuel in physical properties.
[E] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 6.1.
[F] Under United States regulations, Grades No. 1-GT and No. 2-GT are required by 40 CFR Part 80 to contain a sufficient amount of 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.
[G] When the flash point is below 38 °C (100 °F) or when kinematic viscosity is below 1.3 mm^2/s at 40 °C (104 °F) or when both conditions exist, the turbine manufacturer should be consulted with respect to safe handling and fuel system design.
[H] Other sulfur limits may apply in selected areas in the United States and other countries.
[I] For cold weather operation, the pour point should be specified 6 °C below the ambient temperature at which the turbine is to be operated except where fuel heating facilities are provided. When a pour point less than –18 °C is specified for Grade No. 2-GT, the minimum viscosity shall be 1.7 mm^2/s and the minimum 90 % recovered temperature shall be waived.
[J] The electrical conductivity of the gas turbine fuel oil 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 7.1 for detailed requirements) into mobile transport (for example, tanker trucks, rail cars, and barges).

TABLE 2 Detailed Requirements for Gas Turbine Fuels Conforming to Grades No. 3-GT or 4-GT[A, B, C, D]

Property	ASTM Test Method[E]	No. 3-GT	No. 4-GT
Flash Point, °C, min	D93	55	66
Water and sediment, percent by volume, max	D1796	1.0	1.0
Kinematic viscosity at 40 °C, mm^2/s min	D445	5.5	5.5
Kinematic viscosity at 100 °C, mm^2/s max	D445	50.0	50.0
Ash, percent by mass, max	D482	0.03	...

[A] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.
[B] Gas turbines with waste heat recovery equipment may require fuel sulfur limits to prevent cold end corrosion. Environmental limits may also apply to fuel sulfur in selected areas in the United States and in other countries.
[C] See Sections 4 and 5 for further statements on gas turbine fuel oil requirements.
[D] No. 3-GT and No. 4-GT viscosity range brackets Specification D396 Grades No. 4, No. 5 (light), No. 5 (heavy), and No. 6, and D975 Grade No. 4-D diesel fuel in physical properties.
[E] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 6.1.

6.1.4 *Carbon Residue*—Test Method D524.

6.1.5 *Ash*—Test Method D482.

6.1.6 *Distillation*—Distillation of grades No. 0-GT, No. 1-GT, and No.2-GT fuels oils shall be determined in accordance with Test Methods D86, D2887, D7344, or D7345. Results from Test Method D2887 shall be reported as "Predicted D86" results by application of the correlation in Appendix X4 Test Method D2887 to convert the values. Results from Test Method D7344 shall be reported as "Predicted D86" results by application of the corrections described in Test Method D7344 to improve agreement with D86 values. Results from Test Method D7345 shall be reported as "Predicted D86" results by application of the corrections described in Test Method D7345 to improve agreement with D86 values. In case of dispute, Test Method D86 shall be used as the referee test method.

6.1.7 *Viscosity*—Test Methods D445, D7042, or D7945 may be used. Test method D7945 may be used with the same limits as D445 for grades 1-GT and 2-GT. Bias-corrected values from Test Method D7042 may be used as alternative results for Test

Method D445. 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.

6.1.8 *Density*—Test Method D1298 or D4052.

6.1.9 *Sulfur*—Test Methods D2622 for all grades except S15 and D5453 for S15 grades. See Table 3 for alternative test methods for sulfur and the corresponding fuel grades.

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

6.1.11 *Conductivity*—Both conductivity test methods, Test Methods D2624 and D4308 are allowed for all grades of No. 0-GT, No. 1-GT, and No. 2-GT fuels. There is no conductivity requirement for No. 3-GT or No. 4-GT grades.

7. Precautionary Notes on Conductivity

7.1 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 4 exist for the delivery into a mobile transport container (for example, tanker trucks, railcars, and barges).

8. Keywords

8.1 fuel oils; gas turbine; petroleum and petroleum products

TABLE 3 Sulfur Test Methods

Sulfur Test Method	Grades
D2622 (referee for all grades except S15 grades)	All Grades
D129	No. 0-GT S5000, No. 1-GT S5000, No. 2-GT S5000, No. 3-GT, No. 4-GT
D1266	No. 0-GT S500, No. 1-GT S500, No. 2-GT S500
D1552	No. 0-GT S5000, No. 1-GT S5000, No. 2-GT S5000, No. 3-GT, No. 4-GT
D4294	All Grades except S15 grades
D5453 (referee for S15 grades)	All Grades
D7039	S15 grades, S500 grades, S5000 grades only if the sulfur result is 2822 mg/kg or less
D7220	S15 grade, S500 grades

TABLE 4 Transfer Conditions

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

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF ASTM SPECIFICATIONS FOR GAS TURBINE FUEL OILS

X1.1 Scope

X1.1.1 This specification divides the fuel oils encompassed by Specifications D396 and D975 into four grades, based upon their applicability for use in gas turbines. Also there is a No. 0-GT grade to cover low-flash naphthas. The specification does not include fuels primarily intended for aircraft use. It places limiting values on a number of the properties of the fuels in each grade. The properties selected for limitation are those that are believed to be of the greatest significance in determining performance characteristics of the oils in the various gas turbine applications.

X1.1.2 The physical properties of commercial fuel oils that are important in gas turbine operation are generally the same as those specified by Specifications D396 and D975. In addition, gas turbine operating experience has shown that certain chemical properties of the fuel oil ash must be controlled since slag-forming substances present in the oil ash can cause corrosion and deposits on those turbine parts that must operate at surface temperatures of 593 °C and above. This specification includes the applicable physical properties from Specifications D396 and D975. Appendix X2 lists restrictions required to control high temperature corrosion and deposits.

X1.2 Grades

X1.2.1 Grade 0-GT includes naphtha, Jet B, and other light hydrocarbon liquids that characteristically have low flash point and low viscosity as compared with kerosine and fuel oils.

X1.2.2 Grade 1-GT is a light distillate fuel oil suitable for use in nearly all gas turbines.

X1.2.3 Grade 2-GT, which is a heavier distillate than Grade 1-GT, can be used by gas turbines not requiring the clean burning characteristics of Grade 1-GT. Fuel heating equipment may be required by the gas turbine depending on the fuel system design or ambient temperature conditions, or both.

X1.2.4 Grade 3-GT may be a heavier distillate than Grade 2-GT, a residual fuel oil that meets the low ash requirements, or a blend of distillate with a residual fuel oil. Fuel heating will be required by the gas turbine in almost every installation.

X1.2.5 Grade 4-GT includes most residuals and some topped crudes. Because of the wide variation and lack of control of properties, the gas turbine manufacturer should be consulted with regard to acceptable limits on properties.

NOTE X1.1—Fuels prepared to different specifications and sold under different names may meet the requirements of fuels specified under Specification D2880. However, specification tests would normally have to be run to ensure compliance with the requirements of Specification D2880 as other fuels are not necessarily interchangeable with D2880 fuels throughout the range permitted by the other specifications.

X1.3 Selection of Particular Grade

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

X1.3.1.1 Availability of the fuel,

X1.3.1.2 Design of the gas turbine and fuel handling system,

X1.3.1.3 Maintenance of the gas turbine, and

X1.3.1.4 Operating requirements for the gas turbine.

X1.4 Significance of Test Methods

X1.4.1 The significance of the properties of fuel oil on which limitations are placed by the specifications is as follows:

X1.4.1.1 Flash point is an indication of the maximum temperature at which a fuel oil can be stored and handled without serious fire hazard. The minimum permissible flash point is usually regulated by federal, state, or municipal laws and is based on accepted practice in handling and use.

X1.4.1.2 Pour point is an indication of the lowest temperature at which a fuel oil can be stored and still be capable of flowing under gravitational forces. The pour point is prescribed in accordance with the conditions of storage and use. Fuels with higher pour point are permissible where heated storage and adequate piping facilities are provided.

X1.4.1.3 *Water and Sediments*—Appreciable amounts of water and sediment in a fuel oil tend to cause fouling of the fuel-handling facilities and to give trouble in the fuel system of the gas turbine. An accumulation of sediment in storage tanks and on filter screens may obstruct the flow of oil from the tank to the combustor of the gas turbine. Water in distillate fuels may cause corrosion of tanks and equipment, and water in residual fuel may cause emulsions.

X1.4.1.4 Carbon residue is a measure of the carbonaceous material left in a fuel after all the volatile components are vaporized in the absence of air. It is a rough approximation of

the tendency of a fuel to form carbon deposits in the combustor of the gas turbine. Combustion systems designed for use on Grades 3-GT and 4-GT are insensitive to this property, but other gas turbines may require a limit on the carbon residue. To obtain measurable values of carbon residue in the lighter distillate fuel oils, it is necessary to remove 90 % of the oil by distillation in accordance with Test Method D86, and then determine the carbon residue concentrated in the remaining 10 % bottoms.

X1.4.1.5 Ash is the noncombustible material in an oil. Ash-forming materials may be present in fuel oil in two forms: (*1*) solid particles and (*2*) oil- or water-soluble metallic compounds. The solid particles are for the most part the same material that is designated as sediment in the water and sediment test. Depending on their size, these particles can contribute to wear in the fuel system and to plugging of the fuel filter and the fuel nozzle. The soluble metallic compounds have little or no effect on wear or plugging, but they can contain elements that produce turbine corrosion and deposits as described subsequently.

X1.4.1.6 *Distillation*—The distillation test shows the volatility of a fuel and the ease with which it can be vaporized. Distillation temperature is not directly significant to operation of gas turbines designed for Grades 3-GT and 4-GT. In other gas turbines that are most susceptible to carbon deposition and smoke formation, the more volatile fuels may provide better performance.

X1.4.1.7 Viscosity of a fluid is a measure of its resistance to flow. In fuel oil it is highly significant since it indicates both the relative ease with which the oil will flow or may be pumped, and the ease of atomization by the fuel nozzles. Minimum viscosity is limited because some fuel pumps will not perform satisfactorily if the viscosity reaches too low a value. Maximum viscosity is limited since too high a viscosity can cause excessive pressure losses in the piping system, and poor fuel atomization.

X1.4.1.8 Density alone is of little significance as an indication of the burning characteristics of fuel oil. However, when used in conjunction with other properties, it is of value in weight-volume relationships and in calculating the specific energy heating value of an oil.

X1.4.1.9 Sulfur normally burning to sulfur dioxide, also can be oxidized partially to sulfur trioxide which then can combine with sodium and potassium compounds from the ash in the fuel to form sulfates, pyrosulfates, and such compounds as sodium or potassium iron trisulfate. The pyrosulfates, and the trisulfates have melting points in the operating range of the gas turbine. Hence, the compounds produce severe corrosion of the turbine blading. In general, it has been found impractical to prevent corrosion by limiting the sulfur content of the fuel, so corrosion of this type is controlled by limiting the sodium and potassium. Gas turbines with waste heat recovery equipment may require additional sulfur control to prevent cold-end corrosion.

X2. SIGNIFICANCE OF FUEL CONTAMINANTS AND TRACE METALS IN FUEL SYSTEMS AND IN FUEL ENTERING TURBINE COMBUSTOR(S)

X2.1 Scope

X2.1.1 This appendix discusses the sources of fuel contaminants and notes the significance of such contaminants in the operation of gas turbines and gas turbine fuel systems.

X2.1.2 The particular significance of trace metals in gas turbine fuels is noted and upper limits of trace metals are recommended for the various grades of gas turbine fuels.

X2.2 Sources of Contaminants

X2.2.1 Water may be present in the fuel as dissolved water or as free (undissolved) water, or both. The free water may be fresh or saline. Fresh water may enter the fuel from steam coils in storage tanks, from condensation out of moisture-laden air, or from leaking cooling coils. Saline water can enter the fuel during transportation in barges or tankers.

X2.2.2 Microbial slimes may result when conditions are conducive to the growth of microorganisms, which are always present. The presence of free water is essential to the growth of many of these microorganisms, which grow in tank water bottoms and feed on nutrients in the water or on the hydrocarbons.

X2.2.3 A significant source of particulate solids in gas turbine fuel systems can be the degradation of the fuel to form fuel insoluble compounds. The chemical reactions that cause this degradation vary with the chemical composition of the fuel but can include oxidation, polymerization, and acid-base reactions. The use of appropriate fuel additives can often provide some control of these reactions. Particulate solids can enter a fuel from the air (suspended dirt and aerosols) or from the distribution and storage systems (rust, corrosion products, gasket debris, and so forth).

X2.2.4 Metals may be present as metallic compounds in the fuel as a natural result of the composition of the crude oil and of the refining process. However, unless special precautions are taken, additional metallic compounds can be acquired during distribution and storage. A commercial product pipeline may contain residues of lead-containing gasoline which would then be dissolved by the gas turbine fuel. Tank trucks, railroad tankcars, barges, and tankers may be inadequately cleaned and contain residues of past cargos. Acidic components in saline water salts in the fuel may react with distribution and storage equipment.

X2.3 Significance of Contaminants

X2.3.1 Contamination levels in the fuel entering the combustor(s) must be low for improved turbine life. Low contamination levels in the fuel in the turbine's in-plant fuel system is required to minimize corrosion and operating problems. To provide fuel of adequate cleanliness to the gas turbine combustor(s) may require special actions by the user. These actions might include special transportation arrangements with the fuel