



Standard Practice for Receipt, Storage, and Handling of Fuels for Gas Turbines¹

This standard is issued under the fixed designation D 4418; 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.

1. Scope

1.1 This practice covers the receipt, storage, and handling of fuels for gas turbines, except for gas turbines used in aircraft. It is intended to provide guidance for the control of substances in a fuel that could cause deterioration of either the fuel system, or the gas turbine, or both.

1.2 This practice provides no guidance for either the selection of a grade of fuel, a topic covered by Specification D 2880, or for the safety aspects of the fuel and fuel systems. For example, this practice does not address the spacings of storage tanks, loading and unloading facilities, etc., and procedures for dealing with the flammability and toxic properties of the fuels.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- D 1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)²
- D 1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)²
- D 2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)²
- D 2276 Test Methods for Particulate Contaminant in Aviation Fuel by Line Sampling²
- D 2880 Specification for Gas Turbine Fuel Oils³
- D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products³
- D 6469 Guide for Microbial Contamination in Fuels and Fuel Systems⁴

¹ This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.E on Burner, Diesel, and Gas Turbine Fuel Oils.

Current edition approved Dec. 10, 2000. Published January 2001. Originally published as D 4418 – 84. Last previous edition D 4418 – 88(1998).

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

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

⁴ *Annual Book of ASTM Standards*, Vol 05.04.

3. Terminology

3.1 *fuel entering the combustor(s)*— this term is used to designate the fuel that is actually burned in the gas turbine. Fuel may actually 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).

3.2 *fuel contaminants*—in principle, are any fuel component 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. 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 systems, or generated within these systems (rust generated in steel pipes and tanks by moist fuel, etc.). Contaminants may be soluble or insoluble in the fuel.

3.3 *dissolved and free water*—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.

3.4 *particulate solids*—may 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).

3.5 *metallic compounds*—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 that 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.

3.6 *microbial slimes*—may result when conditions are conducive to the growth of microorganisms that are always present. The presence of free water is essential to the growth of many of these microorganisms that grow in tank water bottoms and feed on nutrients in the water or on the hydrocarbons.

4. Summary of Practice

4.1 The body of this practice defines the contaminants frequently found in turbine fuel oils and discusses the sources and significance of such contaminants.

4.2 Annex A1 is a guide for the receipt, storage, and handling of distillate gas turbine fuels, Grades 1-GT and 2-GT, in accordance with Specification D 2880.

4.3 Annex A2 is a guide for the receipt, storage, and handling of gas turbine fuels, Grades 3-GT and 4-GT, that contain residual components.

4.4 Annex A3 is a guide for the selection and storage of fuels intended for long-term storage, when such fuels are distillate fuels.

4.5 Annex A4 is a guide for gas turbine users who are considering the use of fuels from alternative non-petroleum sources.

5. Significance and Use

5.1 This practice provides the user of gas turbine fuel oils and the designer of gas turbine fuel systems with an appreciation of the effects of fuel contaminants and general methods of controlling such contaminants in gas turbine fuel systems.

5.2 This practice is general in nature and should not be considered a substitute for any requirement imposed by warranty of the gas turbine manufacturer, or by federal, state, or local government regulations.

5.3 Although it cannot replace a knowledge of local conditions or the use of good engineering and scientific judgment, this practice does provide guidance in development of individual fuel management systems for the gas turbine user.

6. Significance of Contaminants

6.1 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 are required to minimize corrosion and operating problems. Providing 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 cleanup procedures. Each of the four classes of contaminants defined in 3.2 has its own significance to system operation.

6.1.1 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.

6.1.2 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.

6.1.3 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 6.1.4 through 6.1.5. 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 1 suggests levels of trace metals that would probably yield satisfactory service.

6.1.4 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 in 6.1.5.

6.1.5 *Vanadium and Lead*—Fuel contaminants might include soluble compounds such as vanadium porphyrins, metallic soaps, or tetraethyl lead that cannot be removed from the fuel at the gas-turbine site.

6.1.5.1 Vanadium can form low melting compounds such as vanadium pentoxide which melts at 691°C (1275°F), 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.

6.1.5.2 When vanadium is present in more than trace amounts either in excess of 0.5 ppm 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.

6.1.5.3 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 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.

TABLE 1 Trace Metal Limits of Fuel Entering Turbine Combustor(s)

Designation	Trace Metal Limits by Weight, max, ppm			
	Vanadium	Sodium plus Potassium	Calcium	Lead
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)			

6.1.5.4 For gas turbines operating at turbine-inlet gas temperatures below 650°C (1200°F), 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.

6.1.5.5 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.

6.1.6 *Sodium, Potassium, and Calcium*—Fuel contaminants might also include fuel-insoluble materials such as water, salt, or dirt, potential sources of sodium, potassium, and calcium. These are normally removed at the gas-turbine site, unless such contaminants are extremely finely divided.

6.1.6.1 *Sodium and Potassium* can combine with vanadium to form eutectics that melt at temperatures as low as 566°C (1050°F) 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 (1200°F), additives are not yet in general use that control such corrosion.

6.1.6.2 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.

6.1.6.3 *Calcium*—Calcium is not harmful from a corrosion standpoint: in fact, it serves to inhibit the corrosive action of vanadium. However, calcium can lead to hard-bonded deposits that are not self-spalling when the gas turbine is shut down, and 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.

6.1.7 *Microbial Slimes*—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.

7. Keywords

7.1 contaminants; fuel handling; fuel storage; gas turbine fuels

ANNEXES

(Mandatory Information)

A1. PRACTICE FOR THE RECEIPT, STORAGE, AND HANDLING OF DISTILLATE TURBINE FUELS

A1.1 Scope

A1.1.1 This practice covers the receipt, storage, and handling of distillate gas turbine fuels, Grades 1-GT and 2-GT, purchased in accordance with Specification D 2880.

A1.1.2 This practice may also be used as a guideline for the receipt, storage, and handling of gas turbine fuel, Grade 0-GT, purchased in accordance with Specification D 2880, but only if modifications are made to take into account the volatile nature of Grade 0-GT fuel. Those modifications are not specified in this practice.

A1.1.3 This practice provides guidance in developing an individual fuel management system for the gas-turbine user. It includes suggestions for the operation and maintenance of existing fuel storage and handling facilities, and for identifying where, when, and how fuel quality should be monitored.

A1.2 Terminology

A1.2.1 *fuel storage system*—Fig. A1.1 is a generalized fuel

storage system for use with distillate fuels, Grades 1-GT and 2-GT, conforming to Specification D 2880. It consists of the tankage, piping, fittings, and separation equipment between the point of connection with the delivery truck, railroad car, or other transportation equipment and the point where the fuel enters the gas turbine combustor(s). The specific configuration of components will vary with the manufacturer's and the user's preference for one type of equipment over another, for example, a centrifugal purifier over a coalescing filter/separator. Thus, Fig. A1.1 is merely a guide for discussion and illustration.

A1.2.2 *separation system*—includes equipment for removing foreign materials, for example, water and solids, from fuels. Fuel storage tanks may serve simultaneously as separators, since contaminants can settle to the bottom of such tanks under the influence of gravity. Other commonly used separators are the various types of filters, centrifuges, and electrostatic separators.

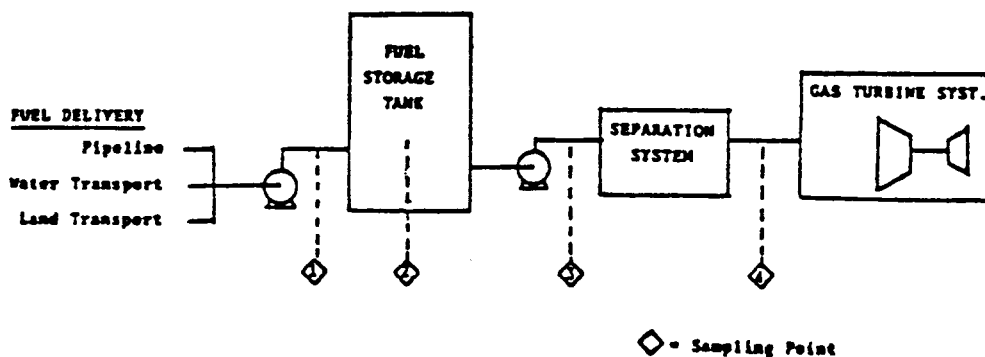


FIG. A1.1 Distillate Fuel Storage and Handling System (Gas Turbine Fuels Grades 1-GT and 2-GT)

A1.2.2.1 *filters*—devices for separating suspended matter from the fuel by passing the fuel through a porous medium.

A1.2.2.2 *screens*—filters designed for the separation of relatively coarse material from the fuel. They are commonly used to remove such materials as rags, weld material, gasket pieces, and other debris from the fuel ahead of a pump, that could be harmed if such debris were to reach the pump.

A1.2.2.3 *mechanical or edge filters*—filters consisting of stacks of metal disks separated at precise intervals by spacer plates. The liquid to be filtered flows radially between the disks removing the particles on the edges. These filters may be cleaned on-line manually or automatically to remove accumulated solids.

A1.2.2.4 *cartridge filters*—filters that use one or more replaceable or renewable cartridges containing the filter medium. Such filters may use elements of fiber, resin-impregnated (often pleated) filter paper, porous stone, or porous stainless steel of controlled porosity.

A1.2.2.5 *coalescing filter/separators*—usually cartridge filters that can remove water as well as particulate solids. The fine droplets of water in a fuel are coalesced into larger drops that are separated by the effect of gravity. Such filters are also termed coalescers, separator filters, and filter/separators.

A1.2.2.6 *depth-type filters*—consist of beds of fine, sometimes graded, solids such as sand. Sometimes clay beds are used to provide adsorptive properties as well as filtration. Salt towers are a specialized class of depth filters for removal of water.

A1.2.2.7 *centrifuge*— a rotating mechanical device for separating solids from liquids and immiscible liquids from each other. When used for fuel or lubricant purification, they are sometimes called centrifugal purifiers or simply purifiers.

A1.2.2.8 *electrostatic separators*—use electrostatic forces to separate water or solids, or both, from a liquid fuel. These include electric desalters that are commonly used to remove saline water from crude petroleum oil prior to distillation.

A1.2.3 *the user's fuel quality control system*—consists of the user's sampling policies and procedures, associated test, and examination procedures. Use of this system establishes the conformity of the fuel to purchase agreements, and ensures that the quality of fuel in storage and as-delivered to the gas-turbine combustors conforms to the necessary quality standards.

A1.3 Summary of Practice

A1.3.1 Sampling and inspection of the fuel should be done upon receipt at the user site, and periodically thereafter at

specified locations and times to identify contaminated or otherwise unsatisfactory fuel before it reaches the combustor(s).

A1.3.2 Fuel system components should be cleaned and maintained either periodically or on the basis of operational evidence (pressure drop across a filter), or on a combination of the two.

A1.4 Significance and Use

A1.4.1 The use of fuel-system monitoring and quality control techniques, combined with scheduled cleaning and maintenance, will minimize the quantity of contaminants reaching the combustor(s) and hence will minimize corrosion and erosion of gas turbine components.

A1.4.2 The use of fuel monitoring, storage, and handling techniques will limit water, suspended solids, and microbial growth in the fuel; this in turn will minimize corrosion and erosion of gas turbine components.

A1.5 Sampling

A1.5.1 Samples should be taken at each of the four points as in Fig. A1.1. Consult Practice D 4057, for sampling procedures.

A1.5.1.1 A sample should be taken at point 1, on delivery, during transfer into the storage tank.

A1.5.1.2 Fuel storage tank samples should include both tank bottom samples and “all-level” samples. These samples shall be taken at a frequency to be determined by the user based on the rate of accumulation of water and other contaminants. When the system consists of multiple tankage, take these samples preparatory to drawing fuel from a given tank. When the gas turbine is used for infrequent standby or emergency service, take the sample on a closely observed schedule.

A1.5.1.3 Sampling at points three and four is essential to determine the effectiveness of the separation system, if any, and to assure the quality of the fuel being supplied to the gas turbine. The frequency of such sampling should be determined by the user's experience and in consultation with the turbine manufacturer.

A1.6 Inspection and Analysis of Samples

A1.6.1 Inspection and analysis of fuel is very important in determining fuel quality at various locations and times in the fuel storage and handling system and will ensure that only fuel of acceptable quality will reach the turbine combustor(s). Brief and visual methods may serve to suggest the presence of some

contaminants, but established fuel analysis methods including chemical analysis for trace elements are needed for more complete judgement of fuel quality.

A1.6.2 The effectiveness of a fuel separation system may best be judged by the use of specialized analytical methods, as recommended by the equipment suppliers or by fuel vendors. These might include conductivity, dielectric properties, color, content and quality of particulates, turbidity, spectral properties, or filterability. From such data, useful inferences may be derived to supplement more detailed chemical analysis.

A1.7 Cleaning and Maintenance

A1.7.1 A relatively long residence of fuel in tankage allows separation of insoluble contaminants, especially water and inorganic solids. Accumulation of water can generate corrosion product solids and biological slimes. These materials can result in gradual or sudden overloading of separation equipment and possibly the erosion or plugging of close-tolerance devices such as fuel pumps and flow dividers.

A1.7.1.1 Water as a separate phase mobilizes oxygen and acidity to effect corrosion or simple rusting of tank metal surfaces, and gives a medium for biological slime development. The rate of accumulation of water and its products in fuel tank bottoms can be established by appropriate samples at point 2. A schedule of tank stripping should be established to maintain water at a low level. Careful, slow drawoff rates enable more complete stripping.

A1.7.1.2 Rust or other inorganic debris present in tank bottom from previous corrosion, from peeling of possible protective coatings, or from tank scale deposits should be removed by appropriate cleaning procedures to prevent downstream damage. Chronic recurrence of these problems may best be solved by use of special corrosion inhibitors, by incorporation of tank linings, or by substitution of tankage with better corrosion resistance.

A1.7.2 The role of separation systems in removing contaminants inevitably involves the fouling of such equipment with debris. In order to sustain effective operation, proper maintenance

schedules for cleaning or equipment renewal must be followed.

A1.7.2.1 The proper operation of all types of fuel filters is reduced by fouling and accumulation of contaminants, resulting in reduced fuel throughput or increased pressure differentials, or both. Operation of screens and barrier filters may be restored by cleaning, for example, a back-flush sequence. Some cartridge filters cannot be back-flushed and hence must be replaced. Some coalescing filters, in addition to becoming plugged, may lose their ability to shed coalesced water droplets because of the accumulation of surfactants on their semipermeable filter media, and also must be replaced.

A1.7.2.2 The proper functioning of both centrifugal and electrostatic separators is compromised to some degree by the accumulation of solid or semisolid debris, that makes small but important changes in internal geometry. The extent of these effects and the rate at which they occur depend on the type and level of contamination in fuels. These malfunctions are manifested in a reduced ability to remove water and particulate matter (see A1.6.2). In both types of equipment, purging sequences for removal of such debris are possible during operation, but thorough cleaning at longer intervals is also advisable to restore design efficiency.

A1.8 Documentation

A1.8.1 In view of the critical requirements for safe and efficient operation, an adequate record to provide evidence of the amount, type, and quality of fuel burned in the gas turbine is important to trace the causes of unusual maintenance problems and to assess the performance of the fuel storage and separation facilities. These records also serve to help the user decide what frequency of sampling and maintenance operations are required. Such a record should include the date, time, and location of all samples, fuel source, flow rate, the record of measurements and analyses performed, and pertinent information relevant to the condition and operation of fuel tankage and contaminant-separation equipment.

A2. PRACTICE FOR THE RECEIPT, STORAGE, AND HANDLING OF TURBINE FUELS CONTAINING RESIDUAL COMPONENTS

A2.1 Scope

A2.1.1 This practice covers the receipt, storage, handling, and chemical treatment of gas turbine fuels, Grades 3-GT and 4-GT, in accordance with Specification D 2880. Grade 3-GT fuel may contain residual components, and Grade 4-GT fuel is defined as one containing residual components.

A2.1.2 This practice provides guidance in the operation and maintenance of fuel systems serving gas-turbine installations based on Grades 3-GT or 4-GT fuel. They identify where, when, and how fuel quality should be monitored; and when and how equipment should be cleaned and maintained. Further they provide guidelines for the washing and chemical treatment of the fuels, a practice that may be beneficial with certain residual fuels to reduce certain trace metal contents.

A2.1.3 This practice is general in nature and should not be

considered a substitute for requirements imposed by the warranty of the gas-turbine manufacturer or by federal, state, or local laws. This practice cannot replace a knowledge of local conditions or the application of sound engineering and scientific judgement, but it does provide guidance for the development of an individual fuel-management system for the gas turbine user.

A2.2 Terminology

A2.2.1 The general descriptions of systems to be used with Grades 1-GT and 2-GT fuels in accordance with Specification D 2880 in A1.2, also hold for Grades 3-GT and 4-GT ash-forming fuels but with added fuel treatment and fuel heating hardware as illustrated by the example shown in Fig. A2.1.

A2.2.2 *fuel desalting*— required for those fuels where the alkali metal content (sodium plus potassium) exceeds the limit

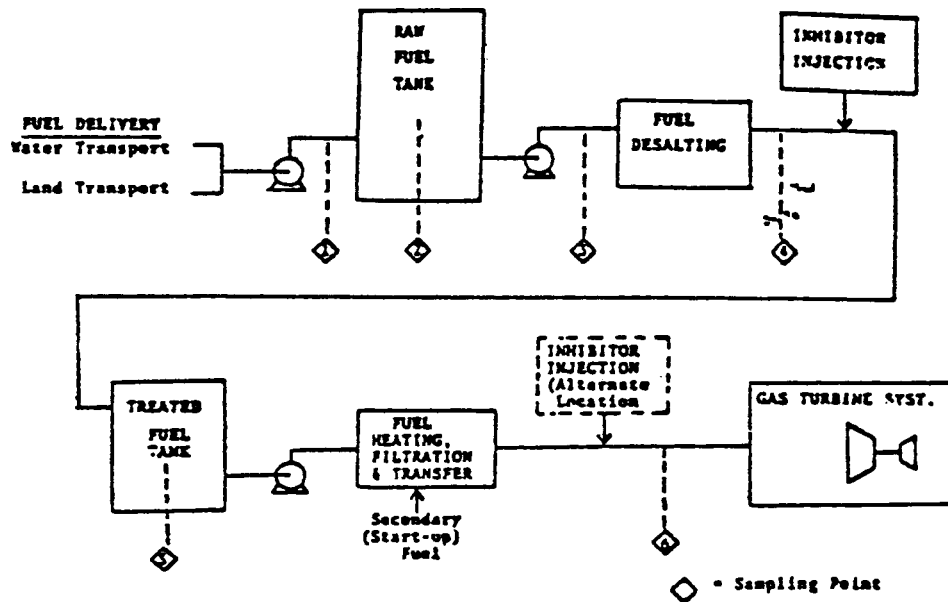


FIG. A2.1 Residual Fuel Storage, Treatment and Handling System (Gas Turbine Fuel Grade 4-GT Requiring Complete Treatment)

specified by the turbine manufacturer. Most fuel must be heated to facilitate desalting. Desalting is normally accomplished by extracting the alkali-metal salts from the fuel by contacting the fuel with low-salt wash water and then mechanically removing the salt-laden water by centrifugation or electrostatic precipitation. Multiple desalting stages may be required to achieve the required reduction in salt concentration.

A2.2.3 *chemical inhibitors*—required for fuels with vanadium levels in excess of the turbine manufacturer’s specified limit. Magnesium-based inhibitors are normally used. They may be added batch-wise to the fuel as a pre-mix or injected on-line into the fuel. Silicon-based inhibitors or magnesium-silicon mixed inhibitors are used in some applications.

NOTE A2.1—Special precautions may be required to keep some inhibitors uniformly dispersed in the fuel.

A2.2.4 *combined heating and separation system*—normally required for Grades 3-GT and 4-GT fuels (Fig. A2.1). Most ash-forming fuels require heating to lower the fuel viscosity for proper pre-combustion atomization. Grade 4-GT and some Grade 3-GT fuels require a secondary fuel for light-off and for flushing the fuel lines at shutdown. The fuel system must have a fuel transfer valve with proper controls to accomplish the transfer on start-up and shutdown. These systems generally contain filters for the removal of particulates. (Fuels containing residual components or surface active agents, such as in 3-GT and 4-GT fuel, can interfere with the proper operation of coalescing filters.)

A2.3 Summary of Practice

A2.3.1 Sampling and inspection of the fuel should be done upon receipt at the user site, and periodically thereafter at specified locations and times to identify contaminated, improperly inhibited, or otherwise unsatisfactory fuel before it reaches the gas-turbine combustor(s).

A2.3.2 A basis for the cleaning and maintenance of fuel-system components, including both elapsed time since previ-

ous cleaning and maintenance, and operational evidence (pressure drops across filters), should be established.

A2.3.3 Guidelines are provided for the operation of washing and treating facilities sometimes used to limit hot corrosion associated with sodium-vanadium compounds deriving from residual components of heavy fuels.

A2.4 Significance and Use

A2.4.1 The use of fuel system monitoring and quality control techniques, combined with scheduled cleaning and maintenance will minimize the quantity of contaminants reaching the combustor(s) and hence will minimize corrosion and erosion of gas-turbine components.

A2.4.2 The use of fuel monitoring and storage and handling techniques will limit water and suspended solids; this in turn will minimize corrosion and erosion of gas turbine components.

A2.5 Sampling

A2.5.1 Samples should be taken at each of the six points as shown in Fig. A2.1. Consult Practice D 4057 for sampling procedures.

A2.5.1.1 A sample should be taken at point 1 on delivery during transfer into the storage tank.

A2.5.1.2 Fuel storage tank samples taken at points 2 and 5 may include both tank bottom and “all-level” samples. These samples should be taken at a frequency to be determined by the user based on the rate of accumulation of water and other contaminants. When the system consists of multiple tankage, take the samples preparatory to drawing fuel from a given tank. When the gas turbine is used for infrequent standby or emergency service, take the sample on a closely observed schedule.

A2.5.1.3 Sampling at points 3 and 4 is essential to determine the effectiveness of the fuel desalting system, if any. The frequency of such sampling should be determined by the user’s

experience and in consultation with the equipment manufacturers.

A2.5.1.4 Sampling at point 6 is essential to assure the quality of the fuel being supplied to the gas turbine.

A2.5.1.5 Procedures for sampling to control the content and quality of inhibitor should be planned with the inhibitor supplier. Sampling at points 5 and 6 may be used to assure that the required level of inhibitors have been properly incorporated into the fuel.

A2.6 Inspection and Analysis of Samples

A2.6.1 Inspection and analysis of samples will depend on the specific fuel and the fuel treatment system employed.

A2.6.2 Analytical control of fuel quality and composition may require both general inspection techniques and specific analyses for contaminant elements and for inhibitor control.

A2.6.2.1 Inspection of delivered fuel (points 1 and 2) should include general properties of the fuel, its adherence to important purchase specifications, and its content of significant trace elements.

A2.6.2.2 The effectiveness of the fuel desalting system is best measured by the reduction of corrosive or deposit-forming trace elements (such as sodium, potassium, calcium, and lead) by comparisons between chemical analyses for such trace elements in fuel samples taken at point 4 versus point 3, and at a frequency to be determined in consultation with the equipment manufacturers. Useful but less conclusive inferences about the effectiveness of the fuel desalting equipment may be drawn from analyses for water and sediment, by dielectric cell indicators, and by fuel conductivity measurements (see Test Method D 1796).

A2.6.2.3 Analysis of fuel samples taken at points 5 and 6 is required to assure that inhibitor is being properly incorporated in the fuel. Samples at point 5 may also serve to monitor storage effects on the uniformity of inhibitor element distribution. When fuel manifold injection of inhibitor is used, analyses of point 6 samples is required to assure proper inhibition. The frequency of such analyses should be determined by consultation with the turbine manufacturer.

A2.7 Cleaning and Maintenance

A2.7.1 A relatively long residence of fuel in tankage allows separation of insoluble contaminants, especially water and

inorganic solids. Accumulation of water can generate corrosion-product solids and emulsion sludges. These materials can result in gradual or sudden overloading of separation equipment and possibly the erosion or plugging of close-tolerance devices, such as fuel pumps and flow dividers.

A2.7.1.1 Water as a separate phase mobilizes oxygen and acidity to effect corrosion or simple rusting of tank metal surfaces. The rate of accumulation of water and its products in fuel tank bottoms can be established by analyses of samples at points 2 and 5. A schedule of tank stripping should be established to maintain water at a low level. Careful, slow drawoff rates enable more complete stripping.

NOTE A2.2—Water may be present as a stable water-in-oil emulsion in fuels having residual components.

A2.7.1.2 Rust and other inorganic debris present in the fuel or in tank bottoms, stemming from previous corrosion or contamination, may require removal to prevent downstream damage. Chronic reoccurrence of these problems may best be solved by use of special corrosion inhibitors or by substitution of tankage with better corrosion resistance.

A2.7.2 The role of separation systems in removing contaminants can involve the fouling of such equipment with debris. In order to sustain effective operation, follow proper maintenance schedules for cleaning or equipment renewal.

A2.7.2.1 The proper operation of all types of fuel filters is compromised by fouling and accumulation of contaminants, resulting in reduced fuel throughput, or increased pressure differentials, or both. Operation of screens and barrier filters may be restored by cleaning, for example, a back-flush sequence. Some cartridge filters cannot be back-flushed and hence must be replaced.

A2.7.2.2 The proper functioning of both centrifugal and electrostatic separators is compromised to some degree by the accumulation of solid or semisolid debris, that make small but important changes in internal geometry. The extent of these effects and the rate at which they occur depend on the type and level of contamination in fuels. These malfunctions are manifested in a reduced ability to remove water and particulate matter. In both types of equipment, purging sequences for removal of such debris are possible during operation, but thorough cleaning at longer intervals is also advisable to restore design efficiency.

A3. LONG-TERM STORAGE OF DISTILLATE FUELS

A3.1 Scope

A3.1.1 This annex provides guidance for consumers of distillate fuels who may wish to store quantities of fuels for extended periods. Fuels containing residual components are excluded. Consistently successful long-term fuel storage requires attention to fuel selection, storage conditions, and monitoring of properties prior to and during storage.

A3.1.2 Normally produced fuels have adequate stability properties to withstand normal storage without the formation of troublesome amounts of insoluble degradation products. Fuels that are to be stored for prolonged periods should be selected

to avoid formation of sediments that can overload filters or plug combustor nozzles or injectors. Selection of these fuels should result from supplier-user discussions.

A3.2 Terminology

A3.2.1 *bulk fuel*—the fuel in the storage facility.

A3.2.2 *combustor fuel*—fuel entering the combustion zone of the burner or engine after filtration or other treatment of bulk fuel.

A3.2.3 *fuel contaminants*—foreign materials which make fuel less suitable or unsuitable for the intended use. Fuel contaminants include materials introduced subsequent to the

manufacture of fuel and fuel-degradation products.

A3.2.4 *fuel-degradation products*—those materials which are formed in fuel during extended storage. 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 in fuels due to complex interactions and oxidation of small amounts of olefinic, sulfurous, oxygenated, and nitrogenous compounds present in fuels. The formation of degradation products may be catalyzed by dissolved metals, especially copper salts.

A3.2.5 *long-term storage*—storage of fuel for longer than 12 months after it is received by the user.

A3.3 Fuel Selection

A3.3.1 Certain distilled refinery products are generally more suitable for long-term storage than others. The stability properties of distillates are highly dependent on the crude oil sources, severity of processing, and whether additional refinery treatment has been carried out.

A3.3.2 The composition and stability properties of distillate fuels produced at specific refineries may be different. Any special requirements of the user, such as long-term storage, should be discussed with the supplier.

A3.3.3 Blends of fuels from various sources may interact to give stability properties worse than expected based on the characteristics of the individual fuels.

A3.4 Fuel Additives

A3.4.1 Available fuel additives can improve the suitability of marginal fuels for long-term storage, 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.

A3.4.2 Biocides or biostats destroy or inhibit the growth of fungi and bacteria that 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.

A3.5 Tests for Fuel Quality

A3.5.1 The suitability of fuel for prolonged storage may be estimated at the time of manufacture. Test Method D 2274, is one test method; alternative or auxiliary methods as agreed upon by supplier and user may be satisfactory.

A3.5.2 Performance criteria for accelerated stability tests which assure satisfactory long-term storage of fuels have not been established.

A3.6 Fuel Monitoring

A3.6.1 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.

A3.6.2 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 D 4057, should be included in the evaluation along with an “All Level” sample.

A3.6.3 The quantity of insoluble fuel contaminants present in fuel can be determined using Test Method D 2276, Procedure A.

A3.6.4 Interpretation of results requires consideration of the end use, the method of sampling, and the capacity of filtration equipment to remove contaminants. For example, bottom tank samples contain typically more filterable deposits than the top or middle-top sample because some of the insoluble contaminants tend to settle. The ability of insoluble contaminants to clog filters is not simply related to quantity of contaminants, particle size and other factors are important.

A3.6.5 Other quality tests like fuel color (Test Method D 1500) and stability tests (Test Method D 2274) after storage may have value. Correlations of these tests with fuel suitability are tenuous.

A3.7 Fuel Storage Conditions

A3.7.1 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.

A3.7.2 Copper and copper-containing alloys should be avoided. Copper may promote fuel degradation and may produce mercaptide gels. Zinc coatings may react with water or organic acids in the fuel to form gels which rapidly plug filters.

A3.8 Use of Degraded Fuels

A3.8.1 Fuels which have undergone mild-to-moderate degradation may often be consumed in a normal way, depending on the fuel system requirements. Filters and other cleanup equipment may require special attention and increased maintenance. Burner nozzle or injector fouling may occur more rapidly.

A3.8.2 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 may 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 A3.8.1. However, very high soluble gum levels or corrosion products from microbiological contamination may cause severe operational problems.

A4. LIQUIDS FROM NON-PETROLEUM SOURCES AS GAS TURBINE FUELS

A4.1 Scope

A4.1.1 This annex provides general guidance for gas turbine users who may consider the use of alternative fuels.

A4.1.2 The nature of a specific alternative liquid fuel is dependent on the source material, the extraction or manufacturing process, and the refining process to which the fuel has been subjected, therefore, this practice can provide only general information on several of the more important classes of such alternative fuels. (**Warning**—The nature of an alternative fuel can differ materially from that of a similar boiling-range petroleum fuel, therefore, the potential user should ensure adherence to federal, state, and local regulations, and should practice good engineering, scientific, and medical judgement when using such alternative fuels.)

A4.2 Terminology

A4.2.1 *alcohol (fuel alcohol)*—for fuel use, ethanol, methanol, or higher alcohols, used alone or as fuel extenders when blended in a hydrocarbon fuel.

A4.2.2 *bitumen*—generally, a flammable, naturally-occurring heavy hydrocarbon mixture such as asphalt; specifically, the heavy hydrocarbons found in tar sands.

A4.2.3 *coal liquids (coal derived liquids)*—liquids, substantially hydrocarbon in nature, derived from lignite, bituminous coals, or other coals by direct or indirect liquefaction processes.

A4.2.4 *direct liquefaction*—of coal, the production of liquid products from coals as the direct result of pyrolysis, hydrogenation, or solvent refining.

A4.2.5 *heavy fuels*—fuels containing high-boiling components, similar to grades 3-GT or 4-GT for petroleum fuels.

A4.2.6 *indirect liquefaction*—of coal, the production of liquid products from coals by first converting the coal into synthesis gas (hydrogen and carbon monoxide), and then converting the gas into a hydrocarbon liquid by a catalytic reaction, as the Fischer-Tropsch process.

A4.2.7 *shale oil*—a hydrocarbon substance obtained from the pyrolysis and distillation of the organic material in oil shale.

A4.2.8 *synthetic liquid fuels*—liquid fuels produced from coal, shale oil, or tar sands that are intended to be used in place of conventional liquid fuels.

A4.2.9 *tar sands (bituminous sands, oil sands)*—naturally occurring mixtures of viscous, heavy crude oils (bitumens) that cannot be produced with conventional production techniques. The sandstone may be rock-like as in some U.S. deposit or unconsolidated sand, as in the case of the huge Athabasca deposits of Canada. Such deposits consist primarily of mineral matter and bitumen, but they also contain various quantities of water and vegetation debris.

A4.3 Significance and Use

A4.3.1 The gas turbine user may have to turn to fuels from alternative sources, as the availability of conventional petroleum crudes decreases. The primary alternative fuels that gas turbine user may consider are alcohols and hydrocarbon-type

liquids derived from sources such as coal, oil shale, and tar sands. Such fuels may differ in their properties from those produced from conventional crude oils. Some of the consequences of such differences are reflected in the operator hazards, the turbine performance, and material compatibility. This practice provides information on such fuel properties and consequences for the potential user of alternative fuels.

A4.4 Special Hazards Associated with Alternative Fuels

A4.4.1 The following information is furnished only as an indication of some of the hazards that must be considered by a user of alternative fuels. This guidance does not purport to address all of the health and safety problems associated with the use of such fuels, but it does attempt to indicate the kinds of hazards the potential user must investigate. It is the responsibility of the user to consult competent medical, scientific, and engineering authorities and to establish appropriate safety and health practices (see 1.4).

A4.4.2 *Methanol Toxicity*⁵—Methanol is classified as moderately toxic in classification schemes that categorize chemicals according to their acute toxicity. It is rapidly and well absorbed following exposure such as inhalation, skin contact, or oral ingestion. Methanol does not have an appreciable odor that warns of its presence. In general, prolonged skin contact with neat methanol of liquid fuels containing methanol is to be avoided.

A4.4.3 *Ethanol Toxicity*⁵—Fuel grade ethanol can be denatured by the addition of toxic or of noxious chemicals. The nature of the denaturant used in a specific ethanol fuel must be ascertained and its effects on the operators must be determined by consultation with competent medical authority. Regardless of the exact denaturant, operators are to avoid swallowing the fuel. They are to avoid also inhaling the vapor or spray mist, or any contact with the eyes or skin.

A4.4.4 *Methanol and Ethanol Fire Hazards*—Both methanol and ethanol present unique fire and explosive hazards. Methanol has a published flash point (closed-cup method) of 12°C (54°F), and ethanol has a flash point of 13°C (55°F), so their fire hazards are greater than that of 1-GT and heavier grades of turbine fuels. Methanol burns with a non-luminous flame that is virtually invisible in direct sunlight. At normal ambient temperatures, mixtures of either methanol or ethanol vapors and air in closed storage vessels can be within the explosive range. Careful electrical grounding, lightning protection, and control of other accidental ignition sources is extremely important in all storage and use of fuel alcohols and their blends with other fuels.

A4.4.5 *Health Hazards of Coal-Derived Fuels*—Although the toxic properties of liquid fuels derived from coal have not been fully established, the available information indicates the need for care in handling. Coal liquids produced by direct liquefaction processes are usually characterized by high percentages of aromatic hydrocarbons and polynuclear aromatics

⁵ Sax, N. I., "Dangerous Properties of Industrial Materials," Van Nostrand Reinhold, Co., 1984, pp. 1764, 1316.

have been identified in the higher-boiling fractions. Compounds of nitrogen, sulfur, and oxygen are usually present in concentrations dependent upon their levels in the source coal and upon the liquefaction process. Some of these compounds have been reported to be toxic. Fetotoxic, mutagenic, and carcinogenic properties have been ascribed to some coal-derived liquids. The potential user of the resultant liquid fuels is to ascertain the specific properties of the fuels and is to consult medical authority regarding health hazards.

A4.4.6 Health Hazards of Liquid Fuels from Oil Shale—As produced from a retort, shale oil is noted for its high nitrogen content, which can exceed 2 % by mass, and for the presence of arsenic at levels up to 40 ppm. It also contains sulfur and oxygen compounds and particulate matter. Appropriate processing to produce finished fuels from this crude shale oil will reduce such materials to acceptable levels. The potential user of the resultant liquids fuels is to ascertain the specific properties of the fuels and is to consult medical authority regarding health hazards.

A4.4.7 Health Hazards of Liquid Fuels from Tar Sands—The bitumen extracted from Athabasca tar sands contains about 4.5 % sulfur, 1.1 % nitrogen, and 0.9 % oxygen. Bitumen from other tar sands can contain higher or lower concentrations of these elements. Most processing of the bitumen will reduce such elements to acceptable levels. The potential user of the resultant liquids fuels is to ascertain the specific properties of the fuels and is to consult medical authority regarding health hazards.

A4.5 Potential Material Compatibility Problems

A4.5.1 Problems with Methanol and Ethanol—Both of these alcohols have an affinity for water, which they can absorb from humid air or from other sources. The absorbed water can aggravate corrosion problems in a fuel system. Both alcohols degrade some polymeric materials, so care must be taken in the selection of elastomers for use in gaskets, seals, and hoses. Such materials can shrink, swell, harden, or even dissolve when contacted by the alcohols. There have been some reports of the softening and delamination of fiberglass-reinforced polyester underground storage tanks used for alcohol storage.

Although the alcohols are compatible with most metals, the use of magnesium and aluminum is to be avoided.

A4.5.2 Problems with Other Alternative Fuels—The properties of alternative fuels from coal, tar sands, and oil shale vary so greatly depending upon the source material, the extraction process, and the refining processes used to produce the fuel, that little general guidance can be provided. High aromatic contents, characteristic of some coal-derived fuels are known to attack some elastomers, so particular care must be taken in the selection of O-rings, gaskets, seals, and hoses for such fuels.

A4.6 Potential Operational Problems

A4.6.1 Operational Problems with the Alcohols—Both methanol and ethanol can be burned with relative ease in a gas turbine, to yield combustion products consisting largely of water vapor and carbon dioxide. The volumetric heats of combustion of these two alcohols are lower than that of petroleum distillate fuels, so fuel system components (storage tanks, pumps, nozzles) of higher capacity than those with the normal fuels can be required. Lubricity is poorer with the alcohols so that additives or increased maintenance may be required. When alcohol/hydrocarbon fuel blends are used, the affinity of alcohols for water can lead to a phase separation with the denser aqueous alcohol falling to the bottom of the storage tanks. This can lead to difficulties in flow control, pumping, etc.

A4.6.2 Operational Problems with Other Alternative Fuels—Some of the liquid fuels derived from coal, oil shale, and tar sands can contain higher than usual levels of either nitrogen or sulfur, or both. On combustion, such materials are converted into nitrogen or sulfur oxides. These oxides are acidic so care must be taken to keep the stack temperatures above the dew point. Some of the higher-boiling fuels, those comparable to grades 3-GT and 4-GT, can contain such elements as arsenic, boron, iron, titanium, and vanadium. These can lead to the deposition of significant amounts of potentially corrosive ash on the turbine blades or elsewhere in the combustion system.

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