INTERNATIONAL STANDARD

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Petroleum products — Fuels (Class F) — Specifications of gas turbine fuels for industrial and marine applications

Produits pétroliers — Combustibles (classe F) — Spécifications des combustibles pour turbines à gaz en service dans l'industrie et la marine

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 4261 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Sub-Committee SC 4, *Classifications and specifications*.

Annex A forms an integral part of this International Standard. Annexes B, C and D are for information only.

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Petroleum products — Fuels (Class F) — Specifications of gas turbine fuels for industrial and marine applications

WARNING — The use of this International Standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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.

1 Scope

This International standard specifies the requirements for petroleum fuels for gas turbines (see ISO 3977) used in public utility, industrial and marine applications. It does not cover requirements for gas turbine fuels for aviation use. This International Standard is intended for the guidance of users such as turbine manufacturers, and suppliers and purchasers of gas turbine fuels.

This International Standard sets out the properties of fuels at the time and place of transfer of custody to the user. Further information and recommendations for the quality of the fuel entering the turbine combustion chambers are provided in annex B. The recommendations of annex B as well as additional modifications by the gas turbine manufacturer may, however, be specified by mutual agreement between the interested parties.

The terminology used and the test methods referred to in these specifications are presented in annex C.

Nothing in these specifications shall preclude observance of legal or fiscal regulations that may be more restrictive.

NOTES

1 Additional information on fuels for gas turbines is given in ISO 3977.

2 The requirements for petroleum fuels for diesel engines and steam turbines for marine use are given in ISO 8217.

The fuel categories in this International Standard have been classified in accordance with ISO 8216-2:1986, *Petroleum products — Fuels (class F) — Classification — Part 2: Categories of gas turbine fuels for industrial and marine applications.*

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2160:1985, *Petroleum products — Corrosiveness to copper — Copper strip test.*

ISO 2719:1988, *Petroleum products and lubricants — Determination of flash point — Pensky-Martens closed cup method.*

ISO 3104:—[1], *Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity.*

ISO 3170:1988, *Petroleum liquids — Manual sampling.*

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[1] To be published. (Revision of ISO 3104:1976)

ISO 3171:1988, *Petroleum liquids — Automatic pipeline sampling.*

ISO 3405:1988, *Petroleum products — Determination of distillation characteristics.*

ISO 3675:1993, *Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method.*

ISO 3733:—[2], *Petroleum products including bitumen — Determination of water — Distillation method.*

ISO 3735:1975, *Crude petroleum and fuel oils — Determination of sediment — Extraction method.*

ISO 4259:1992, *Petroleum products — Determination and application of precision data in relation to methods of test.*

ISO 4260:1987, *Petroleum products and hydrocarbons — Determination of sulfur content — Wickbold combustion method.*

ISO 4262:1993, *Petroleum products — Determination of carbon residue — Ramsbottom method.*

ISO 6245:1993, *Petroleum products — Determination of ash.*

ISO 8217:1987, *Petroleum products — Fuels (class F) — Specifications of marine fuels.*

ISO 8754:1992, *Petroleum products — Determination of sulfur content — Energy-dispersive X-ray fluorescence method.*

3 General requirements

3.1 The fuel shall be a homogeneous mixture of hydrocarbons free from inorganic acids and adventitious foreign matter.

NOTE 3 Guidelines for limits for trace metal for fuels entering the turbine combustion chambers are contained in annex A.

3.2 Fuels of all categories shall remain homogeneous during storage and handling in the countries or locality where the fuel is to be used, taking into account local storage conditions, handling and duration of storage.

4 Detailed requirements

NOTE 4 The properties listed in this specification are those which permit acceptable performance of the turbine. However, certain metals, even in trace quantities, are detrimental to gas turbine service life. Information on the significance and concentration of critical metallic elements in the fuel as it enters the turbine combustion chambers is provided in annex B.

4.1 The various categories of gas turbine fuel shall conform to the limiting requirements shown in table 1 when the fuel is tested by the methods specified.

4.2 Incorporation of additives by the fuel supplier for legal purposes or to improve certain aspects of performance is permitted, provided that the amount and type incorporated do not cause the additive-treated fuel properties to fall outside the general requirements and specification limits laid down in table 1.

NOTE 5 Additives may also be introduced subsequent to delivery, as noted in annex C.

4.3 A limit for low-temperature operability is a requirement of this International Standard, but limits cannot be included in table 1 because of the need to conform to local or national requirements. When this specification is called up, such limits, together with the test methods required, shall be stated.

Information on internationally available test methods for low-temperature operability is given in annex C (C.2.5).

5 Sampling

Sampling for the requirements in table 1 shall be carried out by the methods described in ISO 3170, ISO 3171 or equivalent national standards.

NOTE 6 If sampling for trace metals is agreed upon by the interested parties, the recommendations in annex B should be followed.

6 Precision and interpretation of test results

The majority of test methods specified in table 1 contain a statement of the precision (repeatability and reproducibility) to be expected from it. Attention is drawn to ISO 4259, which covers the use of precision data in the interpretation of test results; this procedure shall be used in cases of dispute.

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[2] To be published. (Revision of ISO 3733:1976)

Table 1 — Detailed requirements for gas turbine fuels at time and place of custody transfer to user

Property	Test method	ISO-F Category 1)					
		DST.0	**DST.1/DMT.1**	**DST.2/DMT.2**	**DST.3/DMT.3**	**RST.3/RMT.3**	**RST.4/RMT.4**
		Low flash point petroleum distillate (naphtha type)	**Medium flash point petroleum distillate** [jet fuel (kerosine) type]	**Petroleum distillate** (gas-oil type)	**Low ash petroleum distillate**	**Low ash residual fuel or a distillate fuel containing heavy components from petroleum processing**	**Petroleum fuel containing heavy components from petroleum processing**
Flash point, °C, min.	ISO 2719 2)		inland – 38 marine – 43 3)	inland – 56 marine – 60	inland – 56 marine – 60	60	60
Kinematic viscosity at 40 °C mm^2/s to 100 °C mm^2/s, max.	ISO 3104	1,3 min. 4)	1,3 – 2,4 4)	1,3 – 5,5	1,3 – 11,0	1,3 – 20,0	55 (see C.2.2)
Density at 15 °C in kg/m^2, max. 5)	ISO 3675	Value to be reported	Value to be reported	880	900 (see B.6)	920 (see B.6)	996 (see B.6)
Distillation 90 % (*V/V*) recovered at °C, max.	ISO 3405	288	288	365	—	—	—
Low-temperature operability, °C	See 4.3	Value to be reported	Value to be reported	Value to be reported	Value to be reported	Value to be reported	Value to be reported
Carbon residue % (*m/m*), max.	ISO 4262	0,15 (on 10 % residue)	0,15 (on 10 % residue)	0,15 (on 10 % residue)	0,25	1,50	Value to be reported 6)
Ash content % (*m/m*), max.	ISO 6245	0,01	0,01	0,01	0,01	0,03	0,15
Water % (*V/V*), max.	ISO 3733	0,05	0,05	0,05	0,30	0,50	1,0
Sediment % (*m/m*), max.	ISO 3735	0,01	0,01	0,01	0,05	0,05	0,25
Sulfur % (*m/m*), max. 7)	ISO 4260 ISO 8754	0,5 0,5	0,5 0,5	— 1,3	— 2,0	— 2,0	— 4,5
Copper corrosion, max.	ISO 2160	1	1	1	—	—	—
Calculated net specific energy in MJ/kg, min. (lower calorific value)	See annex A	Value to be reported	42,8	41,6	40,0	40,0	39,4

1) Crude oils, because of their varied properties, do not necessarily fit any category designation. If crude oil is considered as a turbine fuel for industrial applications, the manner of its use should be agreed between the turbine manufacturer and user.

2) Other methods may be required by law for the determination of minimum flash point.

3) In marine applications, this category is for use in engines for emergency purposes, and shall conform to the requirements of ISO 8217.

4) Fuel with a viscosity below the minimum value of 1,3 mm^2/s at 40 °C may be substituted by agreement with the turbine manufacturer.

5) Density measured at 15 °C in kilograms per litre or in units of similar magnitude shall be multiplied by 1 000 before comparison with these values.

6) An assessment of the significance of carbon residue for RST.4/RMT.4 is given in C.2.6.

7) Gas turbines with waste heat recovery equipment may require additional sulfur control to prevent cold end corrosion (see C.2.9).

Annex A
(normative)

Method of calculation of specific energy

A.1 Specific energy (lower calorific valve) is controlled indirectly by the specification of other properties. Specific energy shall be calculated with a degree of accuracy acceptable for normal purposes from the density of the fuel, applying corrections as follows for any sulfur, water and incombustibles (ash) content that may be present (see C.2.11):

Specific energy (net), MJ/kg

$$= (46{,}704 - 8{,}802\rho^2 \times 10^{-6} + 3{,}167\rho \times 10^{-3})$$

$$[1 - 0{,}01\ (x + y + s)] + 0{,}01(9{,}420s - 2{,}449x)$$

where

ρ is the fuel density at 15 °C, in kilograms per cubic metre (see table 1, note 5);

x is the water content, expressed as a percentage by mass;

y is the ash content, expressed as a percentage by mass;

s is the sulfur content, expressed as a percentage by mass.

A.2 This method is technically equivalent to that given in annex A of ISO 8217, which also includes figures that may be used for the rapid estimation of gross and net specific energies.

Annex B
(informative)

Trace metal limits of fuel entering turbine combustion chambers

B.1 Introduction

The turbine user should confirm that arrangements are made to ensure that the fuel entering the combustion chambers meets the manufacturer's requirements. This might include transportation arrangements with the fuel supplier, particular care in fuel storage, quality control at the point of use and fuel purification procedures. Distillate fuels are usually of satisfactory purity as refined, but suppliers rarely have control over possible trace contamination by metals during distribution and storage. The limits in the present annex, although recommended for the fuel entering combustion chambers, do not apply to the fuel as delivered unless mutually agreed upon by the interested parties. Fuels may, therefore, require further treatment, quality control procedures, special handling or other arrangements. The significance of trace metals in respect to hot corrosion of turbine components is discussed in C.4. In the absence of specific guidance from the turbine manufacturer, the present annex gives guideline limits for trace metals in the fuel entering the combustion chambers. These limits are shown in table B.1.

B.2 Definition

For the purpose of this annex, the following definition applies.

B.2.1 fuel entering the combustion chambers: Fuel that is actually burned in the gas turbine.

B.3 Analytical methods

Appropriate reference methods for the determination of trace metals are under development. Other methods may be agreed between the user, fuel supplier and turbine manufacturer for quality control purposes. Adapted methods are under development for the determination of concentrations of sodium, potassium, calcium and lead. For vanadium, the recommended method is ISO 8691; for sodium, potassium, lead and calcium a suitable method is ASTM D 3605[3], or equivalent methods pending the publication of relevant International Standards.

B.4 Exceptions to table B.1

There is a relationship between operating conditions, materials, material life and the corrosive trace metal content of the fuel. However, although maintenance may be reduced, and the life of turbine parts prolonged by exceptionally low levels of metals in fuels, the availability of such fuels may be restricted. The user may choose to adopt levels different from those of table B.1 if, after discussion with the turbine manufacturer and the fuel supplier, he determines that his overall operation can thereby be optimized.

B.5 Alternative to trace metals determination

In order to minimize high temperature corrosion, it is important that the melting point of the ash be well above the maximum temperature of materials in the gas passage. Therefore, by agreement between the manufacturer of the turbine and the user, either the melting point or the sticking point can be determined and may be used as an alternative to the limits given in table B.1. This point is discussed further in C.4.

B.6 Fuel purification procedures

The turbine user and manufacturer should agree on the most appropriate method for the removal of solid contaminants and water-soluble compounds so as to ensure the required final quality of the oil at the entrance to the turbine combustion chambers. Fuels of categories 3 and 4 near the density limit specified in table B.1 may require special consideration, or the limits modified to relate to existing fuel purification systems available.

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[3] ASTM D 3605:1977, *Trace metals in gas turbine fuels by atomic absorption and flame emission spectroscopy.*

Table B.1 — Guideline limits, in milligrams per kilogram, for maximum trace metals in fuel entering turbine combustion chambers

Category	Vanadium (V)	Sodium plus potassium (Na + K)	Calcium (Ca)	Lead (Pb)
DST.0 DST/DMT.1 DST/DMT.2 DST/DMT.3	0,5	0,5	0,5	0,5
RST/RMT.3 RST/RMT.4	Consult turbine manufacturer			

B.7 Sampling for trace metal determinations

B.7.1 General

For the purposes of control of trace metals, fuel may be sampled at a point upstream from the point of entry to the combustion chambers, provided that the sample is representative of fuel entering the combustion chambers. Because of the extremely low levels of elements being analysed in distillate fuels, great care has to be taken to ensure that the sample taken for analysis is representative.

B.7.2 Fuel sampling points

Sampling of the fuel at the critical points in the fuel system is recommended to assess the quality of the delivered fuel, to monitor the performance of the fuel clean-up or treatment system and to ensure that the fuel at the gas turbine combustion chambers meets specifications. The sampling points will depend upon the specific fuel system in question. These will include:

a) a sample taken on delivery during transfer into the fuel storage tank;

b) fuel storage tank samples, including both tank bottom samples and samples at various levels in the tank. These should be taken at a frequency determined by the user based on the rate of accumulation of water and other dispersed contaminants. Where the system consists of multiple tankage, it is suggested that such samples be taken preparatory to drawing fuel from a given tank. Where the gas turbine is used for standby or emergency service, the sample should be taken according to a closely observed schedule;

c) in installations which include fuel clean-up and/or treatment, samples should be taken at the fuel input and output to monitor the performance of the equipment;

d) the effectiveness of fuel filters may also be monitored by input and output samples;

e) a sample taken as close as practicable to the gas turbine combustion chambers is essential to ensure that the fuel meets specifications, especially for critical thresholds of trace metal contaminants.

B.7.3 Sample containers

Samples destined specifically for analysis of trace metals should be taken in containers manufactured from plastics materials which are hydrocarbon-resistant and low in trace metal content. These materials include polyethylene, polypropylene and polytetrafluorethylene. Metal and glass containers with unperforated liners of hydrocarbon-resistant plastic film materials are also suitable. Unlined metal and glass containers, while suitable for sampling for some analyses, can both add and remove significant amounts of trace metal contaminants.

The sample container should be filled only three-quarters full to allow shaking of the contents before the sample aliquot is taken for analysis.

B.7.4 Inspection and analysis of samples

Inspection and analysis of fuel to determine fuel quality at various sampling locations and at different times in the fuel storage tanks and the feed system are very important to ensure that only fuel of acceptable quality will reach the turbine combustion chambers. Brief visual inspections may serve to suggest the presence of some contaminants, but established methods of fuel analysis, including chemical analysis for trace elements, are needed for more complete evaluation of fuel quality.

The effectiveness of a fuel separation system can best be judged by the use of specialized analytical methods, as recommended by the suppliers of the equipment or the fuel. These might include measurement of conductivity, dielectric properties, colour, content and quality of particulate matter, turbidity, spectral properties or filterability. From such data, useful deductions may be made to supplement more detailed chemical analysis.

Annex C
(informative)

Significance of specifications for gas turbine fuels

C.1 Introduction

The properties selected for specification in table 1 are those that are considered to be of most importance in determining the characteristics of fuels used in various gas turbine applications, and are chosen to ensure that adequate care has been taken in the handling of these fuels prior to the transfer of custody to the user. In general, these specifications are the same as those required for fuels used in industrial and marine engines and boilers, but gas turbine experience has shown that additional controls on the chemical nature of the fuel ash are desirable to restrict the corrosion potential of certain slag-forming substances which can be deposited on those turbine parts which may operate above 590 °C. This topic is discussed in annex B above, and further details are given in C.4.

C.2 Significance of properties specified in table 1

C.2.1 Flash point

The flash point is a guide to the fire hazard associated with the storage and use of gas turbine fuels. Specification of minimum flash point temperature is usually mandatory.

C.2.2 Viscosity

Viscosity is a measure of the resistance of the fuel to flow. For gas turbine fuels it is extremely important, as it is a measure of how well the fuel will flow or can be pumped and also of the ease of atomization at the fuel nozzles.

A minimum viscosity is specified for categories 0, 1, 2 and 3, as some fuel pumps may not operate satisfactorily if the viscosity is below this figure. A maximum viscosity is specified for these fuels to prevent excessive pressure losses in the system, pumping problems and poor atomization. For category 4, a maximum viscosity is specified because of possible limitations of the fuel preheating equipment. However, fuels of a maximum viscosity higher than that specified for this category may be used, subject to agreement between suppliers, turbine manufacturers and turbine users. In this case the limitation will be the maximum heat load in the fuel preheater. This load should not exceed 1,5 W/cm^2 in a dynamic system, or 1,2 W/cm^2 in a static system, and the maximum preheater surface temperature should be 175 °C to avoid fouling problems.

C.2.3 Density

A knowledge of the fuel density is necessary to establish mass/volume relationships and to calculate specific energy. Maximum densities are specified for categories 2, 3 and 4 to ensure that water can be separated in any fuel treatment process, although for fuels for which these maximum densities are approached, special considerations regarding water separation may be needed.

C.2.4 Distillation

Specifications on other fuel properties in the case of categories 0, 1 and 2 make it unnecessary to specify distillation requirements, apart from the maximum 90 % recovery temperature which is included to control high-boiling material which could affect combustion performance. Fiscal requirements for fuels may require further controls on distillation limits to be specified in some countries.

No distillation requirements are considered necessary for categories 3 and 4, but turbines designed to operate on these fuels may have to start up initially using a fuel of the more volatile categories.

C.2.5 Low-temperature operability

A number of test methods for assessing low temperature operability of gas turbine fuels are available. The method chosen will depend on the category of fuel and on local practice.

C.2.5.1 Category 0

No requirements need be specified as this category will flow freely under all conditions of storage and use. Use at extreme temperatures however, of below – 50 °C, may need a demonstration of suitability.

C.2.5.2 Category 1

Kerosine-type jet fuels should flow freely under all conditions of storage and use down to – 30 °C. The freezing point test (ISO 3013) indicates the minimum flow temperature of fuels stored at lower temperatures.

C.2.5.3 Category 2

There are several different methods for assessing low-temperature properties of gas-oil type fuels.

a) **Cloud point** (for determination see ISO 3015), i.e. the temperature, expressed to the nearest 1 °C, at which a cloud or haze of wax crystals appears at the bottom of the test jar when the oil is cooled under specified conditions. It is the most restrictive method of low temperature performance assessment. Most gas-oil type fuels are still capable of flow at temperatures somewhat below their cloud point, but at such temperatures any fine filters in the fuel line may become obstructed and restrict or prevent flow.

b) **Pour point** (for determination see ISO 3016), i.e. the lowest temperature at which movement of the oil is observed, when the sample is cooled under prescribed conditions and examined at intervals of 3 °C for flow characteristics. Pour point can be reduced significantly by the use of certain types of additives (see 4.2).

c) **Cold filter plugging point**[4], i.e. the highest temperature, expressed to the nearest 1 °C, at which the fuel, when cooled under the prescribed conditions, either will not flow through a fine mesh filter or a nominal aperture width of 45 µm or will require more than 60 s for 20 ml of fuel to pass such a filter or aperture when subjected to a vacuum of 2,0 kPa.

C.2.5.4 Categories 3 and 4

These fuels usually require provision of heating facilities for storage and handling. For fuels approaching the maximum viscosity allowed for category 4, a minimum storage temperature of 45 °C and a minimum tank outflow temperature of 55 °C are required. Guidance on type of equipment required and the minimum storage and outflow temperatures should be obtained.

C.2.6 Carbon residue

The Ramsbottom test for carbon residue measures the amount of carbonaceous residue formed during the evaporation and pyrolysis of a petroleum product when burnt with limited excess air. It is intended to provide some indication of the relative coke-forming tendency. The residue is not entirely formed of carbon but is a coke which can be changed further by pyrolysis. Petroleum products containing naturally occurring ash-forming constituents or additives will have an erroneously high carbon residue when measured by the test, depending on the amount of ash which can be formed.

For fuel categories 0, 1 and 2 the carbon residue is determined on the residuum after 90 % of the fuel has been distilled. This improves the precision of the test.

Combustion systems designed for use on fuel categories 0, 1, 2 and 3 will be insensitive to carbon residue within the specification limits set for these categories. No limit is specified for category 4, but carbon residue should be determined and reported to permit evaluation of fuel behaviour in combustion systems.

C.2.7 Ash

The ash test specified in table 1 should not be related to the corrosive ash-forming tendencies discussed in C.4. This test (ISO 6245) measures material remaining after combustion at 775 °C, from ash-forming constituents naturally present in the fuel or from additives or inorganic contaminants.

Fuel ash can form deposits in the hot gas path through the turbine and affect satisfactory performance. It may also cause high-temperature corrosion of metal surfaces. This aspect is dealt with in more detail in C.4 and C.2.9.

C.2.8 Water and sediment

The limits for this adventitious contamination are set at the lowest level consistent with normal transport and handling procedures and with the propensity of a particular category of fuel to hold these materials in suspension. Sediment is defined for this purpose as material insoluble in toluene (see C.4.2.2).

C.2.9 Sulfur

Sulfur is present to some degree in all petroleum fuels. Category selection will normally be made on economic and performance grounds, but fuel sulfur content may be a limiting factor in some localities owing to environmental requirements, and lower maximum limits may need to be specified.

The sulfur components in the fuel are converted to sulfur oxides during the combustion process. These can be corrosive to heat exhaust equipment used in tandem with a gas turbine where metal surfaces are below the sulfuric acid dewpoint. The minimum metal temperatures of such surfaces should be kept above this dewpoint to avoid low-temperature corrosion.

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[4] Pending the publication of an International Standard, a suitable method has been prepared by the European Committee for Standardization (CEN) as EN 116, *Diesel and domestic heating fuels — Determination of cold filter plugging point.*

While the sulfur oxides are not by themselves harmful to the hot sections of the gas turbine, they will combine with any traces of alkali metals in the fuel to form sulfates which can participate in high-temperature metal corrosion.

C.2.10 Copper corrosion

Corrosive sulfur, if present in appreciable amounts, can result in corrosive attack on metallic fuel-handling components of a gas turbine installation.

C.2.11 Calculated specific energy

C.2.11.1 Fuel quantities

The calculated lower specific energy is given as a guide to the minimum value of energy output that can be expected for each category of fuel. It is not a critical parameter for routine gas turbine operation, but rather serves to estimate fuel needs and aids the user and fuel supplier in negociations.

The formula given in annex A is a convenient method for calculation of specific energy compared to other experimental techniques. The accuracy depends largely on the accuracy with which density and the proportions by mass of water, ash and sulfur are measured.

In general these properties can be measured with greater precision than the specific energy can be determined by experimental techniques. Because of coefficients in the equation which depend on the chemical composition of the fuel itself, the formula may from time to time need revision as refining techniques and crude sources change.

C.2.11.2 Turbine performance

When gas turbine performance is being evaluated, precise values for the specific energy and density are needed to establish exactly how much fuel energy is being consumed by the turbine as the output is being measured.

In this case the higher specific energy at constant volume may be determined by means of a bomb calorimeter such as that described in ASTM D 240[5], and the lower specific energy at constant volume determined by deducting the latent heat of the calculated amount of water vapour produced from the measured hydrogen content of the fuel. The technique used to measure specific energy is usually agreed upon prior to the performance test. It is recommended that samples of fuel at the beginning, during, and at the end of the test are evaluated.

C.3 Category selection

The selection of a particular gas turbine fuel for use in a given gas turbine requires consideration of a number of factors, including:

a) the availability of the fuel;

b) the design of the gas turbine and fuel-handling system;

c) the maintenance of the gas turbine;

d) the operating requirements of the gas turbine.

For guidance, commercially available fuel streams are indicated below in the category into which they fall in this specification.

C.3.1 ISO-F-DST.0

This category includes light naphthas from petroleum processing, condensate naphthas from natural gas processing, wide-cut aviation fuel, and other low flash point and low viscosity hydrocarbon liquids. Fuels in this category may have high vapour pressures at ambient temperatures, which will affect the design of fuel-handling systems.

C.3.2 ISO-F-DST.1/DMT.1

This category is a light distillate fuel suitable for use in nearly all gas turbines. It includes aviation and domestic kerosines and some light gas-oil components that do not meet the flash point requirements of category ISO-F-DST.2/DMT.2.

C.3.3 ISO-F-DST.2/DMT.2

This category includes most automotive, domestic, industrial and marine gas oils; heating of the fuel may be required for satisfactory fuel handling, depending on the fuel system design and/or the ambient conditions.

C.3.4 ISO-F-DST.3/DMT.3 and ISO-F-RST.3/RMT.3

This category may be a heavy distillate fuel, a light residual fuel meeting the low ash and carbon residue requirements, or a blend of distillate fuel with residual fuel. A typical example would be blended marine diesel fuel.

C.3.5 ISO-F-RST.4/RMT.4

This category includes most residual fuel oils and some topped crude oils. Since special fuel handling and treatment requirements and operating condition

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[5] ANSI/ASTM D 240-76:1980, *Heat of combustion of liquid hydrocarbon fuels by bomb calorimeter.*

restrictions are likely to apply, the gas turbine manufacturer should be consulted on the acceptability of fuel properties related to his gas turbine.

C.4 Significance of properties indicated in annex B

C.4.1 Fuel ash

Ash results from the non-combustible material in a fuel. Ash-forming contaminants occur in liquid fuels in three forms: suspended solid particulates, dispersed salt water and oil-soluble compounds. The solid particulates and salt water can cause maintenance problems in the fuel system. A greater concern is the formation of fouling and corrosive combustion ash deposits from all three types of ash-forming contaminants when the fuel is burned. With distillate-type fuels, these potential problems can be avoided or minimized by maintaining strict cleanliness of the fuel.

The primary condition for corrosion of a metal surface in a hot gas path by an overlying ash deposit is that the metal temperature be higher than the melting point of the ash. A melted ash can dissolve a protective oxide layer and attack the metal substrate, whereas a dry ash could be inert or interact with the underlying metal at a much slower rate. Different compounds present in the combustion ash have different melting points, depending on the specific chemical composition of the ash and the local turbine environment. The major metallic elements occurring in fuel which contribute to corrosion are sodium, potassium, vanadium and lead.

Even very small concentrations of corrosive contaminants in fuel can form significant ash deposits. As an example, at a fuel consumption rate of 25 t/h, each 1 mg of ash per kilogram of fuel means 25 g of ash passing through the turbine each hour.

The total ash in distillate fuels is usually very small and the result of salt water or gasoline contamination during fuel transportation, handling and storage. Residual fuels (and crude oils) have much higher ash contents due to a higher retention of dispersed water and solids and to the presence of soluble organometallic compounds of vanadium, nickel and possibly iron. The ash content of distillate fuels is normally less than 100 mg/kg fuel, and is typically 2 mg/kg to 10 mg/kg for a clean fuel. Residual fuels on the other hand, may contain several hundred milligrams of ash per kilogram, usually necessitating complete fuel treatment; desalting and vanadium inhibition by an additive, usually magnesium- and sometimes silicon-based.

Ash-forming contaminants may also enter the gas turbine in the turbine inlet air, particularly in marine and industrial environments. Unless removed by proper inlet air filtration, these airborne contaminants by themselves, or in combination with fuel ash, may also cause corrosion of hot metal parts.

C.4.2 Corrosive fuel ash

Corrosive combustion ash will form whenever there are significant contaminant levels of vanadium, sodium, potassium or lead in a liquid fuel.

C.4.2.1 Vanadium

Vanadium occurs as an oil-soluble organometallic compound in crude oils, varying in concentration from less than 1 mg/kg to over 100 mg/kg depending largely on the geographic origin of the crude oil. During petroleum refining, the vanadium concentrates in the residual oil, the distillates being virtually vanadium-free. Vanadium cannot be economically removed from crude oils or residual oils to produce vanadium-free fuels.

During combustion, vanadium is converted to vanadium pentoxide, melting at 675 °C. If sodium is present with vanadium, sodium vanadates with melting points as low as 535 °C can form.

The melting point of the ash can be raised by adding a magnesium compound to the fuel. Excess sodium content will counteract this reaction, so consequently the lower the sodium content, the better the response to the magnesium additive. Silicon compounds exert a physical dilution effect, reducing the corrosive action of sodium/vanadium complexes. Whenever additives are used, fouling but non-aggressive ash deposits will build up in the turbine hot gas path and reduce the output of the turbine. They have to be removed periodically to maintain turbine performance.

C.4.2.2 Sodium and potassium

Sodium and potassium are components of salt water, a common contaminant in liquid petroleum fuels. The sodium concentration in salt water is several times the concentration of potassium, and both are capable of forming highly corrosive combustion ash.

Sodium sulfate is formed when liquid fuels are burned; it melts at 884 °C, causing "sulfidation" attack.

Sodium- and potassium-caused corrosion is usually controlled by removal of salt water from the fuel by settling, centrifuging or electrostatic separation, or coalescing filtration. Careful design and management of storage facilities, combined with adequate settling times, will contribute to fuel cleanliness, thus significantly reducing the effects of water-soluble contaminants, and may reduce the need for further separation techniques. Chromium-based additives have been reported to be effective in combatting the corrosive action of sodium.

C.4.2.3 Lead

The presence of lead in gas turbine distillate fuels is usually the result of the fuel being contaminated with leaded gasoline or used lubricating oils during transportation and handling. Lead contaminants are oil-soluble and cannot be removed by fuel cleaning. During combustion lead is converted to lead oxide or lead sulfate. These compounds have fairly high melting points, but the presence of minor amounts of sodium will lower the ash melting point to around 600 °C.

Strict fuel management during transportation, handling and storage is the best way to avoid lead contaminants. Some success has been reported using additives based on magnesium and chromium to increase the ash melting point of a lead-containing fuel.

C.4.2.4 Other elements

Nickel, zinc, arsenic and other heavy metals which are sometimes present in category 4 fuels may form low-melting eutectics with other metals and cause corrosion.

C.4.2.5 Ash content

The amounts of all harmful elements should be kept as low as possible in a gas turbine fuel. However, the ash content has a great influence on the corrosive effect of these elements. The effect of 1 mg sodium and 1 mg vanadium per kilogram fuel can have different significances depending on the total ash content. This is illustrated as follows:

	Fuel A	**Fuel B**
Sodium content	1 mg/kg fuel	1 mg/kg fuel
Vanadium content	1 mg/kg fuel	1 mg/kg fuel
Ash content	10 mg/kg fuel	100 mg/kg fuel
Na + V as % of total ash content	20 % (*m/m*)	2 % (*m/m*)
Influence on ash melting point	Great	Small

Fuel A can be corrosive in the gas turbine while Fuel B can be acceptable, despite the fact they have the same sodium and vanadium contents. The behaviour of the ash of Fuel A can be converted into that of the ash of Fuel B by adding an additive that contributes a further 90 mg/kg fuel of inert or high melting point material to the ash.

C.4.3 Fouling ash deposits

The combustion ash may be harmless due to its high melting point, but accumulation of fouling deposits will disturb blade and vane efficiency and reduce throughput area, resulting in decreased power and increased fuel consumption. The rate of buildup of fouling deposits is a function of many factors, such as total fuel ash content and composition, particle capture efficiency, turbine operating temperature, turbine design and size.

Additive combinations, like magnesium + silicon, can significantly reduce the fouling rate. The turbine manufacturer should always be consulted for recommendations for the use of such additive combinations.

The use of high ash content fuel of category 3 or 4 may result in fouling to such a degree that periodic ash removal from the turbine hot gas path is required.

Calcium in a fuel 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 difficult to remove even with water washing. Calcium is not a problem with distillate fuel categories 0, 1 and 2, but it may occur in category 3 and 4 fuels. Fuel washing systems, normally required for category 3 and 4 fuels, also reduce the calcium contaminant level.

C.4.4 Fuel ash evaluation

A fuel ash evaluation should provide information on both the amount of ash formed during fuel combustion and the potential corrosiveness of this ash. The total amount of ash is determined by carefully burning a measured volume of fuel in the laboratory and weighing the residue obtained from ashing the combustion residue.

Two methods are available for assessing the potential corrosiveness of the combustion ash. The first is the determination of the trace metallic element concentrations in the fuel. The second is a melting point measurement of a fuel ash prepared in the laboratory. Turbine manufacturers set limits on trace metal contents or ash melting point (ash sticking temperature may be used in place of ash melting point) based on correlations with turbine performance experience. Both ash evaluation methods have an uncertainty because the ash deposit formed at a given point in the turbine hot gas path may not have the same composition as the ash produced outside the turbine in the laboratory. Ash-forming elements may not deposit in the turbine in the same proportions in which they are present in the fuel. Composition of turbine deposits can differ at different deposition sites, and given deposits may not be homogeneous.

Low ash content distillate fuels require very careful burning and subsequent ashing of large quantities of fuel to provide the minimum amount of ash required for ash content determination and for ash melting point tests.