BRITISH STANDARD

Shell boilers —

Part 11: Acceptance tests

The European Standard EN 12953-11:2003 has the status of a
British Standard

ICS 27.060.30; 27.100

BSi

British Standards

National foreword

This British Standard is the official English language version of EN 12953-11:2003.

The UK participation in its preparation was entrusted to Technical Committee PVE/16, Shell boilers, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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EUROPEAN STANDARD

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English version

Shell boilers - Part 11: Acceptance tests

Chaudières à tubes de fumée - Partie 11: Essais de réception

Großwasserraumkessel - Teil 11: Abnahmeversuche

This European Standard was approved by CEN on 24 July 2003.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Foreword

This document (EN 12953-11:2003) has been prepared by Technical Committee CEN/TC 269 "Shell and water-tube boilers", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2004, and conflicting national standards shall be withdrawn at the latest by March 2004.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association. This European Standard is considered as a supporting standard to other application and product standards which in themselves support an Essential Safety requirement of a New Approach Directive and will appear as a normative reference in them.

The European Standard EN 12953 concerning shell boilers consists of the following Parts:

— *Part 1: General.*

— *Part 2: Materials for pressure parts of boilers and accessories.*

— *Part 3: Design and calculation for pressure parts of the boiler.*

— *Part 4: Workmanship and construction of pressure parts of the boiler.*

— *Part 5: Inspection during construction, documentation and marking of pressure parts of the boiler.*

— *Part 6: Requirements for equipment for the boiler.*

— *Part 7: Requirements for firing systems for liquid and gaseous fuels for the boiler.*

— *Part 8: Requirements for safeguards against excessive pressure.*

— *Part 9: Requirements for limiting devices of the boiler and accessories.*

— *Part 10: Requirements for boiler feedwater and boiler water quality.*

— *Part 11: Acceptance tests.*

— *Part 12: Requirements for grate firing systems for solid fuels for the boiler.*

— *Part 13: Operating instructions.*

 CR 12953-14: *Guideline for the involvement of an inspection body independent of the manufacturer.*

Although these Parts can be obtained separately, it should be recognized that the Parts are interdependent. As such, the design and manufacture of shell boilers requires the application of more than one Part in order for the requirements of the European Standard to be satisfactorily fulfilled.

The annex A of this European Standard is informative. The annex B of this European Standard is normative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This Part of this European Standard specifies a concise procedure for conducting thermal performance tests, using the indirect (losses) procedure for boilers for steam or hot water. Test results are based on either the gross or net calorific value of the fuel.

This concise procedure provides a convenient means for assessing boilers which are thermodynamically simple, i.e. having a single major source of heat input and a simple circuit for water, steam or high temperature heat transfer fluid.

NOTE 1   The use of the direct method is not advocated, because the estimated measuring error is three to four times greater than with the indirect method.

NOTE 2   An acceptance test may be required:

a) after the commissioning of new plant or after the recommissioning of modified plant in order to verify compliance with a specification or contractual obligation;

b) whenever the user wishes to determine the current performance of the plant either on a routine basis or due to change of load or other operating conditions or when a change of fuel or a modification to the plant is being considered;

c) whenever the user wishes to check combustion conditions.

Regular tests in accordance with this European Standard will enable boiler plant to be monitored in normal operation for optimum efficiency in the interests of fuel conservation.

This procedure does not cover condensing boilers. The application of boilers, where heat is extracted from waste gases is specified in annex B.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full - Part 1: General principles and requirements (ISO 5167-1:2003).*

ISO 157, *Coal — Determination of forms of sulfur.*

ISO 334, *Solid mineral fuels — Determination of total sulfur — Eschka method.*

ISO 589, *Hard coal — Determination of total moisture.*

ISO 609, *Solid mineral fuels — Determination of carbon and hydrogen — High temperature combustion method.*

ISO 625, *Solid mineral fuels — Determination of carbon and hydrogen — Liebig method.*

ISO 1928, *Solid mineral fuels — Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value.*

ISO 1988, *Hard coal — Sampling.*

ISO 3170, *Petroleum liquids — Manual sampling.*

ISO 6976, *Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition.*

3 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply.

3.1
indirect method (Heat loss method)
determination of all accountable heat losses. The efficiency is then equal to 1 minus the ratio of the sum of all heat losses to the sum of heat in the fuel plus heat credits

3.2
standard condition
condition at p_n = 0,101325 N/mm^2 and t_n = 0 °C

3.3
assessed losses
any thermal losses established from predetermined data

3.4
gross calorific value (GCV)
amount of heat liberated by the complete combustion, under specified conditions, of unit volume of a gas or unit mass of a solid or liquid fuel in the determination of which the water produced by combustion of the fuel is assumed to be completely condensed and its latent and sensible heat made available

3.5
net calorific value (NCV)
amount of heat generated by the complete combustion, under specified conditions, of unit volume of a gas or unit mass of a solid or liquid fuel in the determination of which the water produced by combustion of the fuel is assumed to remain as a vapour

3.6
heat input
heat content of the fuel used during the test based on the gross or net calorific value plus the sensible heat in the fuel above reference temperature plus the sensible heat in the combustion air above reference temperature

3.7
heat output
heat gained by the heat carrier from the boiler during the period of the test

3.8
measured loss
any thermal losses calculated from actual measurements made during the test

3.9
radiation, convection and conduction losses
losses from water, steam, combustion air, or gas-backed surfaces prior to the flue gas temperature measurement point and directly from flame to the floor and surroundings of the unit

3.10
test error
combined error due to sampling, measurements, calculations and assumptions used to obtain test results. The overall effect may be positive or negative

3.11
thermal efficiency
the difference between 100 % and the total percentage losses based on either the gross or net calorific value of the fuel which is equivalent to the ratio of the useful heat output to the heat input expressed as a percentage

3.12
turn-down ratio
the ratio of maximum and minimum fuel inputs for continuous firing in unit time specified by the manufacturer which can also be expressed in terms of boiler output provided the appropriate efficiencies are known.

4 Symbols and abbreviations

4.1 Symbols and units

For the purposes of this European Standard the symbols and abbreviations given in EN 12952-1:2002, table 4-1 and the following table 4.1-1 and the subscripts given in table 4.1-2 shall apply.

Table 4.1-1 — Symbols

Symbol	Description	Unit
c	Specific heat capacity [a]	kJ/(kgK)
$\bar{c}$	Integral specific heat capacity [a]	kJ/(kgK)
H	Calorific value (CV)	kJ/kg
h	Specific enthalpy	kJ/kg
i	Number of samples	—
J	Enthalpy of flue gas or combustion air related to fuel mass flow	kJ/kg
L	Latent heat (heat of vaporization)	kJ/kg
l	Single loss	—
l_u	Ratio of unburned combustibles to supplied fuel mass flow	kg/kg
M	Molar mass	kg/kmol
m	Mass	kg
$\dot{m}$	Mass flow	kg/s
n	Air factor at boiler outlet	—
p	Pressure	N/mm^2
$\dot{Q}$	Heat flow	kW
T	Thermodynamic temperature	K
t	Temperature Celsius	°C
u	Unburned combustibles content (by mass)	kg/kg
V	Combustion air and flue gas volume (per unit mass of fuel)	m^3/kg
x	Flue gas/combustion air components content by mass	kg/kg
y	Content by volume	m^3/m^3
η	Thermal efficiency	—
γ	Fuel content (by mass)	kg/kg
ν	Volatile matter content of ash	kg/kg
ρ	Density	kg/m^3
μ	Combustion air/flue gas mass to fuel mass ratio	kg/kg

NOTE 1   1 N/mm^2 = 1 MN/m^2 = 1 Mpa

NOTE 2   The units shown are those normally used. Conversion may be necessary for use in the dimensionless equations.

[a]   'specific heat', for short.

Table 4.1-2 — Subscripts

Symbol	Description
A	Air
Ash	Ash
B	Boiler
C	Carbon
CO	Carbon monoxide
CO2	Carbon dioxide
d	Dry (basis)
E	Useful, effective
FA	Flu dust (fly ash)
F	Fuel, burned fuel
Fo	Fuel supplied
Fw	Feed water
G	Flue gas (combustion gas)
(G)	Gross value
H	Hydrogen
H2O	Water
i	Number of components
m	Average
meas	Measured
min	Minimum
N	Nitrogen
(N)	Net value
n	Standard condition
o	Stoichiometric
O2	Oxygen
p	Constant pressure
r	Reference temperature
RC	Radiation and convection
S	Sulfur
SF	Ash and flue dust
ST	Live steam
tot	Total
u	Unburned matter
Z	Heat input
^	Maximum
0	at 0 °C
1	in
2	out

4.2 Coefficients

For the purposes of this European Standard the coefficients given in Table 4.2-1 shall apply.

Table 4.2-1 — Coefficients

Designation	Symbol	Value	Unit
Specific latent heat at 25 °C	L_r	2 442,5	kJ/kg
Specific heat of steam between 25 °C and 150 °C	$\overline{c}_{pSt}$	1,884	kJ/(kg K)
Specific heat of water between 25 °C and 150 °C	$\overline{c}_{pW}$	4,21	kJ//kg K)
Specific heat of air between 25 °C and 150 °C	$\overline{c}_{pA}$	1,011	kJ//kg K)
Specific heat of ash and flue dust between 25 °C and 200 °C	$\overline{c}_{Ash},\ \overline{c}_{FA}$	0,84	kJ//kg K)
CV of unburned matter:			
Hard coal	$H_{(N)u}$	33,0	MJ/kg
Brown coal	$H_{(N)u}$	27,2	MJ/kg

5 General

5.1 Where a thermal performance assessment is to be carried out after the commissioning of new plant or after the recommissioning of modified plant, it shall be decided at the plant tendering or ordering stage on the test data required and on the accuracy and hence the instrumentation to be used.

It is necessary for the parties concerned to decide whether the test shall be carried out by the contractor or by an independent body and by whom is to be witnessed.

5.2 Tests shall represent the intended method and system of operation of the plant under the intended conditions of installation and normal operation. The determination of electrical consumption is not part of this European Standard.

5.3 Tests shall be carried out at predetermined firing rates, as agreed between the parties concerned.

6 Basic test conditions

6.1 General conditions

Tests shall be carried out whilst the boiler is fired continuously under steady state conditions established prior to the test (see 6.2).

NOTE   An outline of the procedure for calculating the heat output from test measurements is shown in Figure 6.1-1.
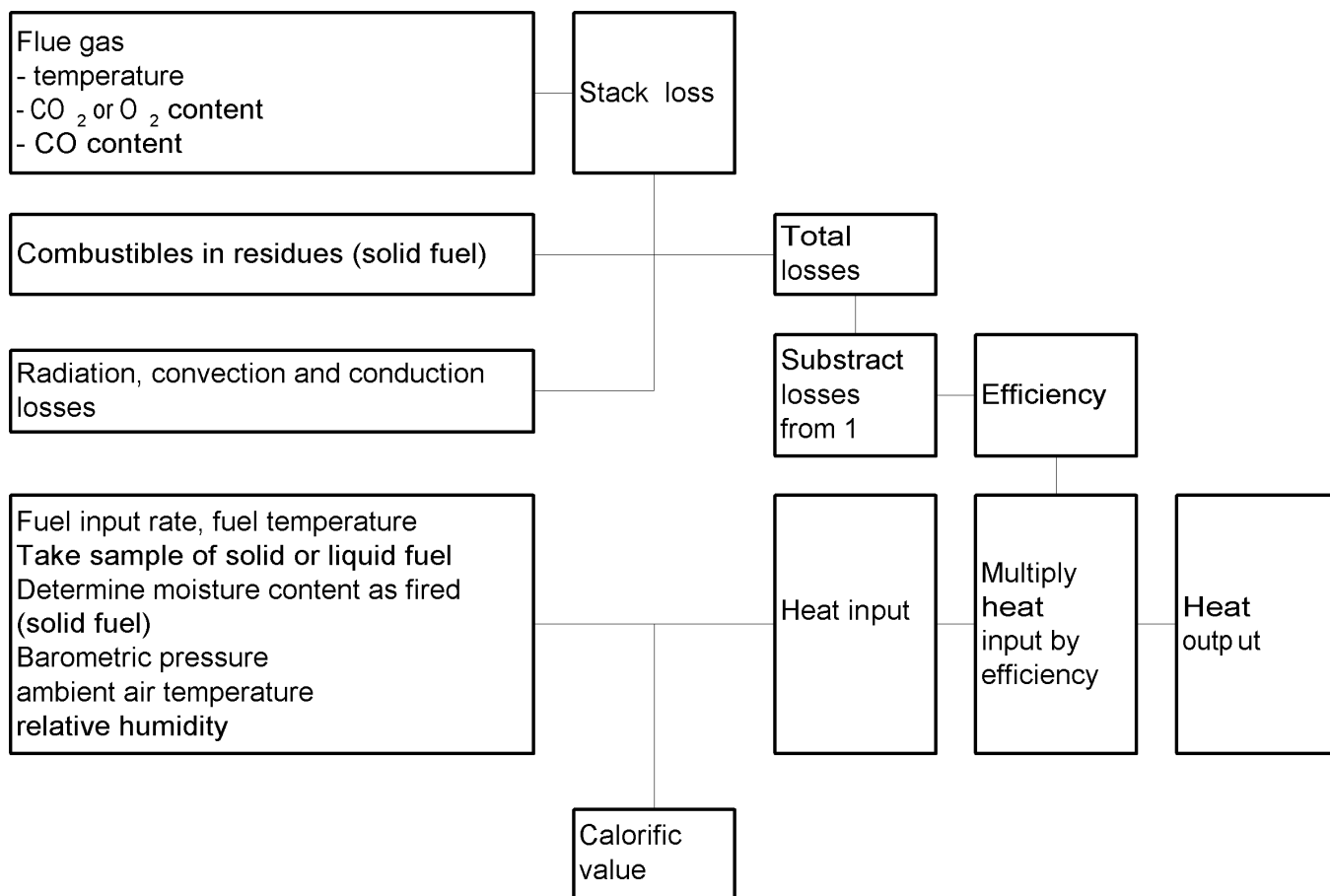
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┌─────────────────────────┐      ┌──────────┐
│ Flue gas                │      │          │
│ - temperature           │──────│Stack loss│
│ - CO₂ or O₂ content     │      │          │
│ - CO content            │      └──────────┘
└─────────────────────────┘
                                    ┌─────────┐
┌─────────────────────────┐         │ Total   │
│Combustibles in residues │─────────│ losses  │
│(solid fuel)             │         └─────────┘
└─────────────────────────┘
                                 ┌──────────┐  ┌──────────┐
┌─────────────────────────┐     │Substract │  │          │
│Radiation, convection and│     │losses    │──│Efficiency│
│conduction losses        │     │from 1    │  │          │
└─────────────────────────┘     └──────────┘  └──────────┘

┌─────────────────────────┐  ┌─────────┐ ┌──────────┐ ┌────────┐
│Fuel input rate, fuel    │  │         │ │Multiply  │ │        │
│temperature              │  │         │ │heat      │ │Heat    │
│Take sample of solid or  │  │Heat     │ │input by  │ │output  │
│liquid fuel              │──│input    │ │efficiency│ │        │
│Determine moisture       │  │         │ │          │ │        │
│content as fired         │  └─────────┘ └──────────┘ └────────┘
│(solid fuel)             │
│Barometric pressure      │
│ambient air temperature  │
│relative humidity        │
└─────────────────────────┘
                              ┌─────────┐
                              │Calorific│
                              │value    │
                              └─────────┘
```

Figure 6.1-1 — Outline of the procedure for calculating the heat output from the test measurement

6.2   Steady-state conditions

6.2.1   Steam pressure, steam and feed water temperature or, for hot water generator, the flow and return temperatures, together with the relevant flow rates, shall be held as steady as possible and at levels close to normal operating conditions. These measurements shall be taken at the boiler exit or as closed as practical at the (same) test prior.

NOTE   During the operation of a boiler the various factors contributing to heat losses can vary from their intended values as a result of the absorption of heat by the boiler structure as it acquires the conditions determined for the test and as a result of the operation of automatic controls. The most important variables are the exhaust gas temperature and the CO_2 or O_2 content of the exhaust gases. It is therefore essential that tests are conducted only after steady-state conditions have been achieved.

6.2.2   For the purposes of this standard, steady-state conditions shall be deemed to have been reached for solid fuel fired boilers with continuous fuel and ash flows and for liquid and gaseous fuel-fired boilers, when during the period of the test, variation in exhaust gas temperature remains within 10 C and variation of oxygen content within 0,5 % from the mean value.

6.3   Test procedure

6.3.1   It shall be confirmed that the water treatment is being carried out in accordance with the instructions of the boilermaker and the supplier of the water treatment plant. Where necessary during the preliminary running of the boiler prior to the test, except when testing under 'as found' conditions (see 6.3.2), the gas side surfaces shall be cleaned, the fuel input and fuel air ratio shall be set and adjustment of the combustion chamber draught or pressure shall be made to conditions laid down by the boilermakers before establishing steady-state conditions.

6.3.2   When testing under 'as found' conditions, e.g. whenever the user wishes to determine the current perform-ance of the plant, no adjustments to the firing equipment shall be made and no cleaning of the gas-side surfaces shall be carried out prior to the commencement of the test.

NOTE   Factors relating to maladjustment of the firing equipment, grit and dust emission, fouled heat transfer surfaces or the formation of CO be shown up by such tests and will be a guide to improvements in operation, which should be confirmed by retest. A comparison with the manufacturer's performance data should be made.

6.4   Requirements during test

During the running of the test, the blowdown of steam boilers shall be avoided and the water level in the gauge glasses shall be held as steady as possible during the establishment of steady-state conditions and during the subsequent test.

Where automatic high/low or fully modulating firing equipment is fitted, no manual adjustment of combustion settings during the overall test period shall be carried out (see 5.2).

6.5   Duration of tests

Following the establishment of the steady state, the test shall be of sufficient duration for at least six complete sets of readings of fuel input, flue gas temperature and flue gas analysis. The readings shall be within the variations permitted by the strict terms of steady conditions (see 6.2).

6.6   Procedure for the determination of exhaust gas temperature and CO, CO_2 and O_2 content

The procedure for the determination of exhaust gas temperature and CO, CO_2 and O_2 content shall be in accordance with the methods in clause 7.

6.7   Undetermined losses

Undetermined losses, i.e. losses which are neither measured nor assessed, can occur but shall be regarded as insignificant for the purpose of this European Standard.

7   Instrumentation and methods of measurements

7.1   Instruments

All measurements shall be made with suitable calibrated instruments. Portable or mobile instruments shall be used unless it can be shown that the sensors of installed instruments have been located correctly and the system checked for accuracy.

Only such measuring instruments and/or transducers shall be used whose indications and/or output values are verifiable and whose limits of error are known. These shall include:

a)   instruments for which a verification certificate (calibration certificate issued by an authority) is submitted;

b)   verifiable instruments which have been calibrated before and after the test with the readings both rising and falling, preferably under conditions simulating those existing during the test, and compared with the instruments as per item a) above;

c)   standard instruments with known limits of error;

d)   other approved instruments with known limits of error, the use of which has been agreed upon by the parties to the test.

The measuring equipment shall not be subject to any appreciable permanent changes during the test.

Analog or digital readings may be taken, and the data shall be recorded manually or automatically. The test report shall detail the instruments used and their limits of error.

If the data are recorded by automatic equipment, random checks shall be made to verify that the signals are correctly processed.

7.2 Pressure measurements

Pressure measurements shall be made using suitable pressure gauges or transducers. As far as possible, differential pressures shall be directly measured by means of suitable gauges and instruments (e.g. U-tube manometers, inclined-tube micromanometers of differential pressure transducers). Mercury, water or other liquids of suitable density shall be used as indicating fluid.

7.3 Temperature measurements

Measurements of temperature shall be taken using instruments in accordance with 7.1, items a) and b) (e.g. mercury-in-glass thermometers, thermocouples and resistance thermometers, the latter in conjunction with appropriate measuring circuits of transducer [1]).

7.4 Mass and mass flow

7.4.1 Weighing

The weighing machines used shall be checked prior to testing for accuracy.

7.4.2 Volumetric measurements

Measurements of volume flow shall be carried out by volumetric meters which shall be calibrated prior to and, where possible, after the test. Only genuine volumetric meters (i.e. no vane-type meters) shall be permitted downstream of reciprocating pumps. A uniform specific volume or density shall be maintained throughout the test.

The volume shall also be determined by means of tanks that have been filled from verified tanks or containers and checked by metering or calibrated with weighed increments of water.

In the use of volumetric tanks, density corrections shall be made for differences in water temperature during testing and calibration. Corrections shall also be made for the thermal expansion of the tank. (The volume of a steel tank, for example, increases by roughly 0,4 % when heated by 100 C).

7.4.3 Flow measurement

7.4.3.1 Flow measurement with orifices and nozzles

Flow measurements with orifices and nozzles shall be in accordance with EN ISO 5167-1.

Since dimensions cannot be checked and measurements taken prior to the acceptance test, this shall be carried out before the welding operations, and the results recorded. Inconsistencies of inflow shall be dealt with in accordance with EN ISO 5167-1.

Where flow rate transducers are used, the working characteristics under test conditions shall be determined before the test or a calibration graph plotted.

7.4.3.2 Flow measurement with velocity probes

Flow measurements using velocity probes (Pitot tubes or anemometers) shall be made in accordance with ISO 1217, ISO 5389 or ISO 6801.

7.4.4 Measurement of flue dust flow

A suitable method shall be agreed for measuring the flue dust flow through a particular cross section (see also [2] and [4]).

7.4.5 Determination of density

Where the density is unknown, it shall be taken from the appropriate tables [5], employing the variables, i.e. pressure and temperature, and the composition, or the value shall be obtained from the gas supplier.

7.5 Calorific values

7.5.1 Calorific values of fuel

The gross calorific value (GCV, $H_{(G)}$) and net calorific value (NCV, $H_{(N)}$) of solid and liquid fuels shall be determind in accordance with ISO 1928 [1]. the GCV and NCV shall be determined from an analysis of gases of known and fixed composition in accordance with ISO 6976[2].

7.5.2 Sampling of fuels

Solid fuel samples shall be taken and prepared in accordance with ISO 1988. The sampling of liquid and gaseous fuels shall be carried out respectively, in accordance with ISO 3170 (see also [6]). The samples taken shall adequately represent the grade, composition and quality of the fuel fired during the test.

7.5.3 Net calorific value and sampling of carbon in ash and flue dust

When required by 6.6.2 the NCV of the carbon in ash and/or flue dust the NCV shall be determined in accordance with ISO 1928.

The parties to the test may agree upon a simplified method for determining the NCV from the carbon content or loss on ignition. If determination of the NCV has not been agreed upon, the values specified in 4.2 shall be employed as the NCV of total organic carbon.

7.6 Chemical composition

7.6.1 Fuels

If required, the ultimate analysis of solid and liquid fuels shall be made in accordance with ISO 589, ISO 609, ISO 625, ISO 334, ISO 157 and see also [7], and of gaseous fuels by means of a gas analysis.

7.6.2 Flue dust and ash

For solid fuel fired boilers, when determining the efficiency by the heat loss method, the flue dust and ash shall be analysed for their combustibles content, the method of determination being the subject of agreement.

7.6.3 Flue gas

The composition of flue gas shall be determined by means of analysing equipment which operates on chemical, physicochemical or purely physical principles, either intermittently or continuously. The instruments shall be designed so that the scatter of measured values, with a confidence level 95 %, conforms to the following:

— carbon dioxide: ± 0,2 percentage points;

— oxygen: ± 0,15 percentage points;

— carbon monoxide content by volume: ± 1 % of the full-scale value of the measurement range, but not less than ± 0,01 percentage points.

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1) The calorific value of the fuel may be obtained from the gas supplier.

2) For gases the usual symbols for GCV is H_s and NCV is H_i, see EN 437.

Where automatically operating gas analysers are used, the zero and sensitivity adjustments made prior to the test shall be checked (e.g. by the admission of test gases) after the test.

When making CO_2 measurements with chemical analysers, it shall be taken into account that the CO_2 and SO_2 contents will be measured in relation to dry flue gas.

The ambient temperature local to the sensor shall be kept constant. For traverses 7.3 shall be applied accordingly.

Where measurements taken in tubes of large diameter yield varying values at different points of the same cross section at the same test period, a check shall be made as to whether such differences in composition of flue gas are acceptable. Otherwise, the average values shall be determined by a traverse. To that end, the cross section shall be divided into equal sub-areas, making sure that there is no cross flow or backflow in the measured section (see also [2] and [3]). Normally, the arithmetic average of the measured values shall be taken as the average composition.

8 Heat balance and thermal efficiency

8.1 General

The calculations necessary to complete the assessment of thermal performances shall be in accordance with the equations given in 8.4 to 8.7.

The equations provide for calculations on a basis of either the gross (subscript G) or the net (subscript N) calorific value of the fuel; whichever value is used the basis shall be stated in the test report.

NOTE 1   An outline of the procedure for calculation from test measurements is shown in figure 6.1-1.

NOTE 2   The data required to complete the calculations are fully itemized in the test report, which includes a tabulation of the heat account.

NOTE 3   Further information of the calculation of combustion air/flue gas mass to fuel mass ratios and specific heat are summarized in annex A.

Under normal operation condition the electrical energy shall not be taken under consideration.

8.2 Envelope boundary

The normal envelope shall encompass the entire steam-water system, see figures 8.2-1 and 8.2-2, and forms the basis for the equations in 8.3 to 8.7.

Key
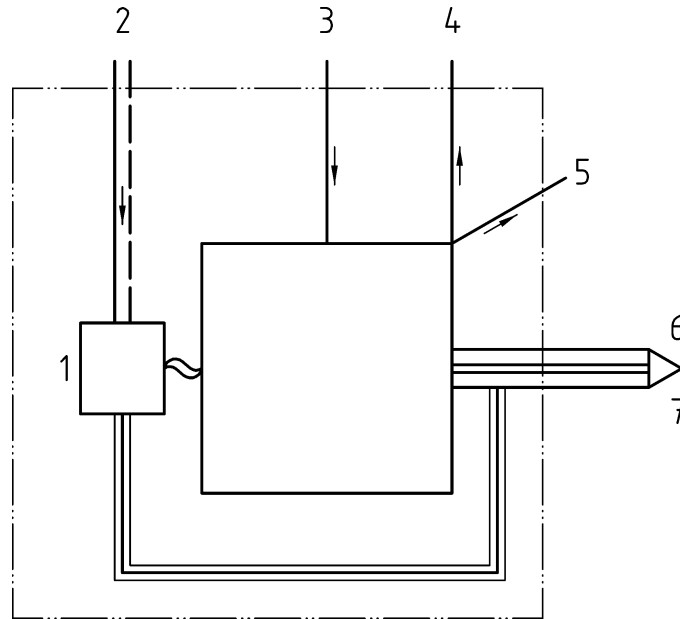
1   fuel (m_F, $H_{(N/G)}$, h_F)

2   combustion air (J_A)

3   hot water outflow Q_2

4   hot water inflow Q_2

5   loss due to radiation and convection Q_{RC}

6   loss due to flue gas ($Q_{(HN/G)G}$)

7   loss due to enthalpy and unburned combustibles in ash and flue dust (Q_{SF})

Figure 8.2-1 — Hot water generator diagram with input, losses and mass flows

Key
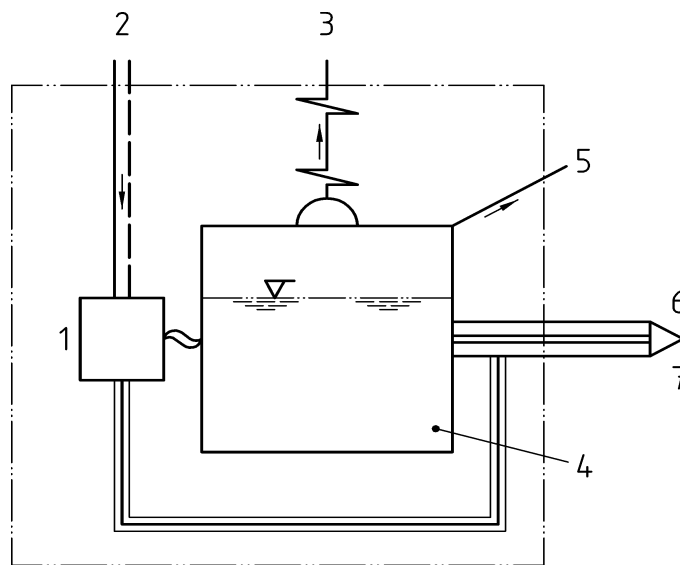
1   fuel (m_F, $H_{(N/G)}$, h_F)

2   combustion air (J_A)

3   live steam ($\dot{Q}_2$)

4   feed water inflow ($\dot{m}_{FW}$, h_{FW})

5   loss due to radiation and convection $\dot{Q}_{RC}$

6   loss due to flue gas ($Q_{(N/G)G}$)

7   loss due to enthalpy and unburned combustibles in ash and flue dust (Q_{SF})

Figure 8.2-2 — Steam generator diagram with input, losses and mass flows

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8.3   Reference temperature

For acceptance testing, the reference temperature, t_r, shall be 25 °C. A correction of the gross or net calorific value (CV) shall not be necessary.

8.4   Heat input

8.4.1   General

The specifications and equations given in 8.4.2 shall apply to acceptance tests in which only a single fuel is being fired. The indirect method shall be used.

8.4.2   Heat input proportional to fuel burned

The heat input proportional to fuel burned $Q_{(N/G)Ztot}$ shall include the heat in fuel (chemical heat), and heat in combustion air as expressed by equation (8.4-1 and 8.4-2):

$$\dot{Q}_{(N)Ztot} = \dot{m}_F \left[\frac{(H_{(N)} + h_F)}{(1 - l_u)} + J_A \right] \tag{8.4-1}$$

$$\dot{Q}_{(N)Ztot} = \dot{m}_F H_{(N)tot}$$

$$\dot{Q}_{(G)Ztot} = \dot{m}_F \left[\frac{(H_{(G)} + h_F)}{(1 - l_u)} + J_A \right] \tag{8.4-2}$$

$$\dot{Q}_{(G)Ztot} = \dot{m}_F H_{(G)tot}$$

where

$\dot{m}_F$ is the fuel mass flow;

$H_{(N)}$ is the NCV of fuel at reference temperature t_r;

$H_{(G)}$ is the GCV of fuel at reference temperature t_r;

h_F is the enthalpy of fuel;

l_u is the ratio of unburned to supplied fuel mass flows (see 8.5.5);

J_A is the enthalpy of combustion air.

The enthalpy of fuel h_F shall be:

$$h_F = \dot{c}_F \ (t_F - t_r) \tag{8.4-3}$$

where

$\dot{c}_F$ is the integral specific heat between t_F and t_r;

t_F is the temperature of the fuel;

t_r is the reference temperature, t_r = 25 °C.

The ratio of the unburned fuel mass flow to supplied fuel mass flow shall be:

$$l_u = \frac{\dot{m}_{Fv}}{\dot{m}_{Fo}} \qquad\qquad (8.4\text{-}4)$$

and the enthalpy of combustion air J_A shall be:

$$J_A = \mu_A \bar{c}_{pA} \, (t_A - t_r); \qquad\qquad (8.4\text{-}5)$$

where

    μ_A is the combustion air mass to fuel mass ratio;

    t_A is the air temperature at envelope boundary;

    $\dot{c}_{pA}$ is the integral specific heat between t_A and t_r of air;

    $\dot{m}_{Fv}$ is the unburned fuel mass flow;

    $\dot{m}_{Fo}$ is the fuel mass flow.

8.4.3   Heat credits

Heat credits, i.e. amounts of heat other than chemical heat (see 8.4.2) shall be neglected.

8.5   Losses

8.5.1   General

For calculating the losses, a similar distinction shall be made between losses which are proportional to the fuel flow and those which are not and are measured directly.

8.5.2   Flue gas losses

The flue gas losses $Q_{(N/G)G}$ shall be calculated using the following equations:

$$\dot{Q}_{(N)G} = \dot{m}_F \, (J_{(N)G} - J_{(N)Gr}) = \dot{m}_F \left[\mu_{Gd} \bar{c}_{pGd} \, (t_G - t_r) + \mu_{H2O} \bar{c}_{pST} \, (t_G - t_r) \right] = \dot{m}_F \, \mu_G \bar{c}_{pG} \, (t_G - t_r) \qquad (8.5\text{-}1)$$

$$\dot{Q}_{(G)G} = \dot{m}_F \, (J_{(G)G} - J_{(G)Gr}) = \dot{m}_F \left[\mu_{Gd} \bar{c}_{pGd} \, (t_G - t_r) + \mu_{H2O} \, (h_{H2OG} - h_{H2OG} - h_{H2Or}) \right] \qquad (8.5\text{-}2)$$

with

    $\mu_{H2O} = \mu_{H2OF} + \mu_{Ad} x_{H2OAd}$

and

    $\mu_{H2OF} = \gamma_{H2O} + 8{,}937 \, \gamma_H$

where

    $\dot{m}_F$ is the fuel mass flow;

    $J_{(N)G}$ is the enthalpy of flue gas at flue gas temperature, t_G due to NCV calculation;

    $J_{(N)Gr}$ is the enthalpy of flue gas at reference temperature, t_r due to NCV calculation;

    $J_{(G)G}$ is the enthalpy of flue gas at flue gas temperature, t_G due to GCV calculation;

    $J_{(G)Gr}$ is the enthalpy of flue gas at reference temperature, t_r due to GCV calculation;

    μ_{Gd} is the mass of dry flue gas to fuel mass ratio;

μ_G is the flue gas mass to fuel mass ratio;

μ_{H2O} is the mass of water in flue gas to fuel mass ratio;

μ_{H2OF} is the mass of water coming from fuel (water stored and produced by combustion) to fuel mass ratio;

μ_{AD} is the dry combustion air mass to fuel mass ratio;

x_{H2OAd} is the moisture content of wet air based on the mass of dry air

$$\left(m_A = m_{AD} + m_{H2O} \; ; \qquad x_{H2OAd} = \frac{m_{H2O}}{m_{AD}} \right) \text{ in kg/kg;} \tag{8.5-3}$$

γ_{H2O} mass of H_2O in fuel by fuel mass;

γ_H mass of H in fuel by fuel mass;

$\bar{c}_{pG}$ is the integral specific heat between t_G and t_r of flue gas;

$\bar{c}_{pGd}$ is the integral specific heat between t_G and t_r of dry flue gas;

$\bar{c}_{pST}$ is the integral specific heat of steam;

t_G is the flue gas temperature;

t_r is the reference temperature;

h_{H2OG} is the enthalpy of steam or water at $p_G \approx 1$ bar and flue gas temperature t_G;

h_{H2Or} is the enthalpy of water at $p_r \approx 1$ bar and reference temperature t_r.

8.5.3   Loss due to unburned CO

Under normal conditions the loss due to CO shall be neglected.

8.5.4   Losses due to radiation and convection

Since, normally, it is not possible to measure heat losses due to radiation and convection ('radiation and convection losses', for short), empirical values shall be used.

The radiation and convection heat loss, Q_{RC}, in MW, for the most common steam boiler shall be in accordance with equation (8.5-4) and Figure 8.5-1.
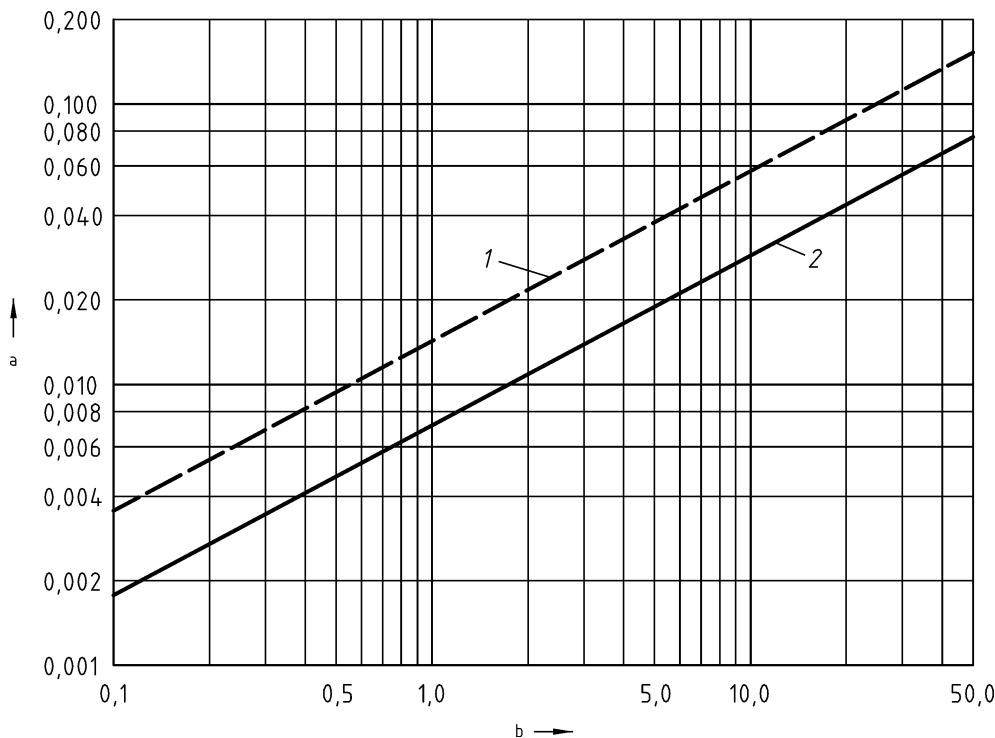
Key
1 Solid fuel boilers
2 Fuel oil and natural gas boilers

a $\dot{Q}_{RC}$
b $\dot{Q}_{E}$

Figure 8.5-1 — Radiation and convection heat loss

The diagram in Figure 8.5-1 is based on the following equation:

$$\dot{Q}_{RC} = C\ \dot{Q}_{E}^{0,6} \tag{8.5-4}$$

where

C is 0,0072 for fuel oil and natural gas boilers and 0,0144 for solid fuel boilers;

$\dot{Q}_{E}$ is the rated useful heat output, in MW.

8.5.5   Losses due to enthalpy and unburned combustibles in ash and flue dust

For systems fired with solid fuels, the losses due to enthalpy and unburned combustibles in ash $\dot{Q}_{Ash}$ and flue dust $\dot{Q}_{FA}$ shall be taken into consideration.

Where ash and flue dust mass flows are measured, the losses, $\dot{Q}_{SF}$ shall be:

$$\dot{Q}_{Ash} = \dot{m}_{Ash}\ u_{Ash}\ H_{(N)u} = \dot{m}_{Ash}\ h_{Ash} \tag{8.5-8}$$

$$\dot{Q}_{FA} = \dot{m}_{FA}\ u_{FA}\ H_{(N)u} = \dot{m}_{FA}\ h_{FA} \tag{8.5-6}$$

$$\dot{Q}_{SF} = \dot{Q}_{Ash} + \dot{Q}_{FA} \tag{8.5-7}$$

and the ratio of unburned combustibles to supplied fuel mass flows, l_{u}, shall be:

$$l_{u} = \frac{\gamma_{Ash}\ (1 - v)\ (\dot{m}_{Ash}\ u_{Ash} + \dot{m}_{Ash} + \dot{m}_{FA}\ u_{FA})}{(1 - \gamma_{Ash} - \gamma_{H2O})\ (\dot{m}_{Ash}\ (1 - u_{Ash}) + \dot{m}_{FA}\ (1 - u_{FA}))} \tag{8.5-8}$$

where

$\dot{m}_{Ash}$ is the ash mass flow;

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$\dot{m}_{FA}$ is the flue dust mass flow;

u_{Ash} is the unburned combustibles content of ash;

u_{FA} is the unburned combustibles content of flue dust;

$H_{(N)u}$ is the NCV of unburned combustibles;

γ_{Ash} is the ash content of fuel;

γ_{H2O} is the moisture content of fuel;

v is the volatile matter content of ash.

As opposed to the determination of ash, v has been introduced here in order to allow for the fact that a further amount of ash is known to e volatilized at higher furnace temperatures. As yet, it has not been determined to what degree v is a function of fuel grade and type of firing system. For acceptance testing it is suggested that a value of 5 % for burner and stoker firing systems should be assumed.

Where results from special measurements are available, then such information should be known at the time of contract award and set forth in the conditions of guarantee.

8.6 Determination of efficiency by indirect method

8.6.1 Determined quantities

For the determination of efficiency by the indirect method, the following quantities shall generally be determined:

a) Combustibles content, NCV or GCV, ash and moisture contents and ultimate analysis of fuel;

b) O_2 or/and CO_2 and CO contents of flue gas;

c) exhaust flue gas temperature;

d) temperature of fuel and combustion air;

e) moisture content of combustion air;

f) ambient air temperature, temperature inside boiler-house and barometric pressure;

g) temperature and mass flow of ash discharged;

h) unburned combustibles or carbon content of ash or NCV or GCV of ash.

When a fuel gas is being fired, its ultimate analysis shall always be known. In the case of solid fuels, fuel oil and natural gas, such analytical data shall only be required in so far as the combustion air and flue gas contents cannot be established statistically.

In addition to the above mentioned quantities all parameters, which document the steady-state condition, shall be measured (e.g. steam pressure, water temperature).

8.6.2 Calculation of efficiency

For the determination of the efficiency, the specific heat can be calculated as follows:

a) l_G is the flue gas loss

$$l_{(N)G} = \frac{\dot{Q}_{(N)G}}{\dot{Q}_{(G)Ztot}} \tag{8.6-1}$$

$$l_{(G)G} = \frac{\dot{Q}_{(G)G}}{\dot{Q}_{(G)Ztot}} \tag{8.6-2}$$

b) l_{RC} is the loss due to radiation and convection

$$l_{(N)RC} = \frac{\dot{Q}_{RC}}{\dot{Q}_{(N)Ztot}} = \frac{\dot{Q}_{RC}}{\dot{Q}_N} \, \eta_{(N)b} \qquad (8.6\text{-}3)$$

$$l_{(G)RC} = \frac{\dot{Q}_{RC}}{\dot{Q}_{(G)Ztot}} = \frac{\dot{Q}_{RC}}{\dot{Q}_N} \, \eta_{(G)b} \qquad (8.6\text{-}4)$$

c) l_{SF} is the loss due to enthalpy and unburned combustibles in ash and flue dust for solid fuels

$$l_{(N)SF} = \frac{\dot{Q}_{Ash} + \dot{Q}_{FA}}{\dot{Q}_{(N)Ztot}} \qquad (8.6\text{-}5)$$

$$l_{(G)SF} = \frac{\dot{Q}_{Ash} + \dot{Q}_{FA}}{\dot{Q}_{(G)Ztot}} \qquad (8.6\text{-}6)$$

Hence, the efficiency can be calculated as

$$\eta_{(N)b} = 1 - l_{(N)G} - l_{(N)RC} - l_{(N)SF} \qquad (8.6\text{-}7)$$

$$\eta_{(G)B} = 1 - l_{(G)G} - l_{(G)RC} - l_{(G)SF} \qquad (8.6\text{-}8)$$

8.7   Useful heat output

The useful heat output, $\dot{Q}_E$, shall be the total heat which is transferred in the steam boilers to the water and/or steam.

$$\dot{Q}_E = \eta_{(N)B} \, \dot{Q}_{(N)Ztot} \qquad (8.7\text{-}1)$$

$$\dot{Q}_E = \eta_{(G)B} \, \dot{Q}_{(G)Ztot} \qquad (8.7\text{-}2)$$

$$\dot{m}_{ST} = \frac{\dot{Q}_N}{(h_{ST} - h_{FW})} \qquad (8.7\text{-}3)$$

where

$\dot{m}_{ST}$ is the live steam mass flow;

h_{ST} is the enthalpy of live steam;

h_{FW} is the enthalpy of feed water.

9   Accuracy

Unless a detailed evaluation of errors is undertaken, it may be assumed that the boiler thermal efficiency calculated in accordance with this European Standard shall be within a limit deviation of $\pm$ 0,5 % points.

Annex A
(informative)

Calculation of combustion air/flue gas mass to fuel mass ratios and specific heat

A.1 Combustion air/flue gas mass to fuel mass ratios

The combustion air/flue gas mass to fuel mass ratios ('combustion air content' and 'flue gas content', for short) is calculated either on the basis of the ultimate analysis (see equation A-1.2) or by statistical methods (see equation A-1.3). Given the uncertainty in the measurement is necessary, first of all, to determine the following stoichiometric parameters:

μ_{Aod} combustion air content (dry basis), in kg/kg

μ_{God} flue gas content (dry basis), in kg/kg

V_{God} flue gas volume (STP condition) (dry basis), in m^3/kg

μ_{CO2Go} carbon dioxide content, in kg/kg

μ_{H2OGF} water vapour content, in kg/kg

The following shall also be known:

x_{H2OAd} (see 8.5.2)

This gives:

$$V_{\text{CO2o}} = \mu_{\text{CO2o}} / \rho_{\text{nCO2}} \tag{A.1-1}$$

$$\hat{\gamma}_{\text{CO2d}} = V_{\text{CO2o}} / V_{\text{God}} \tag{A.1-2}$$

$$\mu_{\text{Ad}} = \mu_{\text{Aod}} + \rho_{\text{nAD}} \, V_{\text{God}} \, \frac{\hat{\gamma}_{\text{CO2d}} - \gamma_{\text{CO2d}}}{\gamma_{\text{CO2d}} - \gamma_{\text{CO2AD}}} = \mu_{\text{Aod}} + \rho_{\text{nAD}} \, V_{\text{God}} \, \frac{\gamma_{\text{O2d}}}{\gamma_{\text{O2AD}} - \gamma_{\text{O2d}}} \tag{A.1-3}$$

$$V_{\text{Gd}} = V_{\text{God}} + V_{\text{God}} \, \frac{\hat{\gamma}_{\text{CO2d}} - \gamma_{\text{CO2d}}}{\gamma_{\text{CO2d}} - \gamma_{\text{CO2Ad}}} = V_{\text{God}} \, \frac{\hat{\gamma}_{\text{CO2d}} - \gamma_{\text{CO2Ad}}}{\gamma_{\text{CO2d}} - \gamma_{\text{CO2Ad}}} = V_{\text{God}} + V_{\text{God}} \, \frac{\gamma_{\text{O2d}}}{\gamma_{\text{O2Ad}} - \gamma_{\text{O2d}}} = V_{\text{God}} \, \frac{\gamma_{\text{O2Ad}}}{\gamma_{\text{O2Ad}} - \gamma_{\text{O2d}}} \tag{A.1-4}$$

$$\mu_{\text{CO2}} = \mu_{\text{CO2O}} + \rho_{\text{nAd}} \, V_{\text{God}} \, \frac{\hat{\gamma}_{\text{CO2d}} - \gamma_{\text{CO2d}}}{\gamma_{\text{CO2d}} - \gamma_{\text{CO2Ad}}} \, x_{\text{CO2Ad}} = \mu_{\text{CO2O}} + \rho_{\text{nAD}} \, V_{\text{God}} \, \frac{\gamma_{\text{O2d}}}{\gamma_{\text{O2Ad}} - \gamma_{\text{O2d}}} \, x_{\text{CO2Ad}} \tag{A.1-5}$$

$$\mu_{\text{H2O}} = \mu_{\text{H2OF}} + \mu_{\text{Ad}} x_{\text{H2OAd}} \tag{A.1-6}$$

$$\mu_{\text{A}} = \mu_{\text{AD}} \left(1 + x_{\text{H2OAd}}\right) \tag{A.1-7}$$

$$\mu_{\text{G}} = \mu_{\text{A}} + 1 - \gamma_{\text{Ash}} \, (1 - v) \tag{A.1-8}$$

$$x_{\text{CO2}} = \mu_{\text{CO2}} / \mu_{\text{G}} \tag{A.1-9}$$

$$x_{\text{H2O}} = \mu_{\text{H2O}} / \mu_{\text{G}} \tag{A.1-10}$$

$$\bar{c}_{\text{pG}} = f\left(x_{\text{H2O}}, c_{\text{CO2}}, t\right) \tag{A.1-11}$$

where

y_{CO2Ad} carbon dioxide content of dry air (= 0,000 33 m^3/m^3)

y_{O2Ad} oxygen content of dry air (= 0,209 38 m^3/m^3)

ρ_{nCO2} standard density of carbon dioxide (= 1,977 0 kg/m^3)

ρ_{nAd} standard density of dry air (= 1,293 0 kg/m^3)

x_{CO2Ad} carbon dioxide content of dry air (= 0,000 505 kg/kg)

NOTE   According to DIN 1871 [8]

A.2 Ultimate analysis

A.2.1 Solid fuels and fuel oil

The composition of solid and liquid fuels is expressed in terms of the following contents, in kg/kg:

γ_C carbon content;

γ_H hydrogen content;

γ_S sulfur content;

γ_O oxygen content;

γ_N nitrogen content;

γ_{H2O} water content;

γ_{Ash} ash content.

The sum of the constituents is equal to unity, i.e.

$$\sum \gamma_i = 1 \qquad\qquad (A.2\text{-}1)$$

For liquid fuels, in most cases only the sum $\gamma_C + \gamma_H = \gamma_{CH}$ is known. to proceed with the ultimate calculation scheme the following values are used:

$\gamma_C = 0{,}86 \ \gamma_{CH}$

$\gamma_H = 0{,}14 \ \gamma_{CH}$

If the sum $\gamma_C + \gamma_H = \gamma_{CH}$ is given also for a solid fuel the following values are used:

$$\gamma_H = 0{,}015 \left(1 - \gamma_{Ash} - \gamma_{H2O}\right) \qquad\qquad (A.2\text{-}2)$$

$\gamma_C = \gamma_{CH} - \gamma_H$

The following parameters is calculated:

$$\mu_{\text{Aod}} = 11{,}512\ 2\ \gamma_{\text{C}} + 34{,}297\ 4\ \gamma_{\text{H}} + 4{,}312\ 9\ \gamma_{\text{S}} - 4{,}321\ 2\ \gamma_{\text{O}} \tag{A.2-3}$$

$$\mu_{\text{God}} = 12{,}512\ 2\ \gamma_{\text{C}} + 26{,}360\ 4\ \gamma_{\text{H}} + 5{,}312\ 9\ \gamma_{\text{S}} - 3{,}321\ 2\ \gamma_{\text{O}} + 1{,}0\ \gamma_{\text{N}} \tag{A.2-4}$$

$$V_{\text{God}} = 8{,}893\ 0\ \gamma_{\text{C}} + 20{,}972\ 4\ \gamma_{\text{H}} + 3{,}319\ 0\ \gamma_{\text{S}} - 2{,}642\ 4\ \gamma_{\text{O}} + 0{,}799\ 7\ \gamma_{\text{N}} \tag{A.2-5}$$

$$\mu_{\text{CO2o}} = 3{,}669\ 9\ \gamma_{\text{C}} + 0{,}017\ 3\ \gamma_{\text{H}} + 0{,}002\ 2\ \gamma_{\text{S}} - 0{,}002\ 2\ \gamma_{\text{O}} \tag{A.2-6}$$

$$\mu_{\text{H2OFfuell}} = 8{,}937\ 0\ \gamma_{\text{H}} + 1{,}0\ \gamma_{\text{H2O}} \tag{A.2-7}$$

A.2.2 Fuel gases

The calorific value is determined by experiment or by analysis of the fuel gas. The properties of fuel gases are given in table A.2-1.

Table A.2-1 — Properties of fuel gases

Gastype		Molar mass	Molar volume	Density	Gas-const.	GCV	NCV	GCV	NCV
Con-stituent	Description	M	V_{mn}	ρ_{n}	R	$H_{\text{(G)N}}$	$H_{\text{(N)n}}$	$H_{\text{(G)}}$	$H_{\text{(N)}}$
		kg/kmol	m³/kmol	kg/m³	kJ/kg/K	MJ/m³	MJ/m³	MJ/kg	MJ/kg
y_{CO}	carbon monoxide content:	28,010 4	22,400	1,250 5	0,296 65	12,633	12,633	10,103	10,103
y_{H2}	hydrogen content:	2,015 8	22,428	0,089 98	4,127 23	12,745	10,783	141,800	119,971
y_{CH4}	methane content:	16,042 8	22,360	0,717 5	0,517 03	39,819	36,883	55,499	50,013
y_{C2H4}	ethene content:	28,053 6	22,245	1,261 1	0,294 14	63,414	59,458	50,284	47,147
y_{C2H6}	ethane content:	30,069 3	22,191	1,355 0	0,273 76	70,293	64,345	51,876	47,486
y_{C3H6}	propene content:	42,080 4	21,998	1,912 9	0,193 92	93,575	87,575	48,918	45,781
y_{C3H8}	propane content:	44,096 2	21,928	2,011 0	0,184 46	101,242	93,215	50,346	46,354
y_{C4H10}	butane content:	58,123 0	21,461	2,708 3	0,136 97	134,061	123,809	49,500	45,715
y_{N2}	nitrogen content:	28,013 4	22,403	1,250 4	0,296 66	0,000	0,000	0,000	0,000
y_{CO2}	carbon dioxide content:	44,009 8	22,261	1,977 0	0,187 63	0,000	0,000	0,000	0,000
y_{O2}	oxygen conent:	31,998 8	22,392	1,429 0	0,259 68	0,000	0,000	0,000	0,000
y_{H2S}	hydrogen sulfide content:	34,076 0	22,192	1,535 5	0,241 68	25,336	23,353	16,500	15,209
NOTE	Based on the standard density [8], [9].								

If C_mH_n is the sum of higher hydrocarbons for a particular fuel gas, the values for propene (C_3H_6) are used in the calculation.

The sum of the constituents is equal to unity, i.e.

$$\sum y_i = 1 \tag{A.2-8}$$

The standard density of fuel gas, in kg/m^3, is expressed by:

$$\rho_n = \sum y_i \, \rho_{ni} \tag{A.2-9}$$

The mass fractions is calculated by:

$$x_i = y_i \, \rho_{ni} / \rho_n \tag{A.2-10}$$

The calorific value is:

$$H_{(G)n} = \sum H_{(G)ni} \, y_i \tag{A.2-11}$$

$$H_{(N)n} = \sum H_{(N)ni} \, y_i \tag{A.2-12}$$

$$H_{(G)} = \sum H_{(G)i} \, x_i \tag{A.2-13}$$

$$H_{(N)} = \sum H_{(Ni)} \, x_i \tag{A.2-14}$$

Table A.2-2 — Combustion air and flue gas contents, flue gas volume, CO$_2$ and water vapour contents of a fuel gas

	μ_{Aod} kg/kg	μ_{God} kg/kg	V_{God} m^3/kg	μ_{CO2o} kg/kg	μ_{H2OF} kg/kg
CO	2,468 25	3,468 25	2,304 04	1,572 44	—
H$_2$	34,297 36	26,360 36	20,972 40	0,017 31	8,937 00
CH$_4$	17,238 26	15,992 34	11,928 59	2,752 01	2,245 92
C$_2$H$_4$	14,786 68	14,502 34	10,628 90	3,145 01	1,284 34
C$_2$H$_6$	16,094 64	15,297 28	11,322 31	2,935 34	1,797 36
C$_3$H$_8$	15,678 59	15,044 42	11,101 74	3,002 03	1,634 17
C$_4$H$_{10}$	15,463 34	14,913 60	10,987 63	3,036 54	1,549 75
C$_3$H$_6$	14,786 68	14,502 34	10,628 90	3,145 01	1,284 34
H$_2$S	6,086 68	6,558 01	4,363 32	0,003 07	0,528 68
O$_2$	− 4,321 20	− 3,321 20	− 2,642 36	− 0,002 18	—
N$_2$	—	1,000 00	0,799 72	—	—
CO$_2$	—	1,000 00	0,505 82	1,000 00	—

Conversion of NCV to GCV is in accordance with the following equations:

$$H_{(N)} = H_{(N)n} \cdot \rho_n \tag{A.2-15}$$

$$H_{(G)} = H_{(N)} + \mu_{H2OF} \, L_r \tag{A.2-16}$$

$$H_{(N)n} \left[MJ/m^3 \right] = H_{(N)n} \left[kWh/m^3 \right] 3,6 \tag{A.2-17}$$

where

$H_{(N)n}$ is the NCV, in kJ/m^3 or MJ/m^3;[3]

$H_{(N)}$ is the NCV, in kJ/kg or MJ/kg;

$H_{(G)n}$ is the GCV, in kJ/m^3 or MJ/m^3;

$H_{(G)}$ is the GCV, in kJ/kg or MJ/kg;

L_r is the specific latent heat, in kJ/kg at 25 °C; $L_r = 2\ 442,5$ kJ/kg.

$$\mu_{Aod} = \sum \mu_{Aodi}\ x_i \tag{A.2-18}$$

$$\mu_{God} = \sum \mu_{Godi}\ x_i \tag{A.2-19}$$

$$V_{God} = \sum V_{Godi}\ x_i \tag{A.2-20}$$

$$\mu_{CO2o} = \sum \mu_{CO2oi}\ x_i \tag{A.2-21}$$

$$\mu_{H2OF} = \sum \mu_{H2OFi}\ x_i \tag{A.2-22}$$

Values for these parameters are listed in table A.2-2.

A.3 Statistical analysis

The statistical combustion calculation is based on the empirical dependency of the mass flow ratios to the calorific value. In this context an evaluation with fuel samples from different countries all over the world shows a common functional coherence. Because a large quantity of independent measurements was used for this and a validation of the mass balances was conducted the result has a high grade of accuracy. The research includes samples with an ash content up to 30 %.

NOTE   Solid fuels require special consideration.

a)   fuel oil

$H_{(N)}$ (NCV) in MJ/kg

$H_{(G)}$ (GCV) in MJ/KG

$$\mu_{Aod} = 0,439\ 73 + 0,324\ 26\ H_{(N)} \tag{A.3-1}$$

$$\mu_{Aod} = 1,784\ 57 + 0,274\ 71\ H_{(G)} \tag{A.3-2}$$

$$\mu_{God} + 3,444\ 02 + 0,250\ 41\ H_{(N)} \tag{A.3-3}$$

$$\mu_{God} + 4,482\ 59 + 0,212\ 15\ H_{(G)} \tag{A.3-4}$$

$$V_{God} = 1,764\ 35 + 0,200\ 60\ H_{(N)} \tag{A.3-5}$$

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3)   MJ/m^3 = 3,6 kWh/m^3

$$V_{God} = 2{,}596\,30 + 0{,}169\,94\,H_{(G)} \tag{A.3-6}$$

$$\mu_{CO2o} = 2{,}503\,14 + 0{,}015\,10\,H_{(N)} \tag{A.3-7}$$

$$\mu_{CO2o} = 2{,}565\,79 + 0{,}012\,80\,H_{(G)} \tag{A.3-8}$$

$$\mu_{H2OF} = 2{,}004\,28 + 0{,}073\,84\,H_{(N)} \tag{A.3-9}$$

$$\mu_{H2OF} = 1{,}698\,03 + 0{,}062\,56\,H_{(G)} \tag{A.3-10}$$

b) natural gas

$H_{(N)}$ (NCV) in MJ/kg

$H_{(G)}$ (GCV) in MJ/kg

$$\mu_{Aod} = -0{,}063\,03 + 0{,}345\,16\,H_{(N)} \tag{A.3-11}$$

$$\mu_{Aod} = 0{,}003\,89 + 0{,}310\,73\,H_{(G)} \tag{A.3-12}$$

$$\mu_{God} = 1{,}014\,90 + 0{,}299\,79\,H_{(N)} \tag{A.3-13}$$

$$\mu_{God} = 1{,}066\,27 + 0{,}269\,88\,H_{(G)} \tag{A.3-14}$$

$$V_{God} = 0{,}649\,72 + 0{,}225\,53\,H_{(N)} \tag{A.3-15}$$

$$V_{God} = 0{,}688\,36 + 0{,}203\,04\,H_{(G)} \tag{A.3-16}$$

$$\mu_{CO2o} = 0{,}551\,57 + 0{,}044\,82\,H_{(N)} \tag{A.3-17}$$

$$\mu_{CO2o} = 0{,}559\,25 + 0{,}040\,35\,H_{(G)} \tag{A.3-18}$$

$$\mu_{H2OF} = 0{,}077\,93 + 0{,}045\,37\,H_{(N)} \tag{A.3-19}$$

$$\mu_{H2OF} = 0{,}070\,16 + 0{,}040\,84\,H_{(G)} \tag{A.3-20}$$

A.4 Specific heat of flue gas and combustion air

The specific heat of flue gas and combustion air shown in figure A.4-1 is calculated by

$$\bar{c}_{pGo} = \bar{c}_{pAdo} + P_{lm}\,x_{H2O} + P_{2m}\,x_{CO2} \tag{A.4-1}$$

$$\bar{c}_{pAo} = \bar{c}_{pAdo} + P_{lm}\,x_{H2OA} \tag{A.4-2}$$

$$\bar{c}_{pGdo} = \bar{c}_{pAdo} + P_{2m}\,x_{CO2} \tag{A.4-3}$$

$$\bar{c}_{pAdo} = a + \frac{b}{2}\,t + \frac{c}{3}\,t^2 + \frac{d}{4}\,t^3\,\frac{e}{5}\,t^4 + \frac{f}{6}\,t^5 \tag{A.4-4}$$

$$P_{1m} = a_1 + \frac{b_1}{2}\,t + \frac{c_1}{3}\,t^2 + \frac{d_1}{4}\,t^3 + \frac{e_1}{5}\,t^4 \tag{A.4-5}$$

$$P_{2m} = a_2 + \frac{b_2}{2}\,t + \frac{c_2}{3}\,t^2 + \frac{d_2}{4}\,t^3 + \frac{e_2}{5}\,t^4 \tag{A.4-6}$$

where

$\bar{c}_{pGo}$ is the integral specific heat of flue gas between 0 °C and t °C, in kJ/(kg K);

$\bar{c}_{pAdo}$ is the integral specific heat of dry air between 0 °C and t °C, in kJ/(kg K);

$\bar{c}_{pAo}$ is the integral specific heat of moist air between 0 °C and t °C, in kJ/(kg K);

$\bar{c}_{pGdo}$ is the integral specific heat of dry flue gas between 0 °C and t °C, in kJ/(kg K);

x_{H2OA} is the water content of moist air, in kg/kg $x_{H2OA} = x_{H2OAd}\,/\!\left(1 + x_{H2OAd}\right)$

The polynomial coefficients is in accordance with table A.4-1 and figure A.4-1 are valid within the following limits.

$0 < x_{H2OA} < 0{,}3$

$0 < x_{CO2} < 0{,}25$

$0\ °C < t < 1\,200\ °C$

The integral specific heat between temperatures t_1 and t_2 is given by:

$$\bar{c}_p = \frac{\bar{c}_{p0}\,(t_1)\,t_1 - \bar{c}_{p0}\,(t_2)\,t_2}{t_1 - t_2} \tag{A.4-7}$$

Table A.4-1 — Polynomial coefficients for determining integral specific heat values

coefficients (A—43)		coefficients (A—44)		coefficients (A—45)	
a	0,100 417 3 E + 01	a_1	0,855 453 5	a_2	− 0,100 231 1
b	0,191 921 0 E − 04	b_1	0,203 600 5 E − 03	b_2	0,766 186 4 E − 03
c	0,588 348 3 E − 06	c_1	0,458 308 2 E − 06	c_2	− 0,925 962 2 E − 06
d	− 0,701 118 4 E − 09	d_1	− 0,279 808 0 E − 09	d_2	0,529 349 6 E − 09
e	0,330 952 5 E − 12	e_1	0,563 441 3 E − 13	e_2	− 0,109 357 3 E − 12
f	− 0,567 387 6 E − 16				
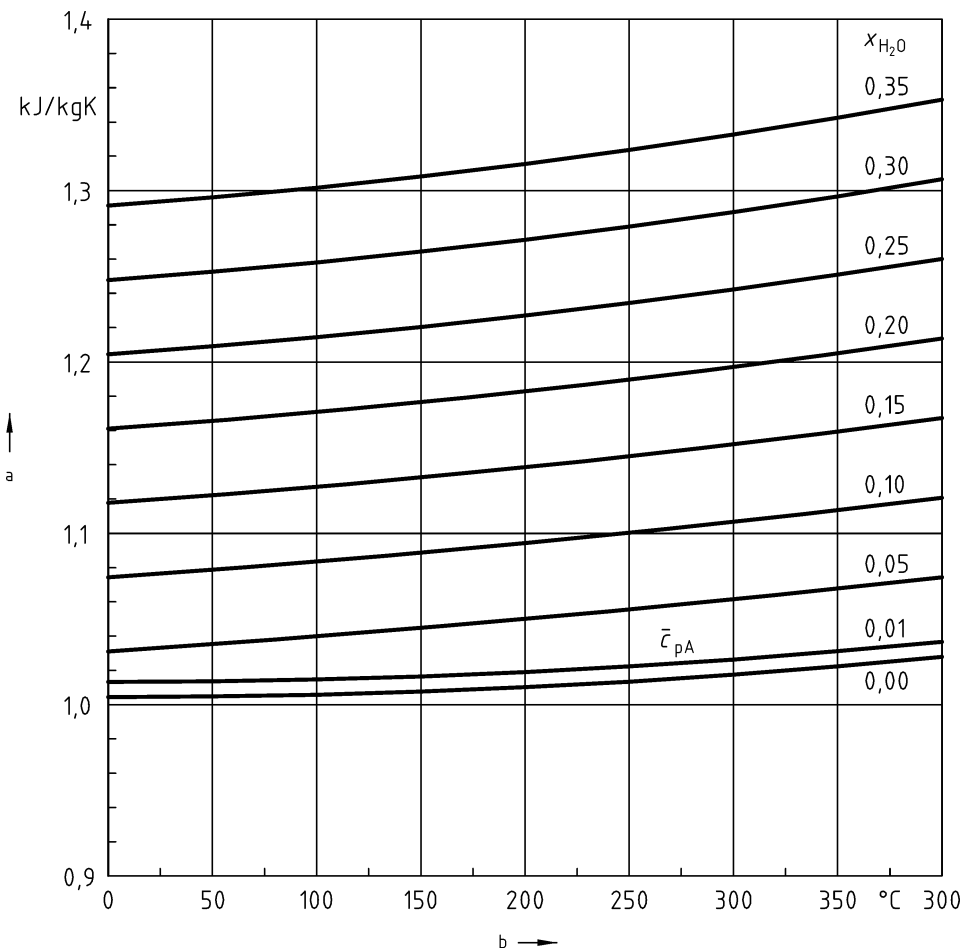
Key
a   Integral specific heat of flue gas, $\overline{c}_{pG}$ and combustion air, $\overline{c}_{pA}$
b   Temperature t

Figure A.4-1 — Integral specific heat of flue gas and combustion air as a function of temperature

Annex B
(normative)

Waste heat boilers

B.1 General

This annex covers the application of waste heat boilers, where heat is extracted from waste gases passing through the boiler.

The gases passing through the boiler may be from a variety of sources, e.g., gas turbines, reciprocating engines, incinerators, and furnaces.

B.2 Useful heat output

If the losses due to radiation and convection from the boiler are ignored, then the useful heat output $\dot{Q}_N$, shall equal that extracted from the waste gases.

$$\dot{Q}_N = \dot{Q}_Z \qquad \qquad \text{(B.2-1)}$$

The radiation and convection losses from a waste heat boiler are generally of a low order, but losses resulting from gas leakage through isolating dampers in bypass ducts, etc., shall also be considered.

The loss $\dot{Q}_{RC}$ can be approximated based on figure 8.5-1 by using curve 1 with the constant C for hard coal boilers.

$$\dot{Q}_N = \dot{Q}_Z - \dot{Q}_{RC} \qquad \qquad \text{(B.2-2)}$$

B.3 Heat from waste gases

The heat from waste gases shall be

$$\dot{Q}_Z = \dot{m}_G \cdot \overline{c}_{pG} \, (t_1 - t_2) \qquad \qquad \text{(B.3-1)}$$

where

m_G is the mass flow of waste gases;

$\overline{c}_{pG}$ is the integral specific heat between temperatures t_1 and t_2 (see equation A.4-7);

t_1 is the temperature of gases at boiler inlet;

t_2 is the temperature of gases at boiler outlet.

The integral specific heat capacity for a mixture shall be determined as follows:

$$\overline{c}_{pG} = \sum_{i=1}^{n} x_i \, C_{pi} \qquad \qquad \text{(B.3-2)}$$

where

C_{pi} is the integral specific heat capacity of the component i between t_1 and t_2;

x_i is the component content of the mixture by mass;

n is the number of components.

In a similar manner to that described in A.4, the integral specific heat capacity of each component, between 273,15 K and t in Kelvin can be determined as follows:

$$C_{pi} = a + bt + ct^2 + dt^3 + et^4 \qquad \text{(B.3-3)}$$

The polynomial coefficients for common gases are given in table B.3-1 below.

Table B.3-1 — Polynomial coefficients for the determination of integral specific heat values

Gas	a	b	c	d	e
CO_2	$4,102\,5 \cdot 10^{-1}$	$1,961 \cdot 10^{-3}$	$-2,029 \cdot 10^{-6}$	$1,199\,7 \cdot 10^{-9}$	$^-3,077\,5 \cdot 10^{-13}$
H_2O	$1,921\,2$	$-7,972\,6 \cdot 10^{-4}$	$2,633\,8 \cdot 10^{-6}$	$-2,122\,9 \cdot 10^{-9}$	$6,577\,6 \cdot 10^{-13}$
O_2	$9,668\,1 \cdot 10^{-1}$	$-6,542\,4 \cdot 10^{-4}$	$2,230\,9 \cdot 10^{-8}$	$-2,157\,8 \cdot 10^{-9}$	$7,041\,3 \cdot 10^{-13}$
N_2	$1,096\,9 \cdot 10^{-0}$	$3,961\,2 \cdot 10^{-4}$	$7,874\,9 \cdot 10^{-7}$	$-2,902\,6 \cdot 10^{-10}$	$-2,964\,7 \cdot 10^{-14}$
SO_2	$4,152\,7 \cdot 10^{-1}$	$7,280\,1 \cdot 10^{-4}$	$-3,214\,9 \cdot 10^{-8}$	$-5,432\,7 \cdot 10^{-10}$	$2,754\,3 \cdot 10^{-13}$
Ar	C_p of Argon is constant at 0,519 kJ/(kg K)				

B.4 Heat input

The heat contained in the gases entering the boiler at t_1 °C shall be determined as follows:

$$\bar{c}_{Ztot} = \dot{m}_G \cdot \bar{c}_{pG1} \cdot t_1 \qquad \text{(B.4-1)}$$

where

$\bar{c}_{pG1}$ is the integral specific heat between 0 °C and t_1 °C

B.5 Thermal efficiency

The boiler thermal efficiency shall be determined as follows:

$$\eta_B = \frac{\dot{Q}_N}{\dot{Q}_{Ztot}} \qquad \text{(B.5-1)}$$

B.6 Methods of measurement

B.6.1 Gas mass flow

Where it is practical, the gas mass flow shall be measured by the method indicated in 7.4.3.2. However, the gas mass flow shall be contractually agreed prior to the test.

NOTE   As the boiler is invariably designed against a specified gas mass flow, it is often convenient to accept that value for test purposes.

B.6.2 Gas temperature

The methods indicated in 7.3 shall be employed.

B.6.3 Gas composition

This shall be determined by the methods indicated in 7.6.3, or by calculation, or shall be contractually agreed prior to the test.

NOTE   As the boiler is invariably designed against a specified gas composition, it is often convenient to accept that analysis for test purposes.

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