Standard Specification for Gas Turbine Fuel Oils[1]

This standard is issued under the fixed designation D 2880; 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 the selection 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. The specification sets forth the properties of fuels at the time and place of custody transfer to the user.

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 D 4418 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—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 gas turbine fuel oils. For more information on the subject, see Guide D 4865.

2. Referenced Documents

2.1 *ASTM Standards:*

D 56 Test Method for Flash Point by Tag Closed Tester[2]
D 86 Test Method for Distillation of Petroleum Products[2]
D 93 Test Methods for Flash Point by Pensky-Martens Closed Tester[2]
D 97 Test Method for Pour Point of Petroleum Products[2]
D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[2]
D 396 Specification for Fuel Oils[2]
D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[2]
D 482 Test Method for Ash from Petroleum Products[2]
D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products[2]
D 975 Specification for Diesel Fuel Oils[2]
D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[2]
D 1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[2]
D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)[2]
D 1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)[2]
D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[2]
D 2709 Test Method for Water and Sediment in Distillate Fuels by Centrifuge[2]
D 3605 Test Method for Trace Metals in Gas Turbine Fuels by Atomic Absorption and Flame Emission Spectroscopy[3]
D 3828 Test Method for Flash Point by Small Scale Closed Tester[3]
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[3]
D 4294 Test Method for Sulfur in Petroleum Products by Energy-dispersive X-Ray Fluorescence Spectroscopy[3]
D 4418 Practice for Receipt, Storage, and Handling of Fuels for Gas Turbines[3]
D 4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems[3]
D 5453 Test Method for Determination of Total Sulfur in

[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 on Burner, Diesel, Non-Aviation Gas Turbine, and Marine Fuels.

Current edition approved May 10, 2003. Published July 2003. Originally approved in 1970. Last previous edition approved in 2000 as D 2880–00.

[2] *Annual Book of ASTM Standards*, Vol 05.01.

[3] *Annual Book of ASTM Standards*, Vol 05.02.

Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence[4]
D 5949 Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method)[4]
D 5950 Test Method for Pour Point of Petroleum Products (Automatic Tilt Method)[4]
D 5985 Test Method for Pour Point of Petroleum Products (Rotational Method)[4]
D 6469 Guide for Microbial Contamination in Fuels and Fuel Systems[5]
D 6728 Test Method for Determination of Contaminants in Gas Turbine and Diesel Engine Fuel by Rotating Disc Electrode Atomic Emission Spectrometry[5]

2.2 *Other Documents:*
26 CFR Part 48 Diesel Fuel Excise Tax; Dye Color and Concentration[6]
40 CFR Part 80 Regulation of Fuels and Fuel Additives[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *fuel contaminants*—fuel components other than hydrocarbon oils. In the present context the contaminants are foreign materials that make the fuel less suitable or even unsuitable for the intended use.

3.1.1.1 *Discussion*—The contaminants of primary interest are foreign materials introduced subsequent to the manufacture of specification quality fuel. Hence they are materials introduced in the distribution system (that is, storage tanks, pipelines, tank trucks, barges, etc.) or in the user's storage and handling system, or generated within these systems (rust generated in steel pipes and tanks by moist fuel, and so forth). Contaminants may be soluble or insoluble in the fuel.

3.1.2 *fuel entering the combustor(s)*—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 fuels herein specified shall be homogeneous mixtures of hydrocarbon oils free of inorganic acid, and free of excessive amounts of solid or fibrous foreign matter likely to make frequent cleaning of suitable strainers necessary.

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 Table 1. 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 D 396, and to Grade Nos. 1-D and 2-D in Specification D 975. The viscosity range of Grade Nos. 3-GT and 4-GT fuel brackets the Grade Nos. 4, 5, and 6 of Specification D 396 and Grade No. 4-D of Specification D 975. It is the intent that fuels meeting Specification D 396 and D 975 requirements may also be supplied under these specifications provided they meet the requirements listed in Table 1.

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 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-GT and No. 2-GT, Test Method D 56[7] 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 D 93 shall be used as the referee method.

6.1.2 *Pour Point*—Test Method D 97. For all grades, the automatic Test Methods D 5949, D 5950, or D 5985 can be used as alternates with the same limits. In case of dispute, Test Method D 97 shall be used as the referee method.

6.1.3 *Water and Sediment*—Test Method D 2709 is used for Grades 0-GT, 1-GT, and 2-GT. Test Method D 1796 is used for Grades 3-GT and 4-GT.

6.1.4 *Carbon Residue*—Test Method D 524.

6.1.5 *Ash*—Test Method D 482.

6.1.6 *Distillation*—Test Method D 86.

6.1.7 *Viscosity*—Test Method D 445.

6.1.8 *Density*—Test Method D 1298 or D 4052.

6.1.9 *Sulfur*—Test Method D 129, Test Methods D 1552,[8] D 2622, and D 4294 can also be used for all grades. In

[4] *Annual Book of ASTM Standards*, Vol 05.03.
[5] *Annual Book of ASTM Standards*, Vol 05.04.
[6] Available from Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402.
[7] Other mutually acceptable methods may be used.
[8] For information on the precision of the ASTM methods of test for fuel oils refer to "An Evaluation of Methods for Determination of Sulfur in Fuel Oils" by A. R. Crawford and G. V. Dyroff (1969). This document is available from the Publications Section, American Petroleum Institute, 1220 L St., N.W., Washington, DC 20005.

TABLE 1 Detailed Requirements for Gas Turbine Fuel Oils at Time and Place of Custody Transfer to User[A,B]

Property	ASTM Test Method[C]	Grade[D]				
		No. 0-GT	No. 1-GT[E]	No. 2-GT[E]	No. 3-GT	No. 4-GT
Flash point °C (°F) min	D 93	[F]	38 (100)	38 (100)	55 (130)	66 (150)
Water and sediment	D 2709	0.05	0.05	0.05	...	...
% vol max	D 1796	...	...	...	1.0	1.0
Distillation Temperature °C (°F) 90 % volume recovered	D 86					
min		...	...	282	...	...
max		...	288	338	...	...
Kinematic viscosity 2 mm/s[G]	D 445					
AT 40°C (104°F) min		[F]	1.3	1.9	5.5	5.5
max			2.4	4.1	...	...
AT 100°C (212°F) max			...	...	50.0	50.0
Ramsbottom Carbon residue on 10 % distillation Residue % mass, max	D 524	0.15	0.15	0.35	...	...
Ash % mass, max	D 482	0.01	0.01	0.01	0.03	...
Density at 15°C kg/m^3 max	D 1298	...	850	876	...	...
Pour point[G] °C (°F) max	D 97	...	−18	−6	...	...

[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] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 6.1.

[D] No. 0-GT includes naphtha, Jet B fuel and other volatile hydrocarbon liquids. No. 1-GT corresponds in general to specification D 396 Grade No. 1 fuel and D 975 Grade 1-D diesel fuel in physical properties. No. 2-GT corresponds in general to Specification D 396 No. 2 fuel and D 975 Grade 2-D diesel fuel in physical properties. No. 3-GT and No. 4-GT viscosity range brackets specification D 396 Grades No. 4, No. 5 (light), No. 5 (heavy), and No. 6, and D 975 Grade No. 4-D diesel fuel in physical properties.

[E] 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.

[F] 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.

[G] 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.

addition, Test Method D 1266 can be used for Grades No. 0 and No. 1, but only with samples having sulfur contents of 0.4 mass percent and less (down to 0.01 %). Test Method D 5453 can be used for Grades 0, 1, and 2 GT oils, but only with samples having sulfur contents of 0.8 mass % and less (down to 0.001 %). Test Method D 129 is the referee sulfur test method for Specification D 2880.

7. Keywords

7.1 fuel oils; gas turbine; petroleum and petroleum products

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 D 396 and D 975 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 D 396 and D 975. 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 D 396 and D 975. 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 D 2880. However, specification tests would normally have to be run to ensure compliance with the requirements of Specification D 2880 as other fuels are not necessarily interchangeable with D 2880 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 D 86, 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 supplier, particular care in on-site fuel storage and quality control procedures, and establishment of on-site clean-up procedures. Each of the four classes of contaminants defined in X2.2.2 has its own significance to system operation.

X2.3.2 Water will cause corrosion of tanks, piping, flow dividers, and pumps. Corrosion or corrosion products in close tolerance devices such as flow dividers may cause plugging and may stop flow to the turbines. Free water is potentially corrosive; in sulfur-containing fuels, it may be particularly corrosive. Free water may contain dissolved salts that may be corrosive, and may encourage microbiological growth.

X2.3.3 Microbial slimes caused by microorganisms can plug filters and other close-tolerance openings. Some organisms can cause corrosion as well as produce slimes. Under anaerobic conditions, hydrogen sulfide, which may cause corrosion, can be generated by biological action. Biocides are available for controlling the growth of microorganisms, but their effect on trace metal levels and other fuel properties should be considered. Since water is required for the growth of the microorganisms, one way of controlling their growth is to eliminate the presence of water through tank-stripping operations or other separation techniques. Refer to Guide D 6469 for a more complete discussion.

X2.3.4 Particulate solids may shorten the life of fuel system components. Life of fuel pumps and of various close-tolerance devices is a function of particulate levels and size distributions in the fuel. High levels of particulates can lead to short cycle times in the operation of filters, filter/separators, centrifuges, and electrostatic purifiers. Since such separation devices do not remove all the particulates, certain quantities will be present in the down-stream fuel.

X2.3.5 Trace metals refer both to those metals present as metallic compounds in solution and to metals present in particulates like rust. They are dissolved or suspended either in the fuel hydrocarbons or in free water present in the fuel. The significance of several individual trace metals with respect to hot corrosion is discussed in Appendix X1. Although lower levels of trace metals in a fuel will promote longer turbine service from a corrosion standpoint, the specification of excessively low levels may limit the availability of the fuel or materially increase its cost. Table X2.1 suggests levels of trace metals that would probably yield satisfactory service.

X2.3.6 Sodium and potassium can combine with vanadium to form eutectics which melt at temperatures as low as 566°C and can combine with sulfur in the fuel to yield sulfates with melting points in the operating range of the gas turbine. These compounds produce severe corrosion, and for turbines operating at gas inlet temperatures above 650°C additives are not yet in general use which control such corrosion. Accordingly, the sodium-plus-potassium level must be limited, but each element is measured separately. Some gas turbine installations incorporate systems for washing oil with water to reduce the sodium-plus-potassium level. In installations where the fuel is moved by sea transport, the sodium-plus-potassium level should be checked prior to use to ensure that the oil has not become contaminated with sea salt. For gas turbines operating at turbine inlet gas temperatures below 650°C (1200°F), the corrosion due to sodium compounds is of minor importance and can be further reduced by silicon-base additives. A high-sodium content is even beneficial in these turbines because it increases the water-solubility of the deposits and thereby increases the ease with which gas turbines can be water-washed to obtain recovery of the operating performance.

TABLE X2.1 Trace Metal Limits of Fuel Entering Turbine Combustor(s)[A,B]

Designation	Trace Metal Limits, mg/kg			
	Vanadium (V)	Sodium plus Potassium (Na + K)	Calcium (Ca)	Lead (Pb)
No. 0-GT	0.5	0.5	0.5	0.5
No. 1-GT	0.5	0.5	0.5	0.5
No. 2-GT	0.5	0.5	0.5	0.5
No. 3-GT	0.5	0.5	0.5	0.5
No. 4-GT	(Consult turbine manufacturers)			

[A] Test Method D 3605 may be used for determination of vanadium, sodium, calcium, and lead.

[B] Test Method D 6728 may be used for determination of vanadium, sodium, potassium, calcium, and lead.

X2.3.7 Calcium is not harmful from a corrosion standpoint; in fact, it serves to inhibit the corrosive action of vanadium. However, calcium can lead to hardbonded deposits that are not self-spalling when the gas turbine is shut down, and that are not readily removed by water washing of the turbine. The fuel washing systems used at some gas turbine installations to reduce the sodium and potassium level will also significantly lower the calcium content of fuel oil.

X2.3.8 Vanadium can form low melting compounds such as vanadium pentoxide that melts at 691°C, and causes severe corrosive attack on all of the high temperature alloys used for gas turbine blades. If there is sufficient magnesium in the fuel, it will combine with the vanadium to form compounds with higher melting points and thus reduce the corrosion rate to an acceptable level. The resulting ash will form deposits in the turbine and will require appropriate cleaning procedures.

X2.3.8.1 When vanadium is present in more than trace amounts either in excess of 0.5 mg/kg or a level recommended by the turbine manufacturer, it is necessary to maintain a weight ratio of magnesium to vanadium in the fuel of not less than 3.0 in order to control corrosion.

X2.3.8.2 An upper limit of 3.5 is suggested since larger ratios will lead to unnecessarily high rates of ash deposition. In most cases, the required magnesium-to-vanadium ratio will be obtained by additions of magnesium-containing compounds to the fuel oil. The special requirements covering the addition of and type of magnesium-containing additive, or equivalent, shall be specified by mutual agreement between the various interested parties. The additive will vary depending on the application, but it is always essential that there is a fine and uniform dispersion of the additive in the fuel at the point of combustion.

X2.3.8.3 For gas turbines operating at turbine inlet gas temperatures below 650°C, the corrosion of the high-temperature alloys is of minor importance, and the use of a silicon-base additive will further reduce the corrosion rate by absorption and dilution of the vanadium compounds.

X2.3.9 Lead can cause corrosion and in addition it can spoil the beneficial inhibiting effect of magnesium additives on vanadium corrosion. Since lead is only rarely found in significant quantities in crude oils, its appearance in the fuel oil is primarily the result of contamination during processing or transportation.