TC 70 199

INTERNATIONAL STANDARD ISO 3977

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Gas turbines — Procurement

Turbines à gaz — Spécifications pour l'acquisition

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 3977 was developed by Technical Committee ISO/TC 70, *Internal combustion engines*, and was circulated to the member bodies in March 1976.

It has been approved by the member bodies of the following countries :

Australia	Japan	Switzerland
Belgium	Korea, Rep. of	Turkey
Czechoslovakia	Mexico	United Kingdom
Denmark	Netherlands	U.S.A.
France	Philippines	U.S.S.R.
Germany	Romania	Yugoslavia
India	Spain	
Italy	Sweden	

No member body expressed disapproval of the document.

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Gas turbines – Procurement

1 SCOPE

1.1 This International Standard provides technical information to be used for the procurement of a gas turbine and its auxiliaries by a purchaser from a manufacturer. Because of the very widely varying operating modes for gas turbines in practice, distinct categories of operating modes are specified with which a "standard" rating can be associated. These ratings must also be made on the basis of the ISO standard ambient reference conditions.

1.2 This International Standard provides a basis for the submission of proposals to meet different environmental and safety requirements and also gives, wherever possible, criteria to establish whether these are met. It does not attempt to deal with local or national legal requirements to which the installation may be required to conform.

1.3 This International Standard defines a standard framework for dealing with questions of fuel and other matters such as the minimum information to be provided by both the purchaser and the manufacturer. It does not, however, purport to include all the necessary information for a contract and each gas turbine installation must be considered in its entirety. Attention is drawn to the need for technical consultation between the manufacturer and the purchaser to ensure compatibility of equipment being supplied, particularly where the responsibility for supply is divided.

NOTE – Where the term "manufacturer" is used in this International Standard, it is deemed to mean the gas turbine manufacturer or the appropriate responsible contractor.

2 FIELD OF APPLICATION

This International Standard is applicable to open cycle gas turbine power plants using normal combustion systems and also includes closed cycle and semi-closed cycle gas turbine power plants. In cases of turbines using free piston gas generators or special heat sources (for example, chemical process, nuclear reactors, furnace for a supercharged boiler), this International Standard may be used as a basis but will need to be suitably modified. This International Standard excludes gas turbines used to propel aircraft, road construction and earth-moving machines, agricultural and industrial types of tractors and road vehicles.

3 REFERENCES

ISO/R 1996, *Acoustics – Assessment of noise with respect to community response.*

ISO 1999, *Acoustics – Assessment of occupational noise exposure for hearing conservation purposes.*

ISO 2041, *Vibration and shock – Vocabulary.*

ISO 2314, *Gas turbines – Acceptance tests.*

4 DEFINITIONS

For the purpose of this International Standard, the following definitions apply :

4.1 gas turbine : A machine which converts thermal energy into mechanical work; it consists of one or several rotating compressors, a thermal device(s) which heats the working fluid, one or several turbines, a control system and essential auxiliary equipment. Any heat exchangers (excluding waste exhaust heat recovery exchangers) in the main working fluid circuit are considered to be part of the gas turbine.

Examples of gas turbine systems are shown in figure 1.

4.2 gas turbine power plant : A gas turbine and all essential equipment necessary for the production of power in a useful form.

4.3 open cycle : A thermodynamic cycle in which the working fluid enters the gas turbine from the atmosphere and discharges to the atmosphere.

4.4 closed cycle : A thermodynamic cycle having a recirculation working fluid independent of the atmosphere.

4.5 semi-closed cycle : A thermodynamic cycle utilizing combustion in a working fluid which is partially recirculated and partially exchanged by atmospheric air.

4.6 simple cycle : A thermodynamic cycle consisting only of successive compression, combustion and expansion.

4.7 regenerative cycle : A thermodynamic cycle employing exhaust heat recovery, consisting of successive compression, regenerative heating, combustion, expansion and regenerative cooling (heat transfer from the exhaust to the compressor discharge fluid) of the working fluid.

4.8 intercooled cycle : A thermodynamic cycle employing cooling of the working fluid between stages of successive compression.

4.9 reheat cycle : A thermodynamic cycle employing the addition of thermal energy to the working fluid between stages of successive compression.

4.10 single-shaft gas turbine : A gas turbine in which the compressor and turbine rotors are mechanically coupled and the power output is taken either directly or through gearing.

4.11 multi-shaft gas turbine : A gas turbine combination including at least two turbines working on independent shafts. The term includes cases referred to as compound and split shaft gas turbines.

4.12 bled gas turbine : A gas turbine which has, for external use, extraction of compressed air between compressor stages and/or at the discharge of compressor, or extraction of hot gas at the inlet of turbine and/or between turbine stages.

4.13 gas generator : An assembly of gas turbine components which produces heated pressurized gas to a process or to a power turbine. It consists of one or more rotating compressors, thermal device(s) associated with the working fluid, and one or more compressor driving turbines, a control system and essential auxiliary equipment.

4.14 compressor : That component of a gas turbine which increases the pressure of the working fluid.

4.15 turbine : This term, when used alone, refers to the turbine action only. It is that component of the gas turbine which produces power from expansion of the working fluid.

4.16 power turbine : A turbine having a separate shaft from which output power is derived.

4.17 combustion chamber (primary or reheat) : A heat source in which the fuel reacts to increase directly the temperature of the working fluid.

4.18 working fluid (gas or air) heater : A heat source in which the temperature of the working fluid is increased indirectly.

4.19 regenerator/recuperator : Different types of heat exchanger transferring heat from the exhaust gas to the working fluid before it enters the combustion chamber.

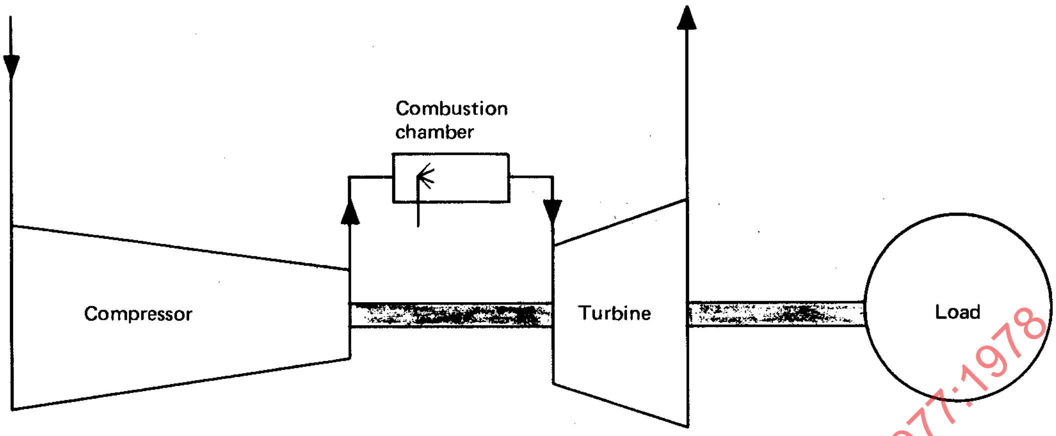
4.20 precooler : A heat exchanger or evaporative cooler which reduces the temperature of the working fluid before initial compression.

4.21 intercooler : A heat exchanger which reduces the temperature of the gas turbine working fluid between stages of compression.

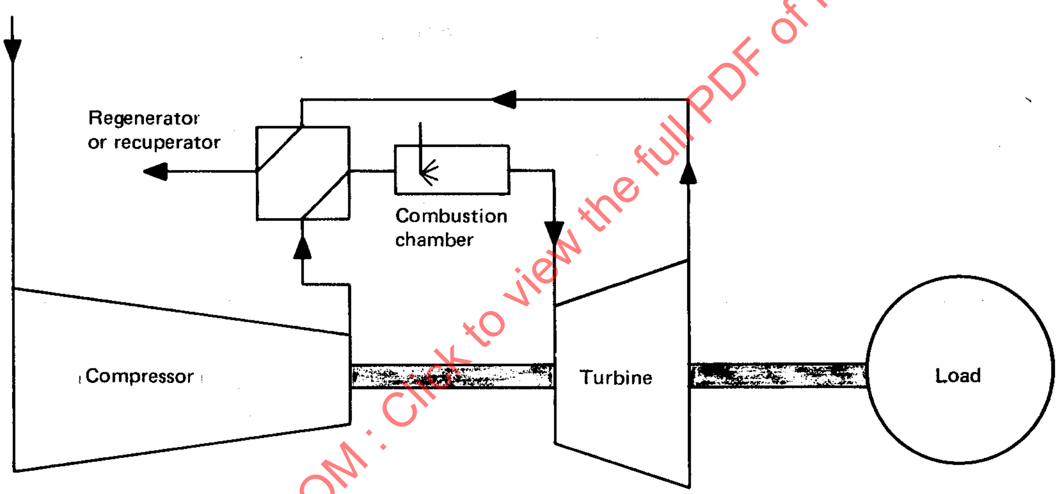
4.22 overspeed trip : A control or trip element which actuates the overspeed protection system when the rotor reaches the speed for which the device is set.

4.23 control system : This includes starting control systems, governor and fuel control systems, alarm and shutdown systems, speed indicator(s), gauges, electrical power supply controls and any other controls necessary for the orderly startup, stable operation, monitoring of operation, shutdown, warning and/or shutdown for abnormal conditions.

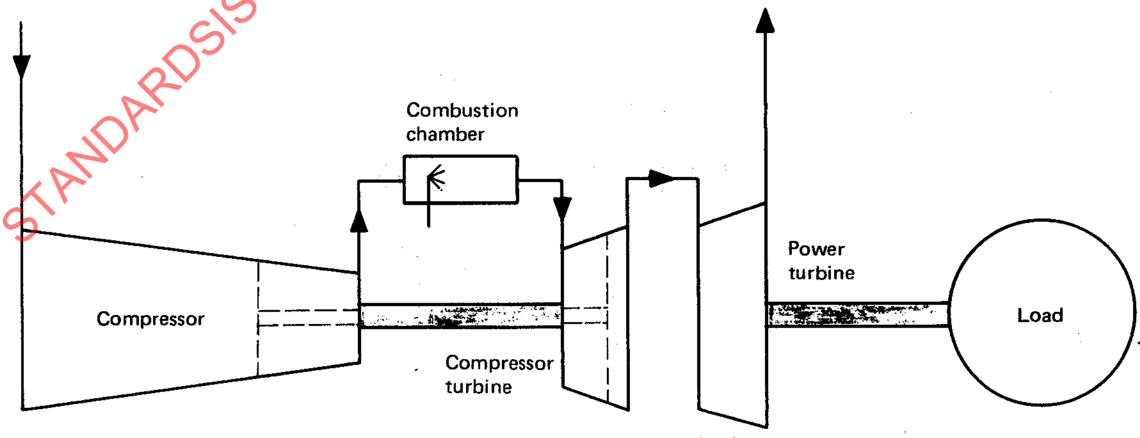
4.24 governing system : Control elements and devices for the control of critical parameters such as speed, temperature, pressure, power output, etc.



a) Simple cycle, single-shaft gas turbine



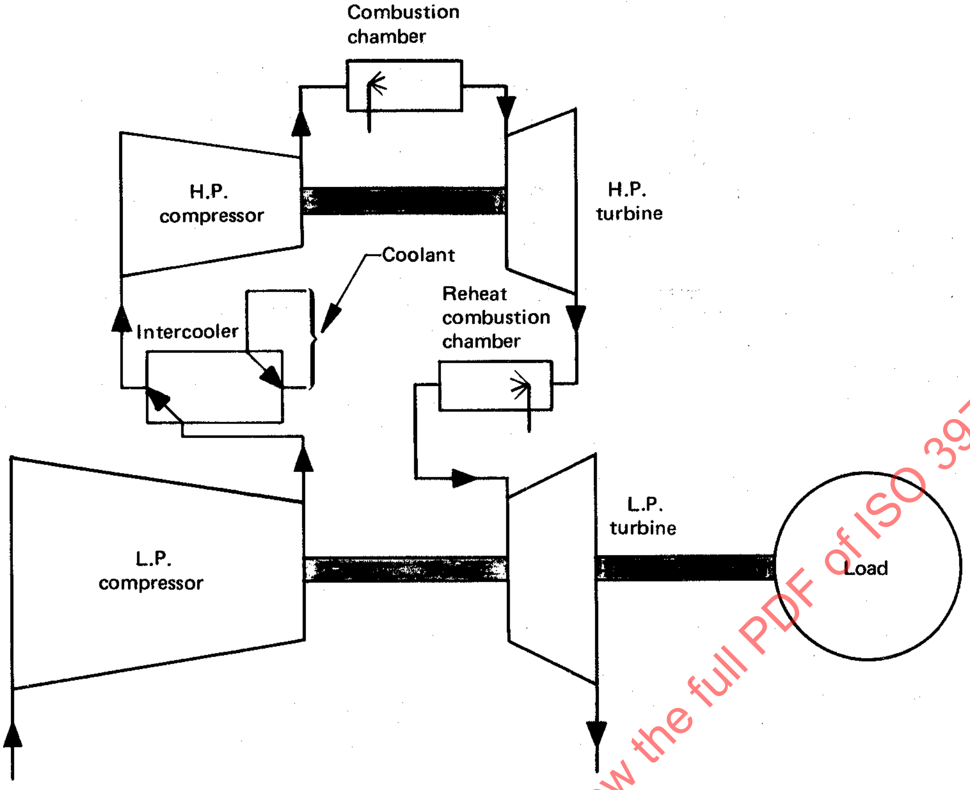
b) Regenerative cycle, single-shaft gas turbine



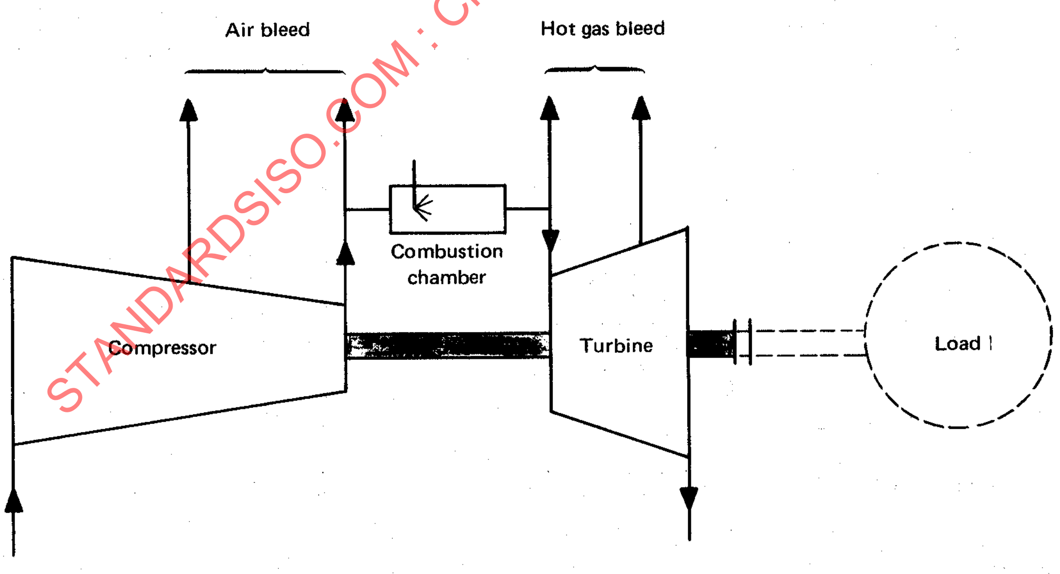
c) Simple cycle, split shaft gas turbine, i.e. with separate power turbine

(Alternative twin spool arrangement shown in dotted lines)

FIGURE 1 — **Examples of gas turbine systems**

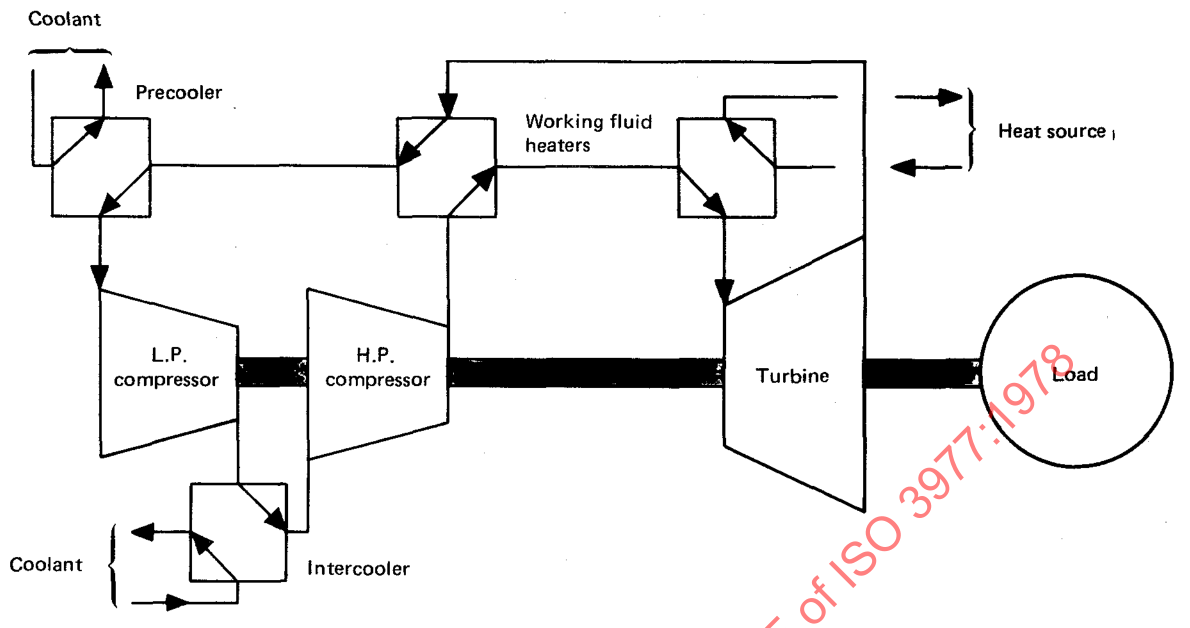


d) **Intercooled and reheat cycle (compound type), multi-shaft gas turbine with load coupled to low-pressure shaft**



e) **Single-shaft gas turbine with air bleed and hot gas bleed**

FIGURE 1 (*continued*)



f) Single-shaft closed cycle gas turbine

FIGURE 1 (*concluded*)

4.25 fuel governor valve : A valve or any other device operating as a final fuel-metering element controlling the fuel input to the gas turbine.

NOTE — Other means of controlling the fuel flow to the turbine are possible.

4.26 fuel stop valve : A device which, when actuated, shuts off all fuel flow to the combustion system.

4.27 dead band : The total range through which an input can be varied with no resulting measurable corrective action of the fuel flow controller. In case of speed, dead-band is expressed in per cent of rated speed.

4.28 governor droop : The steady state speed changes produced by the change of output from zero to the rated output, expressed as a percentage of the rated speed.

4.29 overtemperature detector : The primary sensing element which is directly responsive to temperature and which actuates, through suitable amplifiers or converters, the overtemperature protection system when the temperature reaches the value for which the device is set.

4.30 fuel calorific value : The higher calorific value is the total heat released per unit mass of fuel burned, expressed in kilojoules per kilogram. The lower calorific value is the higher calorific value less the heat absorbed by the vaporized water formed during combustion, expressed in kilojoules per kilogram.

The two calorific values can be obtained for constant volume or for constant pressure respectively, the difference being rather small.

The higher calorific value for constant volume is obtained using a bomb calorimeter. The lower calorific value for constant pressure is used in the steady flow combustion process (see ISO 2314).

4.31 heat rate : The heat consumption per unit of net power of the gas turbine, expressed in kilowatts of heat per kilowatt of power, based on the lower calorific value of the fuel including the sensible heat above 15 °C (see also 8.2.3 in ISO 2314). This may apply also to the test fuel in clause 6. This can also be expressed as the reciprocal of thermal efficiency (see 4.33).

4.32 specific fuel consumption : The mass rate of the fuel consumed per unit of power, expressed in grams per kilowatt hour, using the lower calorific value specified in 7.1.2.

4.33 thermal efficiency : The ratio of the net power output to the heat consumption based on the lower calorific value of the fuel [see 8.2.2 and 8.3.3 e) in ISO 2314].

4.34 turbine inlet temperature : The mean temperature of the working fluid immediately upstream of the first stage stator vanes (as determined in 8.6 in ISO 2314).

4.35 self-sustaining speed : The minimum speed at which the gas turbine operates, without using the power of the starting device, under the most unfavourable ambient conditions.

4.36 idling speed : The speed designated by the manufacturer at which the turbine will run in a stable condition and from which loading or shutdown may take place.

4.37 maximum continuous speed : The upper limit of the continuous operating speed of the gas turbine output shaft.

4.38 rated speed : The speed of the gas turbine output shaft at which the rated power is developed.

4.39 turbine trip speed : The speed at which the independent emergency overspeed device operates to shut off fuel to the gas turbine.

4.40 steam and/or water injection : Steam and/or water injected into the working fluid to increase the power output and/or to reduce the oxides of nitrogen (NO_x) content in the exhaust.

4.41 mass to power ratio (mobile applications) : The ratio of the total dry mass of the gas turbine elements, in accordance with 4.1, to the power in 7.3 of the gas turbine, expressed in kilograms per kilowatt.

4.42 compressor surge : An unstable condition characterized by low-frequency fluctuations in mass flow of the working fluid in the compressor and in the connecting ducts. Since this is a dangerous mode of operation, the surge condition must be avoided for all anticipated operating conditions.

5 STANDARD REFERENCE CONDITIONS

The standard reference conditions on which ISO power, efficiency, heat rate or specific fuel consumption are based are as follows :

5.1 Air intake conditions

5.1.1 For the intake air at the compressor flange (alternatively, the compressor intake flare) as described in 6.6.2 in ISO 2314 :

- a total pressure of 101,3 kPa[1];
- a total temperature of 15 °C;
- a relative humidity of 60 %.

5.1.2 Except in the case where intercooling is involved or where water spray coolers are used, the effect of humidity may generally be ignored.

5.2 Exhaust conditions

For the exhaust at turbine exhaust flange (or regenerator outlet, if a regenerative cycle is used) :

- a static pressure of 101,3 kPa.

5.3 Cooling water conditions (if applicable)

An inlet water temperature of 15 °C applies if cooling of the working fluid is used.

5.4 Working fluid heater or cooler

Where a heater or a cooler is employed and uses ambient air, the standard reference conditions shall be 15 °C and 101,3 kPa.

6 TEST FUELS

If the fuel to be used for testing the gas turbine is different from that agreed between the purchaser and the manufacturer for service operation (see 11.7), a test fuel of a mutually agreed specification shall be used.

7 RATINGS

7.1 General

7.1.1 The output power of a given gas turbine at a given turbine inlet temperature is, in general, proportional to the absolute ambient pressure and is also greatly dependent on air intake temperature (normally outside dry bulb temperature). Likewise, the output at a given air intake temperature is dependent on turbine inlet temperature. To achieve a rating it is necessary to adopt a standard condition of ambient temperature and pressure but gas turbine ratings will nevertheless vary considerably owing to the differing operational modes demanded of them as well as the varying criteria used in the design of the basic elements. ISO standard ratings neglect pressure drop at the inlet and exhaust but site ratings allow for these losses.

7.1.2 The performance ratings of gas turbines shall be assessed on the lower calorific value of the fuel used as follows :

a) turbines intended for use on liquid fuel : 42 000 kJ/kg;

b) turbines intended for use on gaseous fuel : 100 % methane — 50 000 kJ/kg.

The calorific value at constant pressure of the fuel, whether liquid, gaseous or solid, is based on a pressure of 101,3 kPa and a temperature of 15 °C.

1) 100 kPa = 1 bar = 750,1 mmHg

7.2 Operational modes

Unless special circumstances apply, and these must be specially agreed between the purchaser and the manufacturer, the rating of a gas turbine shall be specified under a combination of one of the classes in 7.2.1 together with one of the ranges of average number of starts per annum in 7.2.2 (for example, B II refers to operation of up to 2 000 h per annum associated with any number of starts up to 500 per annum).

The manufacturer shall state the type, frequency and degree of inspection and/or maintenance required for the relevant operational mode (see 12.1 c)).

NOTE — It should be recognized that some gas turbine applications will operate with a combination of the classes in 7.2.1. In such cases the purchaser should specifiy the anticipated number of annual hours of operation at the specified power ratings in each class. Operation outside these specified power ratings/operational modes could materially affect the inspection intervals and maintenance required.

7.2.1 *Classes*

Class A : operation up to and including 500 h per annum (Reserve peak);

Class B : operation up to and including 2 000 h per annum (Peak-load);

Class C : operation up to and including 6 000 h per annum (Semi-base-load or mid-range);

Class D : operation up to and including 8 760 h per annum (Base-load).

7.2.2 *Ranges*

Range I : over 500 starts per annum average;

Range II : up to 500 starts per annum average;

Range III : up to 100 starts per annum average;

Range IV : up to 25 starts per annum average;

Range V : continuous operation without planned shut-down for inspection and/or maintenance within a specified period.

7.3 ISO standard ratings

The manufacturer shall declare standard ratings, based on net shaft power adjusted for any auxiliaries not driven directly by the turbine as defined in 8.1 in ISO 2314, under the standard reference conditions in clause 5, associated with the following operational modes :

a) ISO standard peak load rating (2 000 h and 500 starts per annum average) Class B : Range II.

b) ISO standard base load rating (8 760 h and 25 starts per annum average) Class D : Range IV.

NOTE — For gas turbines used for generation, the above ratings are known as "ISO peak load" and "ISO base load" respectively.

In each case, the manufacturer shall state the type, frequency and degree of inspection and/or maintenance required.

7.4 Site ratings

The site power rating shall be specified by the manufacturer as follows :

a) Generating plant : The net electrical power at the generator terminals, with adjustment for auxiliary loads as given in 8.1.2 in ISO 2314.

b) Mechanical drives : The net shaft power, adjusted for any auxiliaries not driven directly by the turbine (as defined in 8.1.1 in ISO 2314).

In either case, the site power rating shall relate to specified site conditions of the installation (such as ambient pressure and temperature, and pressure losses, etc.) and operating modes under which the plant is intended to run in service.

Where the gas generator is supplied separately, its site power shall be expressed as the gas power arising from the isentropic expansion of the gas generator exhaust flow (using total pressure and temperature) to the ambient atmospheric pressure when it is operated under the specified site conditions of the installation and operating modes under which the plant is intended to run in service (see 6.3.5 in ISO 2314).

8 CONTROLS AND PROTECTION DEVICES

8.1 Starting

The starting control system, including any pre-start requirements, such as barring, may be manual, semi-automatic or automatic as defined below :

8.1.1 Manual start shall require the operator to start the auxiliary equipment; initiate, hold and advance the starting sequence (crank, purge, fire) and accelerate to minimum governor setting or ready for synchronizing in the case of generating sets.

8.1.2 Semi-automatic sequence start may require manual starting of the auxiliaries and shall permit the operator to commit the turbine by a single action to the complete starting sequence up to minimum governor setting or ready for synchronizing in the case of generating sets.

8.1.3 Automatic sequence starts require only a single action (manual or otherwise) to start the required auxiliary equipment and initiate the complete starting sequence up to minimum governor setting or ready for synchronizing in the case of generating sets.

8.2 Loading

Subsequent loading of the set may be manual, semi-automatic or automatic up to a specified power level. Automatic loading may follow directly the starting sequence without any additional action of the operator.

In any mode of loading, periods of dwell at specific loads may be introduced to provide for warm-up requirements.

Where a generator requires synchronizing to a particular system prior to loading, this may also be achieved by manual or automatic means.

8.3 Shutdown

This may be achieved by manual, semi-automatic or automatic means. In all cases, however, the principal sequence of operations is essentially as follows :

8.3.1 *Generator drives*

a) Controlled unloading to zero output at synchronized speed.

b) Opening the circuit breaker.

c) Reduction to idling speed and period of cooling where applicable.

d) Fuel cut-off and shutdown of auxiliaries not required for barring.

e) Barring period, if necessary.

f) Shutdown of remaining auxiliaries, for example lubricating oil pumps.

g) Return to starting conditions.

8.3.2 *Mechanical drives*

a) Controlled unloading to minimum load conditions.

b) Cooling period where applicable.

c) Fuel cut-off followed by shutdown of auxiliaries not required for barring.

d) Barring period, if necessary.

e) Shutdown of remaining auxiliaries, for example lubricating oil pumps.

f) Return to starting conditions.

8.3.3 *Emergency shutdown*

a) Emergency shutdown shall be capable of manual selection and shall also occur automatically as a result of automatic operation of plant protection devices. The system shall operate directly on the fuel stop valve to cut-off the turbine fuel supply.

b) Except where otherwise specified, automatic means shall be provided for isolating upon shutdown the driven equipment from the system which it is supplying in order to prevent motoring or reverse flow.

c) It may also be necessary to operate venting systems for the release of stored energy.

d) Normal barring and shutdown sequences, as appropriate, shall subsequently take place, but where automatic restart is included, means shall be provided to prevent automatic restart without manual reset.

8.4 Purging

8.4.1 Where gaseous fuels are used, the starting control system shall provide an automatic purge period (whether the starting sequence is manual or automatic) of sufficient duration to permit the gas turbine to displace at least three times the volume of the entire exhaust system (including the stack) at least three times before firing the unit. In cases where alternative precautions are taken, this may not be necessary.

8.4.2 Where liquid fuels of a highly volatile nature are used, special precautions may be necessary.

8.5 Fuel control

Fuel supply must be under a controlled opening sequence which may be over-ridden by the turbine temperature or other protective devices.

8.6 Constant speed

Gas turbines which are to be regulated to a substantially constant speed (in particular those driving electric generator where, in some cases, isochronous speed control is necessary) shall be fitted with a governor sensing the output shaft speed. Unless otherwise agreed between the purchaser and the manufacturer, no-load speed shall be adjustable, while running, within the range of 95 to 105 % of the rated speed.

The speed changer, when remotely operated, shall typically, when held synchronized, be capable of reducing the output from maximum site rated output to zero in not more than 40 s but the operating time taken shall be specified by the purchaser to be compatible with other speed changers on units running in parallel.

8.7 Variable speed

For gas turbines which are required to run over a range of speeds, for example as in ship propulsion, suitable control equipment shall be provided.

8.8 Governor

The governor for mechanical-drive applications shall limit the output speed at 105 % of the rated speed under all conditions of steady load. Unless otherwise specified by the purchaser, governor systems for generator drive shall prevent the gas turbine from reaching the turbine trip speed with an instantaneous loss of load when the turbine is operating under conditions within the limits of capability set by specified ambient conditions with design fuel pressures, temperature and fuel calorific values, and with the speed changer set and controlling at the rated speed.

8.9 Fuel governor valve

The fuel governor valve (see 4.25) shall return to minimum position under any turbine shutdown condition.

8.10 Fuel shut-off

8.10.1 In addition to the fuel governor valve or control valve, the fuel control system shall include a separate stop valve or "shut off valve" which stops all fuel flow to the turbine in any shutdown condition and which will not open until all permissible firing conditions are satisfied.

8.10.2 For electric generation, means shall be provided, either on the gas turbine or on the generator, for prevention of motoring of the generator when the fuel stop valve is closed. Where synchronous compensation is specified, these requirements may be operationally over-ridden.

8.10.3 For gaseous fuels, appropriate vent valve(s) shall be used to reduce the risk of leakage into the gas turbine when the turbine is shut down.

8.11 Overspeed control

Each separate line of shaft shall be fitted with either an overspeed governor or an overspeed trip unless it can be shown that dangerous overspeeding is not a practical possibility.

8.12 Manual check on overspeed controls

Facilities shall be available for the operator to check manually the overspeed governor/overspeed protective devices.

NOTE — It is desirable that this should be done as far as is practicable without trip shutdown and without temporary loss of protection.

8.13 Overspeed settings

The overspeed governor or overspeed trip shall be set to operate at a level which will not allow the transient speed to exceed the maximum safe limit for the line of shafting under any sudden loss of load. Their main functions are respectively to cause the fuel to be reduced or to be cut off near the burner(s) by means independent of the main governor.

8.14 Transient speeds

In a gas turbine, particularly a multi-shaft unit, where a line of shafting may be subject to high acceleration on loss of load, speed may continue to rise after the operation of the overspeed trip. Hence, transient speeds significantly greater than the cut-off speed may be attained. The turbine shall be capable of subsequent normal operation without the need for inspection. Attention is drawn to the necessity of ensuring also that all coupled equipment, including auxiliaries, etc., electrically, mechanically or hydraulically coupled, withstands the corresponding overspeed.

8.15 Additional overspeed protection

Gas turbines with separate power turbines or with heat exchangers may require additional protection against overspeeding due to stored heat or large stored volumes of high pressure air, or both. Such protection may, for example, take the form of blow-off valves, load resistors, actuated by the main governor or overspeed trip, or both.

8.16 Flame failure

Where installation requirements indicate, consideration shall be given to providing a device to shut off the fuel in the event of flame failure.

8.17 Fuel override control

The fuel control system shall include an override system to prevent exceeding the turbine rated firing temperature or maximum gas generator speed if this is a more stringent limitation.

8.18 Dead band

The dead band at rated speed and at any power output up to and including the maximum power output shall not exceed 0,1 % of the rated speed. However, for large output generator applications the dead band will be expected to be generally lower.

8.19 Stability of the speed governing system

8.19.1 The speed governing and fuel control systems, with the turbine operating between zero and its maximum turbine capability, shall be capable of stable control of :

a) the speed of the turbine when the driven equipment is operated isolated;

b) the fuel energy input to the turbine when the driven equipment is operating in parallel with other driven equipment.

In certain cases the control is obtained by a combination of a) and b) above. Stability of operation is also required in these cases.

8.19.2 The speed governing and fuel control systems shall be considered stable when :

a) the driven equipment is operated and under sustained load demand, provided that the magnitude of the sustained oscillations of turbine speed produced by the speed governing system and fuel control system does not exceed ± 0,12 % of the rated speed;

b) the magnitude of the sustained oscillations of energy input produced by the speed governing system and fuel control system does not produce a change in output exceeding ± 2 % of the rated output when the driven equipment is operated at rated speed in parallel with other driven equipment at constant speed and under sustained load.

For gas turbines of large output, the permissible magnitude of oscillations is expected to be generally lower.

8.20 Stability of the temperature control system

The temperature control and fuel control systems shall be capable of controlling with stability the temperatures of the gas turbine when the turbine is operating on temperature control at the set limit for the ambient condition existing when the driven equipment is operating in parallel with other driven equipment.

The temperature limiting or control system and fuel control system shall be considered stable when the driven equipment is operating in parallel with other driven equipment at constant speed demand provided the magnitude of the sustained oscillation of turbine fuel energy input produced by the temperature limiting or control system and the fuel control system does not produce a change in output exceeding 6 % of the rated power output.

8.21 Overall system stability

In certain installations where the driven equipment and its associated system excersice an overriding influence, the criteria of stability in 8.19 and 8.20 may not be achievable.

8.22 Lubricating oil system

Gas turbines with main shaft bearings of the hydrodynamic type shall be equipped with at least two oil pumps driven from independent power sources. One of the pumps shall be automatically actuated if the oil pressure is below the safe minimum value specified by the manufacturer.

8.23 Bearing temperature

Gas turbines with main shaft bearings of the hydrodynamic type shall be equipped with temperature monitors which shall measure the bearing metal and return-oil temperatures and which shall actuate alarms and/or trips.

8.24 Pressure fluctuations and excessive pressure drop in air intake

The design of the air intake system shall take into account pressure differentials due to fouling or icing of the air intake filters and fluctuations arising from abnormal operating conditions due to a transient compressor surge.

8.25 Fuel leakage

Consideration shall be given to the need for fuel leakage detection.

8.26 Other safety aspects

Information on other aspects of safety which shall be considered at the tender stage is given in annex E.

9 FUELS

9.1 General

As gas turbines may be designed to burn either gaseous or liquid fuels, or both, with or without changeover while under load, the following information shall be supplied by the purchaser (see 11.7) :

a) the full specification and chemical analysis of the proposed available fuel(s), including expected concentrations of contaminants and possible variations of fuel composition;

b) any proposed treatment of the fuel(s) and the resulting specification;

c) where changeover from one fuel to another is required, the load and speed changeover conditions, the fuel change sequence and any other relevant operational requirement.

If the purchaser's fuel specification is not acceptable to the turbine manufacturer, the latter shall advise the purchaser of acceptable limits of contaminants and acceptable variations of fuel composition.

9.2 Gaseous fuels

9.2.1 *Properties*

The fuel shall be completely gaseous at the turbine manufacturer's termination point and at all points downstream to the fuel nozzle where liquid might be harmful to the gas turbine; liquid eliminators or other special features, such as heaters, may be necessary to achieve this.

The manufacturer shall advise the purchaser of the minimum and maximum acceptable temperatures and pressures of the fuel gas.

The manufacturer shall advise on the degree of fuel cleaning required in respect of solids.

9.2.2 *Corrosive agents*

Special attention shall be given in the analysis to the presence of known corrosive agents such as hydrogen sulphide, sulphur dioxide, sulphur trioxide, total sulphur, alkaline metals, chlorides, carbon monoxide and carbon dioxide which may be present in the fuel gas.

9.2.3 *Calorific value*

The purchaser shall notify the manufacturer of the lower calorific value of the gaseous fuel or information whereby the value may be calculated. If it is anticipated that during steady state operation the lower calorific value will differ from the specified value, both the extent and the rate of change shall be stated by the purchaser in order that special equipment which may be required for proper gas turbine control may be fitted. If the variations in lower calorific value are unacceptable, the manufacturer shall advise the purchaser of acceptable limits.

Annex A gives further information on the calorific values of gaseous fuels.

9.2.4 *Supply pressure and temperature*

The purchaser shall notify the manufacturer of the fuel gas supply pressure and temperature. The amplitude rate of change and period of pressure and temperature fluctuations shall be stated by the purchaser. In the event that these fluctuations are unacceptable, the manufacturer shall advise the purchaser of acceptable limits.

Annex A gives supplementary information on gaseous fuels.

9.3 Liquid fuels

9.3.1 *Properties*

Liquid fuels ranging from the highest aviation grades to the heaviest boiler fuels are burned in gas turbines. However, not all gas turbines are designed to operate on such a wide range of liquid fuels, and the properties of a liquid fuel to be used may seriously affect the operation and maintenance as well as the capital cost of a gas turbine installation.

Therefore, the agreement on the fuel oil specifications between the purchaser and manufacturer should be sought depending on the availability of the fuel and the duty of the gas turbine. The manufacturer shall advise on the degree of fuel cleaning required in respect of solids.

9.3.2 *Liquid fuel grades*

NOTE — ISO/TC 28, *Petroleum products*, is preparing specifications for liquid fuels for gas turbines. In the interim period, and if agreed between the purchaser and the manufacturer, the application of A.2.3 and table 2 of annex A is recommended.

Liquid fuels to specifications recognized locally or authorized by other organizations and being suitable for gas turbines may be used with the mutual agreement of the purchaser and manufacturer.

Recognizing the necessity for additional or more stringent requirements for certain types of gas turbines and applications more restrictive specifications, additional properties and/or necessary fuel treatment may be specified.

Annex A gives supplementary information on liquid fuels.

9.4 Solid fuels

9.4.1 *General information*

Coal, peat and coke have been tried in open cycle (direct-fired) gas turbines. Some experimental work has been done to gasify coal for subsequent use as a fuel in open cycle machines. To date, this effort has not resulted in an economical approach for burning solid fuels in open cycle machines. However, coal and peat have been used in externally-fired air heaters for closed cycle gas turbines. The problems to be dealt with in such an application are similar if not identical to those occurring in steam boilers. Taking into consideration the complexity of the problem due to the influence of the vast variations of physical and chemical characteristics of the fuels it is impracticable to give specific requirements. It is therefore left to the purchaser and the manufacturer to reach agreement on the type of solid fuel to be used.

9.5 Nuclear fuels

9.5.1 *General information*

The application of a nuclear reactor as the heat source for a direct closed cycle gas turbine may be economically advantageous. This will involve the use of an inert gas such as helium as working fluid in the cycle.

Depending upon the design and the working principle of the reactor, special caution has to be taken regarding contamination of the machines and heat exchangers as well as the possible influence of even small amounts of gases such as water vapour, hydrogen, carbon monoxide and carbon dioxide on the corrosion of the cycle elements.

Therefore, when designing a nuclear closed cycle gas turbine plant, the fuel requirements have to be thoroughly investigated jointly by the manufacturers of the reactor and the power equipment and the purchaser.

10 ENVIRONMENT

10.1 General

This clause deals with vibration and other environmental factors which affect gas turbine operating personnel and people in inhabited areas adjacent to the gas turbine power plant. These other factors include sound (noise), atmospheric pollution, thermal pollution and site contamination. Locally recognized or mutually agreed upon standards or regulations shall take precedence over the criteria described in this clause which shall be considered where no such standards or regulations are applicable.

10.2 Vibration

Vibration affects the safety of both men and equipment. It is defined in ISO 2041 as the variation with time of the magnitude of a quantity, which is descriptive of the motion or position of a mechanical system, when the magnitude is alternatively greater and smaller than some average value of reference.

10.2.1 Vibration measurements are made on shafts, bearing housings or casings. The design details including mass, stiffness and accessibility of these parts determine the most significant locations for vibration measurement. This document does not specify numerical limits for vibration. The manufacturer shall ensure that vibration limits are compatible with the intended service (see 12.1).

10.2.2 The suitability of a gas turbine system for performing its intended function is often determined by detailed knowledge of vibration characteristics of system components. The components include shafts, bearings, housings, casings, enclosures, piping, accesories and particularly the internal blading and rotor discs, drums, etc. Obviously such knowledge is vital to the manufacurer;

however, when system components are to be supplied by more than one manufacturer the purchaser is advised to obtain an analysis of the lateral and torsional vibration characteristics of the complete system. A component consultant or one of the manufacturers can usually supply this service at a time that permits corrective action in the event the analysis predicts a troublesome natural mode of vibration within the range of expected operating conditions. It is well established that rotating machinery can encounter severe vibration when components are coupled by their shafts and foundations even though they each operate satisfactorily uncoupled (as during factory tests for example).

10.2.3 Intolerable vibration severity can cause serious damage to equipment and structures. Vibration is also a source of sound.

10.3 Sound

NOTE — An International Standard for the measurement of sound from gas turbines is under preparation by ISO/TC 43, *Acoustics*. In the interim period, the information given in 10.3 may be used for guidance.

10.3.1 *General*

Different people perceive a given sound level with varying degrees of sensitivity. Factors such as frequency, intensity, directivity and duration influence tolerance to objectionable sound. Too high a sound level may be damaging to human beings, and lower levels, while not damaging, may constitute a nuisance to nearby occupied structures. It is, therefore, important to the user to determine the acceptable sound level both in the gas turbine enclosure (if operating personnel are normally or frequently present) and also in the vicinity of the gas turbine power plant. It should be recognized that sound can be due to equipment other than the gas turbine, for example such associated equipment as fans, diesel starting engines, transformers, generators, etc. Since sound reduction equipment and station design concepts which reduce the sound level add cost to the overall power plant, the objective should be to achieve an acceptable sound level satisfactory for the health of the operator, operator communication considerations, and for nearby occupied structures.

The formulation of the sound requirements on the gas turbine manufacturer is to be adapted to the part of the total plant included in the delivery.

In order to meet the design objectives, both the user and the manufacturer must integrate their design of the total sound contributors while recognizing environmental factors that affect the overall sound level. The arrangements for sound reduction must be co-ordinated.

10.3.2 *Gas turbine enclosure interior sound level*

If the operator is to be inside the gas turbine enclosure, the degree and amount of acoustical treatment are to be based on reducing the sound level in the immediate working vicinity of the gas turbine installation to a level in accordance with the relevant national standard. If no such standard exists, ISO 1999 gives guidance in determining the appropriate sound level.

If the plant normally is unmanned, the use of ear-protectors is accepted in engine rooms. Normal conversation shall be feasible in control rooms.

10.3.3 *Sound level outside the gas turbine plant*

The sound generation must be limited to prevent disturbing noise in the vicinity. The local authority demands shall be fulfilled.

The purchaser shall specify the required sound level and indicate if possibilities shall be provided for extending the sound reduction equipment, for example for settlement that may arise in the vicinity. The durability of the sound reduction equipment shall be taken into account.

The influence that surrounding country, settlement, etc. has on shielding and reverberation shall be taken into account.

The requirements for the sound level can be formulated as a fixed maximum sound level not to be exceeded at any point at a specified distance from the plant. The requirements can also be specified for certain points or certain directions.

The requirements for the sound level must be formulated to enable checking. The distance between the point of measuring and the plant should be not greater than that permitting easy correction for the background sound.

The requirements shall include the maximum sound level in dB(A) or the allocation of frequencies, for example the NR–graph according to International Standards and/or any criterion that protects against interfering tones.

The method of sound measurement shall be agreed before the contract is finalized.

The background sound should be measured before the specified value is fixed, and possible time-variation should be taken into consideration.

Meteorological factors seriously affect the sound extension. In view of this, considerations should be taken, for example by detailed description in the contract, of the weather conditions expected at the location of controlling if the sound requirements are fulfilled.

Measuring tolerances should also be stated.

Guidance for acceptable sound levels outdoors are indicated in ISO/R 1996, where certain instructions regarding sound measurements are also given.

10.4 Atmospheric pollution

10.4.1 *Smoke*

Tests shall be made in accordance with a recognized and mutually agreed test method for stack emission. Information on existing methods is given in annex B.

If a limit on exhaust smoke is required by the purchaser, it shall be specified in the Bacharach scale under :

a) steady state conditions;

b) a specified condition of load or loads, 5 min after reaching these conditions.

NOTE — Other suitable methods of smoke measurement are under development and consideration will be given to their inclusion at a later date.

10.4.2 *Chemical pollution*

Local codes and standards must be consulted to determine the acceptable level of chemical pollution from gas turbine exhaust independent of light-reflective characteristics.

Gas turbine power plants generally generate less noxious gases than gasoline engines or diesel engines.

Unburned hydrocarbons and oxides of nitrogen and sulphur, however, can cause severe atmospheric pollution, especially in smog-prone areas.

Particles are typically of submicron size but are smog producers by providing condensation sites or nuclei.

In the event that fuel additives will be used for either smoke reduction or inhibiting corrosion with residual fuel oils, then there is greater possibility of stack emissions containing deleterious chemicals. This shall be checked against local codes.

10.4.3 *Total nitrogen oxides content*

The method for determining the total nitrogen oxides contents in gas turbine exhausts shall be made in accordance with a recognized and mutually agreed test method. Water or steam injection may be required to reduce nitrogen oxides emissions, in which case the rate of water consumption shall be indicated.

Information on suitable methods is given in annex C.

10.4.4 *Atmospheric thermal effects*

In the simple cycle gas turbine without exhaust heat recovery, the exhaust stack temperature is normally higher than for other types of fossil fuel power plants with resultant greater buoyancy and faster dissipation of the exhaust. The rapid mixing with surrounding air reduces the temperature of the mixture substantially in a distance of a few exhaust duct diameters. In the event that a large number of gas turbines are to be located near an airport flight path, possible deleterious effects of turbulence induced by exhaust gas shall be analysed.

10.5 Water thermal effects

Most gas turbines use little, if any, cooling water and therefore there is little heating of rivers, lakes, etc. Cooling water is frequently used for cooling lubricating oil for the power plant, but for self-contained units water-to-air heat exchangers are used to dissipate this heat. If compressor precoolers or intercoolers are used then cooling water requirements are more substantial.

10.6 Site pollution

Design of civil engineering features of a power plant site shall provide protection for plant environs in the event of abnormal operation, fire, or failure of plant equipment. Potential spillages from fuel storage and handling facilities shall be contained by means of compounds in accordance with the appropriate standards or regulations. A method for disposing of waste materials shall be provided. Waste materials include fuel from false start drains, lubricating oil contamined with fuel oil or water such as accidental leakage and spillage. Site selection shall give consideration to prevailing winds and the possibility of stack gases being drawn into neighbouring structures.

11 TECHNICAL INFORMATION TO BE SUPPLIED BY THE PURCHASER WITH THE ENQUIRY

The following particulars shall be supplied to the manufacturer with the enquiry :

11.1 Driven equipment

Electric generator, pump, compressor, etc.

11.2 Application

Stationary, portable, marine, locomotive, etc.

11.3 Extent of supply

The purchaser shall state the manufacturer's total responsibilities and define the extent of supply, including the interfaces between the manufacturer's supply and the supply by the others. Typical examples of the manufacturer's total responsibility and extent of supply may, for instance, include equipment supply and delivery time, erection, testing and guarantees, etc.

11.4 Environment

a) Elevation referred to sea level or normal barometric pressure, coincident wet and dry bulb air temperature and cooling water inlet temperature including average and extreme values and daily time/temperature air curves under the hottest and coldest conditions. Mean wet bulb temperature and range of variation experienced or relative humidity shall be furnished. The former is preferred.

b) Nature of surroundings as affecting purity of the air and possible fouling by dirt, dust or salt and any other environmental conditions, for example whether an industrial district, rural or near the sea, or region liable to dust storms or freezing fog.

c) Nature of surroundings as affecting exhaust emissions and suppression of sound, for example smoke-free zone, proximity to residential property, whether the gas turbine has to comply with any special requirements, for example statutory regulations, electricity requirements or standards, sound and smoke levels, etc. (see clause 10).

d) Particulars of any special conditions relative to fire risks, for example installation in an oil refinery, gas works or explosives works.

11.5 Details of site

a) State if installation will be outdoors or in a new or existing building and whether heating exists or is to be supplied. State also whether the manufacturer will be required to supply the building or enclosure.

b) Space available for the installation, including limitations in regard to size of engine room, depth of basement, etc.

c) Maximum size and mass (weight) of parts which can be transported to site and handled there.

d) Information required for foundation design, nature of ground, soil bearing capacity, sub-oil conditions and transmission of vibration.

e) Expected wind loads or levels, snowfall, rainfall, earthquake zone, and "G" loads for portable, marine and locomotive applications.

f) Details of access to site i.e. waterway, railway or road; distance of unloading point to final location.

g) Required sound level in the control room and other designated areas within the station.

h) Properties and conditions of preferred cooling media (see 11.8).

11.6 Expected duty

a) Site rating and ambient conditions at which this is required.

b) Ambient temperature (and, if relevant, coolant inlet temperature) at time when maximum output is required.

c) Expected number of running hours per annum, duration of runs and the number of starts. If known, average load to be carried and extent and duration of peaks.

d) Any other information regarding the required duty, for example black start, minimum time required for reaching full load from standstill in normal emergency conditions, and the power required over the proposed range of operating speeds.

e) Particulars of any other machines with which the driven machine is to run in parallel.

f) Where an electrical generator is to be included, the number of phases, the preferred method of generator cooling, whether required to operate as synchronous compensator and relevant data under normal and abnormal operating conditions, such as voltage, frequency and duration of operation at abnormal frequencies.

NOTE — Where extremes of temperature are encountered, consideration should be given to specifying a larger generator to make use of the extra capacity available from the gas turbine at low ambient temperature.

g) If the driven machine is not supplied by the turbine maker, its nature, characteristics, for example, fault conditions, speed in revolutions per minute, direction of rotation (if significant) range of required variation of speed and end thrust imposed, together with breakaway torque, low speed torque and polar moment of inertia of the driven unit. In addition, details of any special control requirements (for example where the speed of a gas turbine driving a compressor or pump may require to be controlled so as to give a constant delivery pressure) and requirements for lubricating oil, if this is to be supplied from the main turbine oil system.

h) Where the gas turbine exhausts to a waste-heat boiler not supplied by the gas turbine maker, the pressure drop across the boiler including ducting, and whether arrangements will be made for bypassing the boiler.

11.7 Fuel

a) Complete specifications of available fuels shall be submitted (see clause 9).

b) Cost of proposed fuel may be stated, if required, to assist in discussions on the most economical fuel and cycle for intended duty, balancing capital and operating cost.

11.8 Cooling water

Type, quantity, temperature and chemical analysis of water available (for example clear fresh water, sea water, abundant, restricted, available only for make up to recooling circuit), also pressure head and price where applicable and any restrictions on return temperature.

NOTE — Water may be required for precoolers, intercoolers, generator cooler, lubricating oil cooler, compressor and turbine washing, or for treatment of crude and residual oil fuels.

11.9 Auxiliary power supply

Details of electric, hydraulic or pneumatic power available on site for auxiliaries, for example starter motor, lubricating oil pump, etc.

11.10 Special requirements

a) Whether the gas turbine is to be :

1) attended or unattended;

2) controlled locally, remotely or automatically.

b) Whether the gas turbine is required to function over a range of inclinations.

c) Preferred lubricating oils.

d) Details of optional tests required in accordance with ISO 2314.

e) Expected maximum duration of operation without external services and/or power supplies.

11.11 Data sheets

If it is convenient, the information required in clause 11 may be presented by the purchaser in the form of data sheets.

12 TECHNICAL INFORMATION TO BE SUPPLIED BY THE MANUFACTURER WHEN TENDERING

The following particulars shall be supplied to the purchaser when tendering :

12.1 General information

a) A detailed list of any and all exceptions taken to the procurement specification. In the absence of such a list, it will be understood and agreed that the manufacturer's proposal is in complete conformity to the procurement specification.

b) Performance. Information supplied shall include, but not necessarily be limited to, the following :

1) Site rating. Power output under clearly stated ambient conditions (see 12.1 j)).

2) Expected thermal efficiency or specific fuel consumption, based on the lower calorific value of the fuel, at site rating and at three-quarters and half site rating. Also, data on power losses and heat consumption during operation as a synchronous compensator and spinning reserve under the conditions specified by the purchaser in 11.6 f).

3) Compressor air inlet flow or turbine exhaust flow.

4) Turbine inlet or exhaust gas temperature.

c) An indication of the anticipated replacement frequency of major components and type, frequency and degree of inspection and/or maintenance required for the relevant operational mode (see 7.2 and 7.3).

NOTE — The life expectancy of major components is difficult to assess and may vary with operating patterns, site conditions, fuel used, etc.

d) 1) Rotational speed of each shaft.

2) Direction of rotation of the output shaft(s).

3) Minimum continuous idling speed.

4) Critical speeds or combined resonance speeds, if known.

e) Leading particulars, for example cycle arrangement, nominal turbine inlet temperature, pressure ratios, mass flow and number of compressors, number of turbines, whether separate power turbine, intercooling, reheat, heat exchanger.

f) Method of starting, peak starting demand, time to reach rated speed and time to reach rated output, time on barring gear before start and after shutdown.

g) If fuel is gas, the pressure required.

h) Speed variation;

1) transient and permanent speed rise of output shaft on sudden loss of full load;

2) transient and permanent speed variations resulting from the changes of load notified by the purchaser following 11.6 d).

j) Curves showing the effect on output of ambient temperature and any limitations, including that of maximum power; also, if appropriate, corrections for ambient pressure, different external pressure losses and variation of thermal efficiency of fuel consumption with ambient temperature, any restriction in operating the machine over the full power and speed range, and, where relevant, a curve relating output power and output shaft speed.

k) Sufficient information, including heat rejection rates where required by the purchaser, to enable the plant ventilation and cooling requirements to be determined.

l) If a waste-heat recovery system is part of the installation, the manufacturer shall state his tolerances on exhaust temperatures and/or gas flow, related to a stated back-pressure.

If the installation is to include turbine exhaust heat recovery equipment not supplied by the manufacturer, the manufacturer shall include details of exhaust flow, temperature and pressure at stated ambient conditions and details of the variations with ambient pressure, temperature and exhaust back-pressure.

m) Type of lubricating oil recommended and consumption rate if significant.

n) Quantity of cooling water required, and any other auxiliary services, for example compressed air.

o) Statement of all contractors' terminating points.

p) Painting and any special protection required for startup, operation and periods of idleness under site conditions as specified by the purchaser in 11.4.

q) If the driven equipment is supplied by the turbine manufacturer, he must provide leading particulars, including description, performance, size, mass (weight), lubrication system, etc.

r) Where the purchaser provides his own starting device, the starting torque/speed characteristics of the gas turbine should be provided by the manufacturer.

s) The manufacturer should if possible by agreement with the purchaser state the sequence of delivery of the components and the extent of packing.

12.2 Mass (weight) and dimensions

a) Dry mass (weight) [defined as the mass (weight) without liquid, including all accessories essential to running or any drives incorporated for non-essential accessories].

b) 1) Mass (weight) of heaviest part to be lifted during erection.

2) Mass (weight) of heaviest part to be lifted during overhaul.

3) Dimensions of the largest part.

4) Maximum hook height required during erection (underside of base to crane hook).

5) Maximum hook height required during overhaul (underside of base to crane hook).

12.3 Drawings

12.3.1 The following drawings shall be supplied with the tender :

a) Preliminary plant layout and associated descriptive literature.

b) Outline drawing of the gas turbine giving overall dimensions and draw-out space.

c) An outline dimension drawing showing the location of the inlet and exhaust openings and such information needed by the purchaser to recognize what specific supports and supporting services are required.

d) Preliminary foundation requirements.

12.3.2 The following drawings shall, if possible, be supplied with the tender :

a) Cross-section of the gas turbine.

b) Piping and instrumentation diagram of lubricating oil, fuel oil, cooling water control air, etc.

c) Diagram of the control system.

12.4 Environmental considerations

a) Where required by the purchaser, the tender shall list the expected sound pressure level data for the gas turbine installation in accordance with clause 10.

b) Where required by the purchaser, the tender shall list the expected exhaust gas composition and smoke emission in accordance with clause 10.

12.5 Auxiliary equipment

a) A tabulated list of auxiliaries for which a power allowance has been made in the maker's site rating and which are necessary for the running of the turbine, for example :

- main lubricating oil pump;
- fuel pump, etc.

b) A list of other auxiliaries stating the power and voltage (where applicable) required for each (whether driven by the turbine or independently) for example :

- auxiliary lubricating oil pump;
- auxiliary fuel pump;
- air blast oil cooler fan;
- water circulating pump;
- battery charger;
- barring gear and jacking oil pump;
- starting equipment, etc.

c) Statement of other equipment and materials supplied by the maker and included with the turbine, for example :

- main speed reduction or increasing gear;
- sole plate, bedplate supports, foundation bolts;
- normal exhaust ducting;
- normal intake ducting;
- control cabinet and instrumentation;
- fuel filters;
- lubricating oil filters;
- lubricating oil tanks;
- lubricating oil cooler;
- lubricating oil purifier;
- tools, lifting gear;
- piping;
- batteries;
- essential spare parts, for example igniter;
- spares list;
- instruction manual;
- external insulation;
- list of essential protection devices, including controls, etc.

d) Statement of additional equipment available from or through the maker, for example :

- exhaust silencer;
- air filters or silencers, or both;
- house generator;
- extra ducting and cascade elbows;
- fuel and lubricating oil tanks, pumps, heaters, treatment plant and piping;

- turbine or compressor washing or cleaning equipment;
- platform, handrailing;
- additional spare parts recommended;
- supervisory, etc;
- fuel gas compression equipment;
- fire-fighting system;
- utility requirements such as compressed air, water, etc.

12.6 Maintenance

Where requested by the purchaser, the manufacturer shall give information on the anticipated maintenance requirements for the proposed gas turbine system. Typical maintenance information is given in annex D for guidance purposes.

12.7 Data sheets

If it is convenient, the information required in clause 12 may be supplied by the manufacturer in the form of data sheets.

ANNEX A

SUPPLEMENTARY INFORMATION ON FUELS

A.1 GASEOUS FUELS

A.1.1 Relative density and density by calculation

The relative density and density of a gas mixture may be calculated from its analysis by computing the relative molecular mass of the mixture. The latter is obtained by multiplying the mole fraction of each constituent in the mixture by its respective relative molecular mass and adding (see table 1 for relative molecular masses). The mole fraction is obtained by dividing the number of moles of gas by the total of moles present. For gases, the mole fraction is the percentage of volume divided by 100. For example, for a gas consisting of :

a) methane (CH_4) – 77,5 %

b) ethane (C_2H_6) – 16,0 %

c) carbon dioxide (CO_2) – 6,5 %

the relative density is determined as follows :

(1) Constituent	(2) Mole fraction (% by volume)	(3) Relative molecular mass	(4) Relative molecular mass of mixture [(2) × (3)]/100
CH_4	77,5	16,043	12,433
C_2H_6	16,0	30,070	4,811
CO_2	6,5	44,011	2,860
			20,104

Average relative molecular mass of gas = 20,104

The relative molecular mass of dry air from table 1 is 28,966 (the relative molecular mass of air at ISO standard conditions is 28,855 since it contains water vapour corresponding to 60 % relative humidity). Therefore, the relative density of the gas above, when compared to air (air referred to as 1,0), is :

$$\text{Relative density} = \frac{20,104}{28,966} = 0,694$$

The density of a gas is obtained by dividing the average relative molecular mass of the gas by the molar volume. The molar volume varies slightly with the compressibility factors of the components, but for most engineering purposes it is sufficiently accurate to use a volume of 22,412 m^3 per kilomole at 0 °C and 101,3 kPa (1 013 mbar).

The density of the gas mixture given in the example above is therefore :

$$\frac{20,104}{22,412} = 0,897 \text{ kg/m}^3 \quad [0\,°\text{C}, 101,3 \text{ kPa } (1\,013 \text{ mbar})]$$

and of air

$$\frac{28,966}{22,412} = 1,293 \text{ kg/m}^3 \quad [0\,°\text{C}, 101,3 \text{ kPa } (1\,013 \text{ mbar})]$$

TABLE 1 — **Properties of gaseous fuels at 15 °C**

Reference No.	Substance	Formula	Relative molecular mass	Calorific values kJ/kg Higher	Lower
1	Carbon	C	12,011	32 780	32 780
2	Hydrogen	H_2	2,016	142 120	120 075
3	Oxygen	O_2	32,000	—	—
4	Nitrogen	N_2	28,013	—	—
5	Carbon monoxide	CO	28,011	10 110	10 110
6	Carbon dioxide	CO_2	44,011	—	—
PARAFFIN SERIES, C_nH_{2n+2}					
7	Methane	CH_4	16,043	55 545	50 000
8	Ethane	C_2H_6	30,070	51 920	47 525
9	Propane	C_3H_8	44,097	50 385	46 390
10	*n*-Butane	C_4H_{10}	58,124	49 565	45 775
11	Isobutane	C_4H_{10}	58,124	49 445	45 660
12	*n*-Pentane	C_5H_{12}	72,151	49 060	45 400
13	Isopentane	C_5H_{12}	72,151	48 970	45 305
14	Neopentane	C_5H_{12}	72,151	48 780	45 115
15	*n*-Hexane	C_6H_{14}	86,169	48 710	45 130
OLEFIN SERIES, C_nH_{2n}					
16	Ethylene	C_2H_4	28,054	50 345	47 205
17	Propylene	C_3H_6	42,081	48 940	45 800
18	*n*-butene (Butylene)	C_4H_8	56,108	48 475	45 350
19	Isobutene	C_4H_8	56,108	48 220	45 085
20	*n*-Pentene	C_5H_{10}	70,128	48 180	45 040
AROMATIC SERIES, C_nH_{2n-6}					
21	Benzene	C_6H_6	78,107	42 360	40 660
22	Toluene	C_7H_8	92,132	42 890	40 985
23	Xylene	C_8H_{10}	106,158	43 380	41 310
MISCELLANEOUS					
24	Acetylene	C_2H_2	26,036	50 010	48 325
25	Naphthalene	$C_{10}H_8$	128,162	40 235	38 865
26	Methanol	CH_3OH	32,041	23 865	21 115
27	Ethanol	C_2H_5OH	46,067	30 615	27 750
28	Ammonia	NH_3	17,031	22 490	18 610
29	Sulphur	S	32,06	9 265	9 270
30	Hydrogen sulphide	H_2S	34,076	16 515	15 225
31	Sulphur dioxide	SO_2	64,06	—	—
32	Water vapour	H_2O	18,016	—	—
33	Air (dry)		28,966	—	—

A.1.2 Calorific value

Table 1 gives the calorific value of various gases which may be used for the calculation of heat values. Once the chemical analysis of the gas is known, the calorific value of the gas is the sum of the products of the mass fraction of each constituent and its calorific value on a mass basis. For the gas given in the example in A.1.1, the calorific values are obtained as follows :

The fraction by mass of each constituent is :

Methane = 12,4/20,104 = 0,617

Ethane = 4,8/20,104 = 0,239

The calorific values are :

HCV = 55 543 (0,617) + 51 917 (0,239) = 46 678 kJ/kg

LCV = 50 056 (0,617) + 47 525 (0,239) = 42 243 kJ/kg

A.1.3 Contaminants

The contaminants likely to be found in fuel gas depend on the kind of gas involved, for example natural gas, producer gas, refinery gas, blast-furnace gas. Some of the contaminants which are likely to be found are :

a) tar, carbon black, coke, dust and other solids;

b) water, salt water, oil and other liquids;

c) naphthalene, gas hydrates and other gases.

A.2 LIQUID FUELS

A.2.1 Properties

Gas turbine operation is improved and maintenance requirements are reduced when fuels have good thermal stability, good combustion quality, with low contaminant levels. These qualities become increasingly important when temperatures of the fuel system and turbine are high, or when long periods between overhauls are desired.

In general, use of a highly refined and therefore more expensive liquid fuel will reduce maintenance and capital cost of a gas turbine for a particular situation. Use of the low cost unrefined and residual fuels (although not all gas turbines are designed to operate on residual fuels) will increase maintenance and capital cost of a gas turbine. Thus, the best choice of fuel is a compromise between availability and cost of fuel, and maintenance and capital cost of the gas turbine.

A general principle can be expressed that for high utilization, a low cost fuel should be sought. For low utilization, the annual cost of fuel will be less and a higher cost fuel is justified to allow purchase of a lower initial cost gas turbine power plant (including possible fuel treatment equipment and supplies). Aircraft engines are designed to operate on a very light pure distillate oil. Some of the properties of aircraft grade fuels are specified for compatibility with the aircraft environments. Thus, aircraft engines converted to industrial use do not require fuels with all the requirements of aviation grade fuels.

Aircraft derivative gas turbines require the lighter grades of fuel, whereas industrial gas turbine designs are compatible with the heavier grades. Heavier grades of oil (other than distillates) usually contain more impurities which are more detrimental at the higher operating temperatures. Thus, to operate at peak ratings, industrial design gas turbines may also utilize the lighter grades of fuel.

A.2.2 The significance of the properties of liquid fuel on which restrictions are placed by specifications is as follows :

a) Density. Density alone is generally of little significance as an indication of the burning characteristics of liquid fuel. However, when used in conjunction with other properties, it is of value in mass-volume relationship and in calculating the calorific value of fuel.

b) Viscosity. The viscosity of a liquid fuel is highly significant since it indicates both the relative ease with which the fuel will flow or may be pumped, and the ease of atomization by the fuel nozzles.

Minimum viscosity is limited because some fuel pumps will not perform satisfactorily if the viscosity reaches too low a value. Maximum viscosity is limited since a given fuel system will not function properly if the viscosity exceeds some upper value.

High viscosity can cause excessive pressure losses in the piping system, and poor fuel atomization.

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

d) Handling and pumpability. The fuel(s) selected for use in a gas turbine can markedly affect the complexity of the fuel handling system. For example, the use of very light distillates classified as naphthas may require the addition of a lubricity agent to the fuel when used with fuel-lubricated pumps. The use of liquid fuels in grades Nos. 2–GT and 3–GT can impose special requirements related to the successful transport of fuel from bulk storage to gas turbine fuel system. These special requirements relate primarily to the viscosity and pour point temperature characteristics of one or more of the following heater systems. Specific requirements should follow the gas turbine supplier's recommendations based on his evaluation of the fuel compositions, ambient temperature range, and specific engine fuel system characteristics.

The high pour point temperature of many grade 3–GT fuels necessitates that heating be provided for tanks, piping and other fuel system components.

General requirements can be summarized as follows :

1) Heaters are required where the ambient conditions are likely to reduce the fuel temperature below the minimum permissible of 5 °C to 10 °C above the fuel pour, cloud or freezing point, depending on fuel viscosity. Bottom heating is preferred.

Local heating may be required where water is present in the fuel to prevent filter blockage as a result of ice particles. Vent lines should be heated to prevent fuel splashes from solidifying in the lines. The fill line should also be heated if provisions for draining or blowing clear are not incorporated. Some fuels exhibit a narrow range between pour point temperature and flash point temperature and, therefore, heating equipment must be capable of close control.

2) Fuel heaters should be installed before the separators and before the filters.

3) Fuel line heaters should be controlled by temperature or viscosity to prescribed levels.

4) All fuel lines, bypass lines, pumps, strainers, filters and valves up to the engine fuel pump inlet should be insulated and have trace heating as required.

In addition to heating, the fuel handling system must incorporate provisions for proper filtration, purging of heavy fuel from the system in both normal and emergency shutdown modes, and fuel cross-overs where more than one type of fuel is to be introduced into the system.

e) Flash point temperature. The flash point is an indication of the maximum temperature at which a liquid fuel can be stored and handled without serious fire hazard. The minimum permissible flash point may be regulated by law and is based on accepted practice in handling for use from the standpoint of safety.

f) Thermal stability. The thermal stability test measures the tendency of a fuel to deposit decomposition products in the fuel system components of the gas turbine. In certain types of gas turbine where the fuel system operates at high fuel temperature, the thermal stability must be specified.

g) Distillation. The distillation test shows the volatility of a fuel and the ease with which it can be vaporized.

h) Luminometer number. Luminometer number measures the flame-radiation characteristics of the fuel. A low luminometer number indicates that a greater proportion of the chemical energy of the fuel is released as thermal radiation. In certain types of gas turbine, this can cause overheating and a reduction in life of the combustion chamber parts.

j) Compatibility. Not all liquid fuels can be mixed without having jellylike or stringy precipitates form at the time of, or soon after, mixing or after mixing and heating. When this occurs, the oils are said to be incompatible. Compatibility is measured by making a 50 – 50 mixture of the two oils and then subjecting the mixture to the thermal stability test. In general, this test is not required on the light distillate oils because it is very rare that they encounter compatibility difficulties with one another.

However, when a light distillate oil is used for start-up and shutdown of a gas turbine burning a heavy oil, the mixture of light and heavy oils must be checked for compatibility.

k) Water and sediment. Water and sediment in a liquid fuel tend to cause fouling of the fuel-handling facilities and to increase maintenance costs in the gas turbine. An accumulation of sediment in storage tanks and filter screens may obstruct the flow of oil from the tank to the combustor of the gas turbine. Water in distillate fuels may cause corrosion of tanks and equipment, and water in residual fuels may cause emulsions. Sea or salt water is particularly detrimental because of the corrosive effect of sodium in combination with sulphur or other impurities.

l) Carbon residue. The carbon residue is a measure of the carbonaceous material left in a fuel after all the volatile components are vaporized in the absence of air. It is rough approximation of the tendency of a fuel to form carbon deposits in the combustor of the gas turbine.

m) Calorific value. The lower calorific value of the liquid fuel is required to calculate the gas turbine performance and to design the gas turbine.

Approximate values of the calorific values of liquid fuels can be obtained from ISO 2314.

Precise values shall be obtained by a bomb calorimeter test.

n) Ash. The ash is the non-combustible material in an oil. Ash-forming materials may be present in the liquid fuel in two forms :

1) solid particles;

2) oil or water-soluble metallic compounds.

The solid particles are, for the most part, the same material that is designated as sediment in the water and sediment test.

Depending on their size, these particles can contribute to wear in the fuel system, and to plugging of the fuel filter and the fuel nozzle. The soluble metallic compounds have little or no effect on wear or plugging, but they can contain elements that produce turbine corrosion and deposits as described subsequently.

o) Determination of melting point and sticking temperature of ash. In order to minimize high temperature corrosion it is important that the melting point of the ash is well above the maximum material temperature in the gas passage. Normally the ash melting point range is determined, but if this is not practicable owing to lack of suitable equipment, the ash sticking temperature may be determined with the aid of a suitable laboratory oven.

In order to examine the melting point range, the ashing must be done at 525 ± 10 °C to avoid sintering of the ash.

Ash melting point range. The ash melting point range covers the following :

1) ash sintering temperature : The temperature at which the ash binds together (sinters) without coherent melting.

2) initial melting point : The temperature at which parts of the ash begin to melt, giving the appareance of glistening spots.

3) final melting point : The temperature at which all the ash has melted.

Ash sticking temperature. The sticking temperature is the temperature at which the ash sticks to a platinum plate.

To discover whether the sticking temperature of an ash lies above the maximum allowed temperature, first set the laboratory oven to this temperature. Place a small sample of ash on a prepared[1)] platinum plate. Avoid fingering the upper surface of the plate. Fold up one side of the plate, pick up with laboratory tongs and carefully place it in the oven, where it should remain for 5 min with the door closed. Carefully remove the plate and allow it to cool down for a few minutes. Gently probe the ash with the forefinger. The sticking point has not been reached if the ash feels powdery and can easily be distributed. The sticking point has been reached if the ash has a hard sintered appearance and only partly loosens from the plate when disturbed. Those parts which have stuck feel like small lumps on the surface of the platinum plate.

Where the sticking temperature has been considerably exceeded, the ash may have completely melted and formed an enamel-like layer over the plate. If it is required to pinpoint the sticking temperature, it is convenient to begin at 660 °C and raise the temperature in 25 °C stages. A fresh ash sample must be used at each stage.

After these tests the platinum plate may be cleaned with the molten potassium pyrosulphate ($K_2S_2O_7$), washed thoroughly, rinsed in distilled water and dried.

p) Vanadium. Vanadium can form low melting compounds, such as vanadium pentoxide which melts at 690 °C, and which causes severe corrosive attack on all of the high-temperature alloys used for gas turbine blades.

Therefore, the maximum concentration of vanadium must be specified, and it is usually limited to 2 ppm. However, more stringent limitation such as 0,5 ppm may be specified according to the type and duty of a gas turbine.

The concentration of vanadium over the specified value will result in an accelerated corrosion of turbine parts. However, 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, causing some loss in power, but the deposits are self-spalling when the turbine is shut down.

In most cases, the required magnesium-to-vanadium ratio will be obtained by additions of magnesium-containing compounds to the liquid fuel. The special requirements covering the addition of and type of magnesium-containing base additive, or equivalent, must be specified by mutual agreement between the purchaser and manufacturer.

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.

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

q) Sodium and potassium. Sodium and potassium can combine with vanadium to form eutectics which melt at temperatures as low as 565 °C, and can combine with sulphur in the fuel yield sulphates with melting points in the operating range of the gas turbine. These compounds may produce severe corrosion, and for turbines operating at gas inlet temperatures above 650 °C, no additive has been found which successfully controls such corrosion without at the same time forming tenacious deposits.

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.

1) Make glowing red and cool in a desiccator before use.

For gas turbines operating below 650 °C, the corrosion due to sodium compounds may be of minor importance and can be further reduced by silicon based additives.

r) 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 which are not self-spalling when the gas turbine is shut down, and which are not readily removed by water washing of the turbine. The oil washing systems used at some gas turbine installations to reduce the sodium and potassium level will also significantly lower the calcium content of liquid fuel.

s) Lead. 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 is primarily the result of contamination during processing or transportation.

t) Chlorine. Gas turbine fuels may contain small amounts of chlorine compounds which form into HCl or even CL_2 during deposition. This compound or element accelerates corrosion of gas turbine austenitic materials.

u) Sulphur. Sulphur, normally burning to sulphur dioxide can also be oxidized partially to sulphur trioxide which can then combine with sodium and potassium compounds from the ash in the fuel to form sulphates and such compounds as sodium or potassium iron tri-sulphate.

The pyrosulphates and the trisulphates have melting points in the operating range of the gas turbine. Hence, these compounds produce severe corrosion of the turbine blading. In general, it has been found impractical to prevent corrosion by limiting the sulphur content of the fuel, so corrosion of this type is controlled by limiting the sodium and potassium.

A.2.3 Typical examples of liquid fuel grades

Gas turbine liquid fuels may be divided into three typical grades, based upon their applicability for use in gas turbines.

Limiting values are placed on a number of the properties of the oils in each grade. The properties considered are those that are believed to be of the greatest significance in determining performance characteristics of the liquid fuels in the various gas turbine applications.

a) Grade No. 1—GT is a very pure light distillate oil. (Certain very light distillates, such as naphtha and highly volatile fuels, may fail outside the limits given in table 2 and attention is drawn to the appropriate footnotes in table 2.)

b) Grade No. 2—GT is a heavier distillate than grade No. 1—GT. This grade can be used by gas turbines not requiring the characteristic of low carbon formation of grade No. 1—GT. Fuel heating equipment may be required, depending on the fuel system design or ambient temperature conditions, or both.

c) Grade No. 3—GT is a heavier distillate than grade No. 2—GT, or a blend of a distillate with a residual fuel oil, or a residual fuel that meets the low ash requirements. Fuel pre-heating equipment will normally be required.

Table 2 gives details of the above typical grades of liquid fuels.

A.2.3.1 The following requirements relating to liquid fuels must be met :

a) The fuel must be homogeneous hydrocarbon oils free from inorganic acid.

b) All grades containing residual components must remain homogeneous in normal storage; that is, they shall not separate by gravity into light and heavy oil components outside the viscosity limits for the grade.

c) Modifications of grade specification to meet special operating conditions must be agreed upon between the purchaser and the manufacturer.

TABLE 2 — **Typical requirements for gas turbine fuel oils (at gas turbine inlet)**
(other grades of fuels may be mutually agreed between the purchaser and the manufacturer)

Designation	Grade of gas turbine fuel oil	Flash point	Pour point[3]	Water and sediment	Carbon residue on 10 % residuum	Ash	Distillation temperature 50 % point		Saybolt viscosity[1] s			Kinematic viscosity[1] mm^2/s			API gravity	Vanadium (V)	Sodium plus potassium (Na + K)	Calcium (Ca)	Lead (Pb)	Sulphur
									Universal at 38 °C		Furol at 50 °C	At 38 °C		At 50 °C						
		°C	°C	% (*V/V*)	%	% (*m/m*)	°C								° API	ppm (*m/m*)	ppm (*m/m*)	ppm (*m/m*)	ppm (*m/m*)	% (*m/m*)
		min.	max.	max.	max.	max.	min.	max.	min.	max.	max.	min.	max.	max.	min.	max.	max.	max.	max.	max.
No. 1—GT[2]		40[6] or legal	− 18	0,05	0,15	0,01		290		(34,4)		1,4[6]	2,5		35	0,5	1	1	1	0,5 or legal
No. 2—GT	See A.2.3	40 or legal	− 7	0,10	0,35	0,01	280	360	32,6	(45)		2,0	5,8		30	1,0	1	1	1	1,0 or legal
No. 3—GT[4]		55 or legal		0,1		0,03			45		300	(5,8)		(638)		2,0[4]	1[4)5]	1[4)5]	1	See note 7)

1) Viscosity values in parentheses are for information only and are not limiting.

2) Recognizing the necessity of additional requirements for certain types of gas turbines, the following may be specified for No. 1—GT fuels :

- Luminometer number, min. = 40;
- Sulphur, % (*m/m*), max. = 1,0;
- Thermal stability test for 5 h at 121 °C preheater;
- Temperature, 177 °C filter temperature and at a flow rate of 2,7 kg/h;
- Filter pressure drop, max. = 40 kPa (400 mbar);
- Preheater deposit code, max. = 2.

3) Lower or higher pour points may be specified whenever required by the conditions for storage or use.

4) For gas turbines operating below 650 °C maximum gas temperature, the limitations on vanadium, sodium-plus-potassium, and calcium may be waived, provided that a silicon-base additive or equivalent is employed. The special requirements covering the addition of and the type of additive shall be specified only by mutual agreement between the purchaser and the manufacturer.

5) Higher values may be agreed between the purchaser and the manufacturer.

6) For certain highly volatile fuels these two minimum limits may be lower.

7) Legal requirements to be met. In some areas of the world the limit on sulphur is less than 1 %. The purchaser should consult local codes for acceptable limits.

ANNEX B

EXHAUST SMOKE MEASUREMENT

B.1 GENERAL

B.1.1 With proper maintenance, there should be no visible smoke from the exhaust of gas turbines burning gaseous fuel. Smoke in the exhaust of oil-burning gas turbines can be deceptive as only 0,1 %, or even less, of unburned carbon can result in extremely dense smoke. Techniques have been developed to measure smoke content, quantitatively, that extend into the invisible range. Specifications and codes for controlling smoke intensity should recognize transient as as well as steady requirements. Smoke intensity can be most critical at :

a) light off;

b) idle;

c) full load;

d) shutdown.

B.1.2 Smoke spot number

The degree of smoke intensity for gas turbine may be specified using the smoke spot number, also known as Bacharach number, where the smoke scale ranges from 0 to 9, with the lower values corresponding to a logarithmically lower value of smoke. The smoke spot number provides a fine discrimination in the vicinity of the threshold visibility.

Information on the Bacharach method of exhaust smoke measurement is given in clause B.2.

B.1.3 Von Brand reflective smoke number

Another method of specifying smoke is the Von Brand reflective smoke number. The Von Brand method allows for continuous sampling and hence permits observation of engine transients. A correlation between the Von Brand and smoke spot number is shown in table 3.

The estimated public response to gas turbine stack plumes is given in table 4.

B.2 SMOKE SPOT (BACHARACH) METHOD FOR GAS TURBINE EXHAUST SMOKE MEASUREMENT

B.2.1 Introduction

This sub-clause gives information on test equipment and procedures based on the smoke spot method for the measurement of smoke emission from gas turbines having exhaust pressures ranging from sub-atmospheric to high positive pressures, for example gas generators. The procedures included are for determining and reporting the amount of smoke emission and to enable a uniform approach to be established.

The information is presented as follows :

— terms and definitions;

— equipment;

— test procedures;

— information and data to be recorded.

TABLE 3 — **Approximate comparison of Von Brand and smoke spot numbers**[1)]

Smoke spot number	Von Brand reflective smoke number	
0	100	
1	99	
2	97	
3	93	
4	89	Perceptible range
5	82	
6	74	
7	67	
8	56	
9	0	

1) For the comparison in this table to be valid, the sampling rate for the Von Brand reflective smoke number is 4,74 m^3 of gas flow per square metre of filter paper area and for the smoke spot number 57,2 m^3 of gas flow per square metre of filter paper. See ASTM D2156–65 for definition of smoke spot number.

TABLE 4 — **Estimated public response to gas turbine stack plumes**[1)]

Smoke spot No.	Von Brand reflective smoke No.	Public response
0 – 3	100 – 90	None, invisible smoke
4 – 5	90 – 80	Acceptable – May satisfy local codes
6	80 – 70	Sporadic complaints
7 – 8	70 – 60	Many complaints leading to community action
9	Below 60	Immediate vigorous community action.

1) For the comparison in this table to be valid, the sampling rate for the Von Brand reflective smoke number is 4,74 m^3 of gas flow per square metre of filter paper area and for the smoke spot number 57,2 m^3 of gas flow per square metre of filter paper. See ASTM D2156–65 for definition of smoke spot number.

B.2.2 Terms and definitions

a) **smoke** : Small gas-borne particles, including but not limited to black carbonaceous material from the burning of fuel in sufficient concentration to create visible opacity.

b) **sampling** : The collection of an exhaust gas sample under controlled conditions for the purpose of analysis.

c) **test filter paper** : Particular filter material used to collect smoke particles from the exhaust gas sample.

B.2.3 Equipment

A schematic illustration of the sampling system is shown in figure 2.

B.2.3.1 Sampling probe, having an internal diameter between 9 and 10 mm. It shall have at least five 2,54 mm diameter holes spaced along its length such that each hole samples an equal area of the exhaust stream when placed across the exhaust duct.

Ideally the probe should be uncooled but if cooling is necessary to make the probe mechanically sound, the coolant flow shall be controlled so that the temperature of the sample gas does not fall below 100 °C.

Probe material shall be stainless steel or nickel-base alloy.

B.2.3.2 Sampling line, straight through with no kinks or loops, and no bends of less than ten line diameters. The sampling line inside diameter shall be between 9 and 10 mm. The sampling line section from the probe exit to valve A shall be as short as practicable and not greater than 30 m. Line material shall be stainless steel or copper. The line and sampling box shall be heated (electrically or by steam) and lagged to ensure that the sample gas is maintained within the range of 100 and 150 °C to prevent condensation of the sample at any position in the line, and overheating of the filter paper.

B.2.3.3 Valving. Valves A and B shall be throttling valves used to establish the sampling pressure in the smoke sampling box. Valve A shall be adjusted to produce minimum impingement in the sampling box.

B.2.3.4 Smoke sampling box, serving as plenum chamber in order to stabilize flow conditions. A schematic illustration of the sample box is shown in figure 2 and detailed requirements are shown in figure 3.

B.2.3.5 Temperature measurement. The temperature of the gas sample shall be measured at the entry to the sampling box.

B.2.3.6 Vacuum pump (if required), capable of producing between 1,2 and 2,5 kPa pressure in the smoke sampling box, when valve A is fully open, and valve B closed. The pump must be of the oil-free variety to avoid the possibility of contamination of the sample.

B.2.3.7 Bacharach pump, providing a total volume of 5 680 ± 250 cm^3 at 15 °C, 100 kPa for each square centimetre of effective surface area of filter paper.

B.2.3.8 Bacharach oil burner smoke scale, complying with ASTM D 2156-65, consisting of ten spots numbered consecutively from 0 to 9, ranging in equal photometric steps from white through neutral shades of grey to black, imprinted or otherwise processed on white paper or plastics stock having an absolute surface reflectance of between 82,5 and 87,5 %, determined photometrically. The smoke spot number is defined as the percentage reduction (due to smoke) in reflected incident light divided by 10.

B.2.3.9 Test filter paper, white having an absolute surface reflectance of 82,5 to 87,5 %, determined by photometric measurement. When making this reflectance measurement, filter paper must be backed by a white surface having an absolute surface reflectance of not less than 75 %. When clean air at standard conditions is drawn through clean filter paper at a rate of 47,6 $cm^3 \cdot min^{-1} \cdot cm^{-2}$ effective surface area of filter paper, the pressure drop across the filter paper should fall between limits of 1,73 and 8,55 kPa.

B.2.4 Cleaning and leak checks

The probe and sampling line shall be thoroughly cleaned prior to taking a smoke sample if more than 5 h running has taken place since they were last cleaned. It is recommended that the probe and line be cleaned by passing a suitable solvent through them, and then blowing clean, dry compressed air through for about 5 min to remove any remaining solvent in the line. While the air is being blown through the line, the line heaters shall be switched on.

The sampling line and probe connections shall be checked for leaks before any smoke samples are taken.

B.2.5 Test procedures

B.2.5.1 *Precautions*

The sample being measured is composed of low micron and/or submicron size agglomerated particles. Precautions must be taken to ensure that steady-state engine conditions have been achieved prior to taking a sample.

To prevent material accumulation in the sampling system, the probe shall be removed when not in use.

B.2.5.2 *Probe orientation*

The probe shall be located across the centre of the engine exhaust with its holes facing upstream. It shall be located at least two exhaust diameters downstream of the power turbine and not within two exhaust diameters of any bends in the exhaust.

B.2.5.3 *Preparation for sampling at each power setting*

The leak checks and cleanliness requirements in B.2.4 shall be confirmed. The following procedure shall then be carried out at each power setting to prepare the system for sampling :

a) Open valve A fully and adjust valve B as necessary to give between 1,2 and 2,5 kPa pressure in the sampling box, with or without the vacuum pump depending on available exhaust pressure.

b) Ensure that the temperature of the sample entering the sampling box is within the range 100 °C to 150 °C.

c) Allow sample to flow for 5 min.

d) Clamp a strip filter paper in the Bacharach pump and ensure that it is firmly secured, i.e. cannot be pulled out.

e) Connect the Bacharach pump to the smoke sampling box and adjust valve B as necessary to maintain between 1,2 and 2,5 kPa pressure in the smoke sampling box.

B.2.5.4 *Sampling procedure*

a) Draw the required sample through the test filter paper, using a Bacharach pump, over a period of approximately 1 min.

b) Having the sample, loosen the clamp on the Bacharach pump, move the filter paper along 10 mm and reclamp it firmly in position.

c) Repeat a).

d) Compare the smoke stains on the filter material (backed with a piece of white paper) with the Bacharach oil burner smoke standard scale. If they are not the same smoke spot number repeat a), b) and c) until two consecutive stains are the same smoke spot.

e) Samples shall be taken at engine conditions as agreed between the manufacturer and the purchaser.

B.2.5.5 *Obtaining the smoke spot number*

The smoke stain on the filter paper shall be compared with the standard smoke spot smoke scale by viewing the stain through the holes in the smoke scale. When the smoke stain and the smoke scale number are the same colour, then the number corresponding to the smoke stain is the smoke spot.

The comparison shall be carried out in daylight, not artificial light, within 1 h of taking the sample.

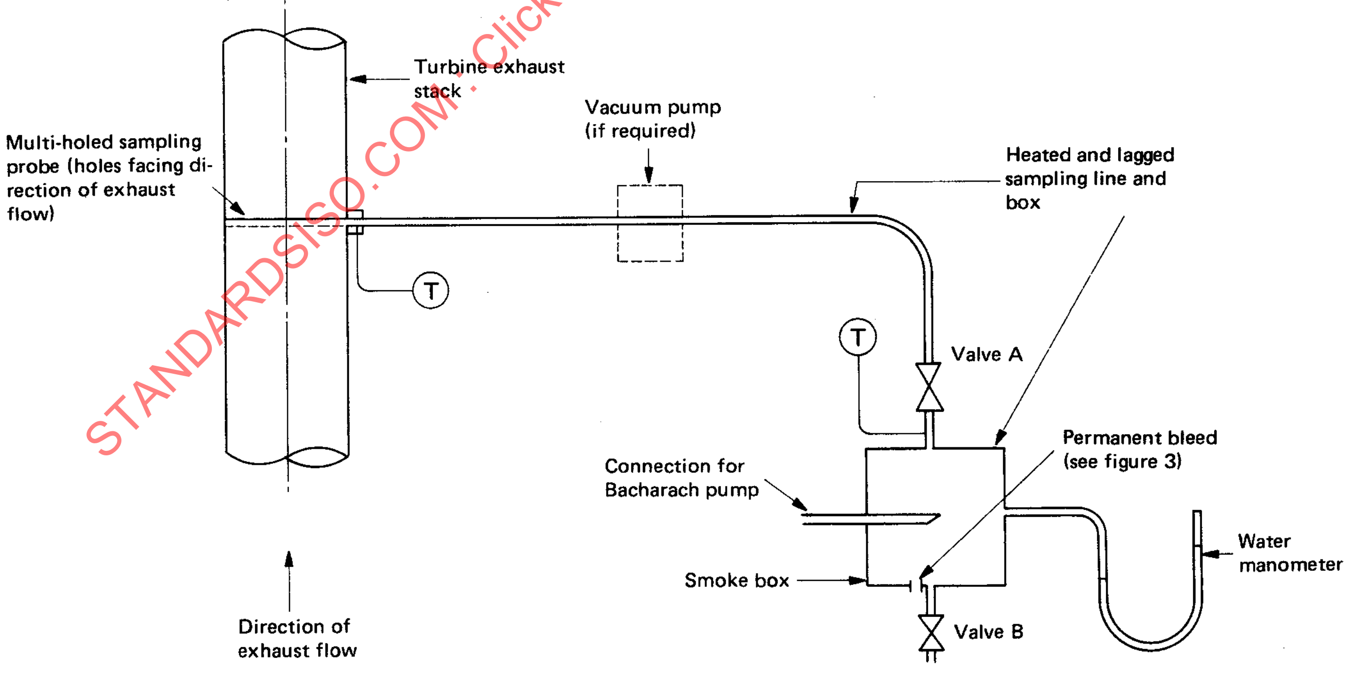


FIGURE 2 — **Schematic illustration of smoke spot smoke sampling system**

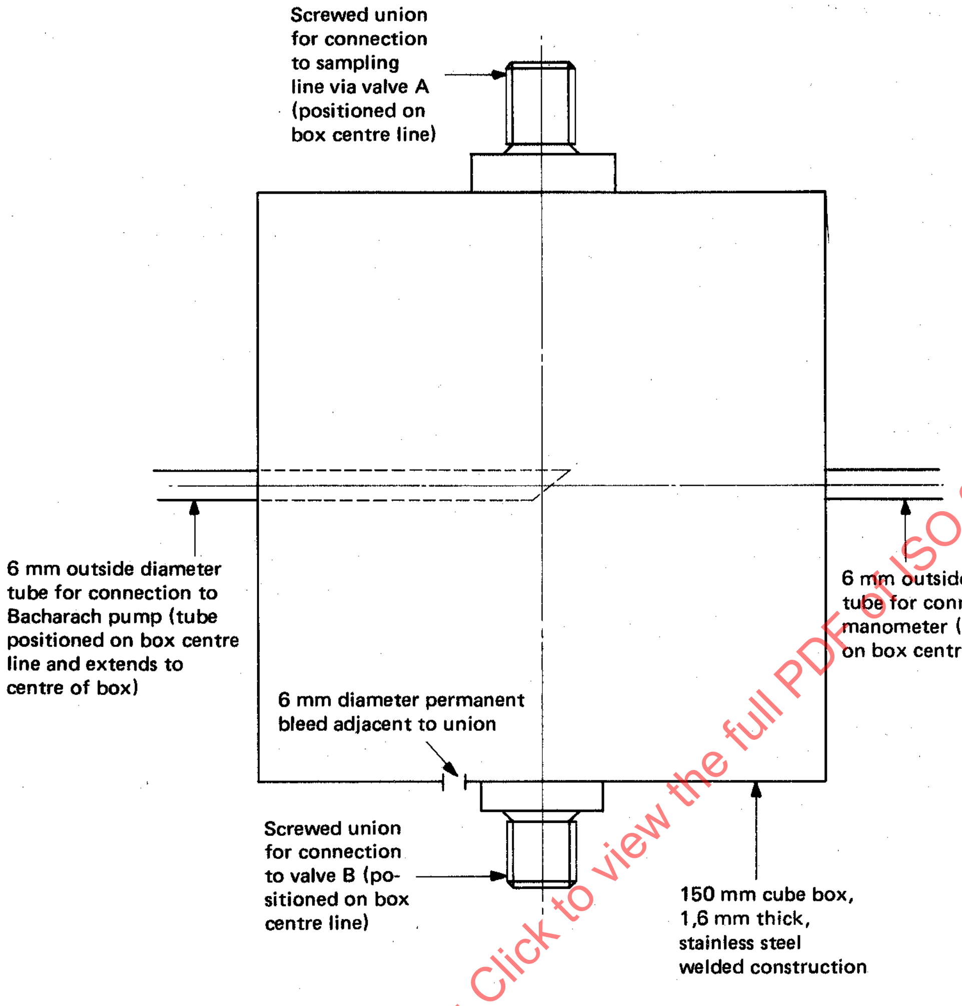


FIGURE 3 — **Smoke spot sampling box (all dimensions approximate)**

B.2.6 Test data

For each Bacharach number measured, the following data shall be recorded :

a) gas turbine power, speed fuel flow and power turbine entry temperature;

b) ambient conditions (pressure, temperature and humidity);

c) fuel type and additives, if used.