BRITISH STANDARD

BS 7190:1989

Method for

Assessing thermal performance of low temperature hot water boilers using a test rig

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Refrigeration, Heating and Air Conditioning Standards Policy Committee (RHE/-) to Technical Committee RHE/10, upon which the following bodies were represented:

Associated Offices Technical Committee
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Association of Shell Boilermakers
Boiler and Radiator Manufacturers' Association Limited
British Coal Corporation
British Combustion Equipment Manufacturers' Association
British Foundry Association
British Gas plc
Building Services Research and Information Association
Chartered Institution of Building Services Engineers
Department of Energy (Energy Efficiency Office)
Department of the Environment (Property Services Agency)
Domestic Solid Fuel Appliances Approval Scheme
Engineering Equipment and Materials Users' Association
Health and Safety Executive
Institute of Domestic Heating Engineers
Institution of Chemical Engineers
Society of British Gas Industries
Waterheater Manufacturers' Association

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Contents

Foreword

This British Standard has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee. It supersedes DD 65-1:1979 and DD 65-2:1982 which are withdrawn.

Due to the lack of authoritative information on the testing of boilers using test rigs for certain applications, the conversion of the Draft for Development into a British Standard has resulted in a restriction of the scope to hot water boilers having a rated heat output up to 600 kW only.

The test procedure detailed in this British Standard requires that boilers be connected to a test rig having closely defined characteristics. It is therefore intended that the tests be carried out in manufacturers' test facilities or in independent test stations.

For on-site thermal performance assessment of boilers for steam, hot water and high temperature heat transfer fluids, reference should be made to BS 845-1 and BS 845-2.

In order not to conflict with the work of CEN[1)] in the field of oil-fired boilers, it has been necessary to restrict the scope of this standard. However, pending the publication of a European standard covering oil-fired boilers up to 300 kW rated heat output, users of this standard will find the information contained useful when determining the specific requirements for such boilers.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 22, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1)] European Committee for Standardization.

1 Scope

1.1 This British Standard describes a procedure for assessing the thermal performance of low temperature hot water boilers which are intended for central heating or indirect hot water supply and which are fired with solid, liquid or gaseous fuels. The thermal efficiency is obtained by the direct method of test and is established to within a tolerance of ± 2 % points[2)]. Flue gas losses and loss due to combustibles in ash, where applicable, are determined by measurement. Surface heat losses and other unmeasured losses are derived by difference. Procedures are also included to determine the associated characteristics of water-side resistance and gas-side resistance.

1.2 This standard applies to boilers designed to operate at flow temperatures not exceeding 100 °C, with rated heat output between 44 kW and 600 kW when used with one or more of the following fuels:

a) smokeless solid fuels, e.g. coke or anthracite, fired by means of automatic combustion appliances;

b) bituminous coal fired by means of mechanical stokers;

c) gaseous fuels of the 2nd and 3rd families (see BS 4947);

and with rated heat output between 300 kW and 600 kW when used with liquid fuels of the classes specified in BS 2869.

1.3 This standard does not apply to steam boilers or to boilers pressurized by steam.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this standard the following definitions apply.

2.1
rated heat output

the heat output(s) to the water in unit time, declared by the manufacturer, of which the boiler is capable during continuous operation

2.2
combustion equipment giving a steady heat release rate

operation of the boiler over extended periods limited only by the need to carry out servicing and maintenance of the combustion equipment and/or boiler

2.3
combustion equipment giving cyclic variations in heat release due to periodic refuelling or de-ashing operations, e.g. manually de-ashed underfeed stokers

operation of the boiler for the test period, defined by the manufacturer, for which it is capable of giving the rated heat output

2.4
turn down ratio

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

2.5
ancillary energy

the electrical (or other) energy required for mechanical draught, firing equipment, oil pumping, gas boosting, solid fuel handling and ash handling, circulation in boiler flow/return by-passes and boiler controls

2.6
convertible boilers (solid, liquid and gaseous fuels)

boilers designed to burn more than one specified category of fuel separately where a changeover necessitates dismantling and erection of the necessary firing equipment

NOTE Recommissioning by a qualified person may be necessary.

[2)] One percentage point is one hundredth of the total amount concerned, in this instance, the heat input.

2.7
changeable boilers (solid, liquid and gaseous fuels)

boilers designed to burn more than one specified category of fuel separately where a changeover can be made by the user without major alteration, e.g. simple electrical switching, or the swivelling of oil and gas burners

2.8
water-side resistance

the pressure loss which occurs in the boiler between the flow and return connection of the boiler at the water flow rate and at a specific difference between flow and return temperatures corresponding to the rated output

2.9
gas-side resistance

the pressure difference created across the boiler by the flow of combustion gases

2.10
combustion space

the space provided in the design of the boiler in which combustion takes place

2.11
gross calorific value

the 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

NOTE Further information on calorific values of fuel was made available in BS 526 (now withdrawn). It is envisaged that the material contained in BS 526 will be revised and published as a new British Standard in due course.

2.12
net calorific value

the 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 the combustion of the fuel is assumed to remain as a vapour

NOTE Further information on calorific values of fuel was made available in BS 526 (now withdrawn). It is envisaged that the material contained in BS 526 will be revised and published as a new British Standard in due course.

2.13
direct procedure

the determination of thermal performance by direct measurement of the heat output and the determination of thermal efficiency by comparison with the thermal input

2.14
thermal input

the heat release rate of the firing equipment based on the amount of fuel burnt in unit time and its calorific value. For pre-heated liquid fuels, the sensible heat in the fuel above ambient temperature is also included in the thermal input

2.15
thermal efficiency

the thermal output divided by the thermal input and expressed as a percentage

3 Test facilities

3.1 General

The design and construction of the test rig, the selection of measuring instruments and the methods for determining the thermal input and output of the boiler shall be such that the error in determining the thermal efficiency does not exceed 2 percentage points.

3.2 Test room

The test room shall be ventilated.

NOTE 1 It is important that the test room is adequately ventilated but there should be no draughts likely to affect performance of the firing equipment and no undue fluctuation of the ambient temperature during testing.
NOTE 2 In determining the necessary ventilation, account should be taken of other firing equipment that may be in use at the same time as the boiler under test.

3.3 Test rig

For test purposes the boiler shall be connected to a test rig which is capable of allowing it to be operated at the specified output and with the desired flow and return temperatures. (See clause **8**.)

NOTE 1 The supporting floor and/or wall for the boiler should be so arranged that heat losses occurring during the test are similar to those expected to occur in practice.
NOTE 2 Suitable test rigs are described in Appendix B and shown in Figure 1 but other arrangements may be used provided that the basic concepts of those rigs are maintained.

4 Instrumentation and measurements

4.1 Measurement tolerances

Only instruments capable of measuring within the tolerances specified in Table 1 shall be used. The instruments shall be so selected that the boiler efficiency can be determined within the prescribed tolerance (see **3.1**).

NOTE Attention is drawn to the necessity for regular calibration of the measuring instruments.

4.2 Temperature measurements

4.2.1 *Water temperature.* The points where the measuring instruments shall be fitted are shown in Figure 1.

NOTE Proper fitting of the instruments is of particular importance. Probes should preferably be fitted into elbow joints against the direction of flow. If immersion sleeves are used these should be tight-fitting and thin-walled to keep the heat dissipation at the point of measurement as small as possible and to avoid delays in response.

4.2.2 *Air temperature.* The temperature of the combustion air (t_8) shall be measured at a position 0.5 m from, and at the same level as, the combustion air inlet to the firing equipment. The temperature of the ambient air (t_a) shall be measured at a position 1.5 m above the floor, 1.5 m from the front of the boiler and on the boiler centre line.

The measuring instruments shall be protected against radiant heat.

Table 1 — Measurement tolerances

Measurement	Tolerance
Atmospheric air pressure	± 0.05 mbar[a]
Boiler gas-side pressure	± 0.05 mbar[a]
Gaseous fuel pressure	± 0.05 mbar[a]
Pressure difference between flow and return connections on hot water boiler	± 0.5 mbar[a]
Water mass	(weighing) ± 0.2 % (flow meter) ± 0.25 %
Fuel mass	
a) solid	± 0.2 % by mass
b) liquid	± 0.2 % by mass
c) gaseous	± 0.5 % by volume
Time	± 0.5 s up to 1 h ± 0.1 % over 1 h
Ancillary electrical energy	± 3 %
Temperatures	
a) heat carrier	± 0.1 °C
b) flue gases	± 5 °C
CO, CO_2 and O_2 for the calculation of flue gas losses	± 0.2 percentage points
[a] 1 mbar = 10^2 N/m^2 = 100 Pa	

4.2.3 *Flue gas temperature.* The temperature of the flue gases shall be measured at the point(s) indicated in **4.3**.

NOTE When thermo-electric methods are used, potentiometric instruments are preferred as they eliminate lead-resistance errors. Otherwise compensating cables should be used.

4.3 Sampling and measurements

4.3.1 *Flue gas*

4.3.1.1 The flue gases shall be sampled and measurements made of flue draught and smoke number, as appropriate, by means of the test probe(s) located at the position(s) in the test flue (see **4.3.1.4**) as specified in **4.3.1.6** and **4.3.1.7**.

4.3.1.2 The carbon dioxide contents (V_{CO_2}) and carbon monoxide contents (V_{CO}) of the dry flue gases shall be measured within the tolerance shown in Table 1.

NOTE If preferred, the oxygen content may be measured instead of V_{CO_2} and this has the advantage of having the same meaning, in terms of excess air, for all fuels.

4.3.1.3 For oil-fired boilers, the Bacharach smoke number shall be measured by following the procedure detailed in **4.1** of BS 4876:1984.

4.3.1.4 The boiler flue outlet shall be fitted with the appropriate test flue as shown in Figure 2. The test flue shall be vertical and shall have the same nominal diameter (or cross-sectional area) as the flue outlet.

The height (h) of the test flue shall be the greatest of the following:

a) four times the nominal diameter of the flue;

b) 1 m;

c) at least the minimum specified by the manufacturer for satisfactory operation of the boiler.

4.3.1.5 The location of the probe(s) for sampling the combustion products and measurement of the Bacharach smoke number for oil-fired boilers shall be as shown in Figure 2. The point of entry of each probe into the test flue shall be sealed against leakage.

NOTE Sufficient measurements should be taken over the cross-section of the flue to ensure reliability of the values obtained.

4.3.1.6 For boilers equipped with an integral draught diverter, the location of the test probe(s) shall be as indicated in Figure 2.

4.3.1.7 For boilers equipped with a separate draught diverter the test probe shall be located either before or after the diverter.

NOTE 1 It is preferred that the test probe be located prior to the diverter.

NOTE 2 The height of secondary flue specified for test purposes is such as to avoid undue dilution of the flue gases by air entrained at the draught diverter and consequent inaccuracy in the measured values. This dilution effect should be borne in mind if it is desired to carry out flue loss measurements on boilers connected to a flue of significantly greater height.

4.3.2 *Combustion residues from solid fuel.* Samples of the solid residues from the ashpit and grit arrestor shall be taken in order to determine the combustible contents.

4.3.3 *Gas-side resistance.* The flue gas pressure shall be measured at the combustion products sampling point (see Figure 2). The gas-side resistance of the boiler shall be measured when the heating surfaces are clean and the boiler is operated at rated output and in accordance with the manufacturer's instructions.

For oil- and gas-fired boilers with a closed combustion chamber, the pressure in the flame space shall be measured with a static tube positioned adjacent to the burner entry.

For solid-fuel-fired boilers, the pressure above the firebed shall be measured with a static tube positioned above the firebed.

4.3.4 *Water-side resistance.* The water-side resistance shall be measured using the equipment shown in Figure 3.

NOTE The feed water to the boiler flows from the feed water supply via the pressure regulator, the water meter, the pressure control valve and the measuring length I into the boiler and from there via the measuring length II into the overflow tank and is then discharged. The resistance of the boiler is read on a differential gauge. This equipment may be incorporated in the test rig.

To avoid measuring errors, the pressure-sensing connections shall be flush with the internal wall of the measuring section and pipes shall be carefully deburred.

The inside diameter of the measuring lengths I and II shall be equal to the diameter of the smallest standard connection available for the boiler.

Before or after the boiler test the two measuring lengths I and II shall be directly connected and their pressure loss determined and plotted for different flow rates. This pressure loss shall then be subtracted from the total pressure loss, i.e. the pressure loss sustained over the measuring lengths I and II and the boiler, to give the water-side resistance.

5 Test fuels

5.1 Selection

5.1.1 *General.* The tests shall be carried out with the fuel or fuels of the appropriate grades specified by the boiler manufacturer.

5.1.2 *Solid fuels.* The size and other relevant characteristics of the test fuel shall be as specified by the manufacturer.

5.1.3 *Liquid fuels.* The fuel, to be selected by the manufacturer, shall be to a class specified in BS 2869. The temperature of the oil at the burner inlet connection shall be as specified by the manufacturer.

5.1.4 *Gaseous fuels.* Tests shall be carried out using either a distributed gas of the family specified by the manufacturer or the corresponding reference gas (see BS 4947).

5.2 Measurement

5.2.1 *Solid fuels.* The quantity of fuel in the combustion system shall be the same at the beginning and at the end of the test period. The amount of fuel added during the test shall be weighed.

NOTE 1 To increase the accuracy of measurement, the fuel in hoppers should be levelled to the same datum line before and after test.

NOTE 2 A correction should be made for any significant change in the moisture content of the fuel that may occur between the weighing point and the furnace.

5.2.2 *Liquid fuels.* When weighing the quantity of fuel, the oil pipe to the burner, as well as any return pipe to the fuel oil tank, shall be suspended freely from the weighing tank (see Figure 4). The return pipe shall be horizontal at the lower end so that the discharge does not bring any additional force to bear on the contents of the weighing tank.

In the case of volumetric measurement of the fuel consumption, the temperature of the fuel oil shall be maintained within a range of ± 5 °C of the initial setting.

5.2.3 *Gaseous fuels.* To determine the volume of gas consumed during the test a gas meter shall be provided in the supply pipe and shall have a capacity appropriate to the maximum input.

NOTE Suitable equipment is required to measure gas temperature, dew point and pressure as well as atmospheric pressure.

5.3 Sampling and analysis

An overall sample of the fuel used is taken according to the appropriate standards specifying the method of sampling the various fuels (see Table 2). This sample is used for the determination of the calorific value and the characteristics of the fuel, as required.

6 Installation and adjustment

The boiler and firing equipment shall be installed connected to the test rig (see **3.3**) and adjusted, in accordance with the manufacturer's instructions, for the fuel(s) to be used.

The fuel flow rate (where applicable), the water flow rate, flow and return temperatures, draught at the boiler exit and primary and secondary air volume shall be set to the values required for the test.

NOTE 1 Except where otherwise specified (see **10.2**), precautions should be taken to prevent water temperature control thermostats or variable controls from acting to interfere with the preset test conditions.

Where the boiler flueways may have been fouled during a period of preliminary running (see clause **7**) they shall be cleaned and the boiler then closed up in accordance with the manufacturer's instructions. No further cleaning or adjustment of the boiler shall be carried out during the duration of the test.

NOTE 2 It is important to ensure that the boiler waterways remain free from scale.

7 Test preparation

Except where otherwise specified for solid-fuel-fired boilers that give cyclic variations in heat release rate (see **9.2**), steady state conditions shall be established before each test run and maintained during the test period.

NOTE The steady state is regarded as having been reached if under constant firing conditions the boiler thermal output does not change from the predetermined setting by more than ± 1 % over four consecutive readings at 15 min intervals. Additionally, for solid-fuel-fired boilers giving a steady heat release rate, the steady state is regarded as reached when, at the required output, firebed conditions in respect of depth, ash and clinker formation are constant, or as near constant as the method of firing will permit.

8 Test conditions

For all boilers a test shall be carried out at a firing rate such that the output is at least 100 %, but does not exceed 105 %, of the rated value.

In addition, a boiler which the manufacturer offers with firing equipment providing a single turndown rate shall be tested also at the turndown rate. Where the firing equipment provides a range of turndown rates, tests shall be carried out at the lowest and middle turndown rates. For these tests the output shall be arranged to be within ± 5 % of the corresponding value stated by the manufacturer.

NOTE For gas-fired boilers to be tested against the requirements of BS 5978, the required firing rates are those specified in that standard.

Table 2 — British Standards for sampling and analysis of fuels

	Fuel		
	Solid	**Liquid**	**Gaseous**
Sampling	BS 1017	—	—
Analysis	BS 1016	BS 2000-12	BS 3156-1, BS 3156-3 and BS 3156-4 BS 3804

9 Test duration

9.1 Oil-fired and gas-fired boilers

For oil- and gas-fired boilers, the test shall last at least 30 min. The test shall be repeated until, in two successive test periods, the thermal efficiency obtained does not vary by more than ± 1 percentage point.

9.2 Solid-fuel-fired boilers

For solid fuel combustion appliances giving a steady heat release rate, e.g. chain grate stokers and coking stokers, a full load test shall last at least 4 h.

The test shall continue or be repeated until, over the course of a minimum test period, the thermal efficiency obtained does not vary by more than ± 2 percentage points.

For appliances that give cyclic variations in heat release rate due to periodic refuelling or de-ashing operations (see **10.2**), a full load test shall last for the period, specified by the manufacturer, over which continuous heat output can be achieved as defined in **2.3**.

10 Test operation

10.1 General

10.1.1 For oil- and gas-fired boilers, the settings of the firing equipment shall not be manually adjusted during a test nor between tests at rated output and turndown rate(s).

10.1.2 For changeable boilers, consecutive tests shall be carried out with each of the relevant fuels. Adjustments to the boiler and firing equipment at changeover shall be limited to the changeover instructions stated in the manufacturer's instructions to the user.

10.1.3 Throughout the period of each test, measurements of water temperatures t_2 and t_3 (see Appendix A) shall be made at least every 5 min for test periods up to 2 h duration and every 10 min thereafter.

Measurements of other test data shall be made at least every 15 min throughout each test period, with a minimum of three measurements per test.

NOTE The use wherever possible of recording instruments is recommended.

10.1.4 For boilers with built-in hot water service generators, hot water shall only be drawn off during the test if it is necessary due to the boiler design.

In these circumstances the thermal contents of both central heating and hot water services shall be taken into account and the maximum central heating output shall be declared by the manufacturer.

10.2 Solid-fuel-fired boilers

Before the test is started, the boiler shall be de-ashed and subsequent ash removal shall be carried out in accordance with the manufacturer's instructions.

If refuelling or de-ashing causes cyclic variations in heat release rate, manual or automatic controls shall be adjusted over the test period, to give the rated heat output as defined in **2.1**.

The combustion residues produced during the test period shall be weighed and sampled for analysis. Weighing of the residues shall take place when the residues are in either the wet or dry state.

NOTE It is preferred that the residues be dry when being weighed.

If water is used to quench burning residues or to facilitate handling, the water content shall be ascertained in order that this may be allowed for in the calculations. Where a grit arrestor is fitted, the grit shall be weighed and sampled for analysis.

11 Calculations

NOTE For a summary of the symbols and their units used in this clause see Table 3.

11.1 General

The calculations necessary to complete the assessment of thermal performance shall be in accordance with the equations given in **11.2** to **11.7**.

The equations provide for calculations on a basis of either the gross (subscript $_{gr}$) or the net (subscript $_{net}$) calorific value of the fuel; whichever value is used, the basis shall be stated in the test report (see Appendix A).

11.2 Calculation of the heat supplied by the fuel, Q_i

11.2.1 *Heat supplied by solid fuels*

Gross calorific value	Net calorific value
$Q_{i,gr} = \frac{M_f Q_{gr}}{T}$ (1)	$Q_{i,net} = \frac{M_f Q_{net}}{T}$ (2)

11.2.2 *Heat supplied by liquid fuels*

Gross calorific value	Net calorific value
$Q_{i,gr} = \frac{M_f}{T} [Q_{gr} + C_f (t_f - t_8)]$ (3)	$Q_{i,net} = \frac{M_f}{T} [Q_{net} + C_f (t_f - t_8)]$ (4)

NOTE 1 Unless specifically determined C_f should be taken as follows:

Fuel oil to BS 2869	Specific heat C_f kJ/(kg·K)
class D	2.05
class E	1.92
class F	1.90
class G	1.88

NOTE 2 The term $C_f (t_f - t_8)$ may be neglected in the case of unheated fuels.

11.2.3 *Heat supplied by gaseous fuels*

Gross calorific value	Net calorific value
$Q_{i,gr} = 1\,000\ VQ_{gr}$ (5)	$Q_{i,net} = 1\,000\ VQ_{net}$ (6)

where

$$V = \frac{V_m (p_a + p_m - p_v)\ 288}{1013 (t_g + 273)}$$

11.3 Calculation of the heat output to water

$$Q_c = \frac{M_1 c (t_2 - t_3)}{T} + L_9 \qquad (7)$$

NOTE If L_9 is less than 0.1 % of $Q_{i,gr}$ or $Q_{i,net}$ it may be ignored. Derivation of L_9 is explained in Appendix B.

11.4 Calculation of the losses

NOTE The losses to be taken into account are shown in this clause; other losses are regarded as negligible.

11.4.1 *Loss due to sensible heat in dry flue gases, L_1 (solid and liquid fuels)*

Gross calorific value	Net calorific value
$L_{1,gr} = \frac{k_{gr}(t_7 - t_8)[1 - 0.01(L_{5,gr} + L_{6,gr})]}{V_{CO_2}}$ (8)	$L_{1,net} = \frac{k_{net}(t_7 - t_8)[1 - 0.01(L_{5,net} + L_{6,net})]}{V_{CO_2}}$ (9)

L_5 and L_6 are applicable to solid fuel only.

k is a constant, and its value for any carbon-containing fuel is given by equations (10) and (11).

$k_{gr} = \frac{255C}{Q_{gr}}$ (10)	$k_{net} = \frac{255C}{Q_{net}}$ (11)

NOTE 1 If values of the carbon content C are not available, typical values of k for common fuels are as follows:

Fuel	k_{gr}	k_{net}
Coke	0.75	0.76
Anthracite	0.67	0.69
Bituminous coal	0.62	0.65
Fuel oil, BS 2869, classes E, F, G	0.51	0.54
Fuel oil, BS 2869, classes C_2 and D	0.48	0.51

If V_{O_2} rather than V_{CO_2} is measured, then V_{CO_2} is given by the following equation:

$$\left(1 - \frac{V_{O_2}}{21}\right) V_{CO_2 s} \qquad (12)$$

where

$V_{CO_2 s}$ is the stoichiometric volume of CO_2.

NOTE 2 Typical values of $V_{CO_2 s}$ for common fuels are as follows:

Fuel	Stoichiometric volume of CO_2, $V_{CO_2 s}$, dry basis
	%
Coke	20.6
Anthracite	19.1
Bituminous coal	18.4
Fuel oil, BS 2869, classes E, F, G	15.8
Fuel oil, BS 2869, classes C_2 and D	15.5

11.4.2 ***Loss due to enthalpy in the water vapour in the flue gases, L_2 and L_3 (solid and liquid fuels)***

Gross calorific value	Net calorific value
$L_{2,gr} = \frac{(m_{H_2O} + 9H)(2488 - 4.2t_8 + 2.1t_7)}{Q_{gr}}$ (13)	$L_{3,net} = \frac{(m_{H_2O} + 9H)(210 - 4.2t_8 + 2.1t_7)}{Q_{net}}$ (14)

For solid and liquid fuels, the value for m_{H_2O} is taken from items b) (1) and b) (2) of Appendix A respectively.

NOTE In the absence of detailed fuel analyses, typical values of the hydrogen content H for use in equations (13) and (14) may be as follows:

Fuel	Hydrogen content of fuel H (as fired)
	%
Coke	0.4
Anthracite	3.0
Bituminous coal	4.0
Fuel oil, BS 2869, class C_2	14.1
Fuel oil, BS 2869, class D	13.2
Fuel oil, BS 2869, class E	11.7
Fuel oil, BS 2869, class F	11.5
Fuel oil, BS 2869, class G	11.4

The latent heat of evaporation has been taken as 2 278 kJ/kg, the specific heat of superheated steam as 2.1 kJ/(kg · K) and the specific heat of water as 4.2 kJ/(kg · K).

11.4.3 ***Loss due to unburned gases in the flue gases, L_4 (solid and liquid fuels)***

Gross calorific value	Net calorific value
$L_{4,gr} = \frac{k_1 V_{CO}[1 - 0.01(L_{5,gr} + L_{6,gr})]}{V_{CO_2} + V_{CO}}$ (15)	$L_{4,net} = \frac{L_{4,gr} Q_{gr}}{Q_{net}}$ (16)

NOTE Values of the constant k_1 in equation (15) may be taken as follows:

Fuel	Constant k_1
Coke	70
Anthracite	65
Bituminous coal	63
Fuel oil, BS 2869, classes E, F, G	54
Fuel oil, BS 2869, class D	53

11.4.4 *Loss due to combustible matter in ash residues, L_5 (solid fuel)*

Gross calorific value	Net calorific value
$L_{5,gr} = \frac{33820 M_3 a_1}{M_f Q_{gr}}$ (17)	$L_{5,net} = \frac{33820 M_3 a_1}{M_f Q_{net}}$ (18)
NOTE The combustible matter is assumed to be carbon with a calorific value of 33 820 kJ/kg.	

11.4.5 *Loss due to combustible matter in grit and dust, L_6 (solid fuel)*

Gross calorific value	Net calorific value
$L_{6,gr} = \frac{33820 M_4 a_2}{M_f Q_{gr}}$ (19)	$L_{6,net} = \frac{33820 M_4 a_2}{M_f Q_{net}}$ (20)
NOTE The combustible matter is assumed to be carbon with a calorific value of 33 820 kJ/kg.	

11.4.6 *Losses in the flue gases (total for gaseous fuels)*

11.4.6.1 *For distributed second family gas*

Gross calorific value	Net calorific value
$L_{7,gr} = \left(\frac{0.343}{V_{CO_2}} + 0.009\right)(t_7 - t_8) + 9.78$ (21)	$L_{7,net} = \left(\frac{0.380}{V_{CO_2}} + 0.010\right)(t_7 - t_8)$ (22)
NOTE Equations (21) and (22) are appropriate for the natural gases distributed in the UK at the time of publication of this standard. If the characteristics of these gases change significantly in the future, revised equations will be included.	
If for any reason the tests are carried out using reference gas NGA (see BS 4947), equations (23) and (24) shall be used instead of (21) and (22) respectively.	
$L_{7,gr} = \left(\frac{0.338}{V_{CO_2}} + 0.009\right)(t_7 - t_8) + 9.92$ (23)	$L_{7,net} = \left(\frac{0.375}{V_{CO_2}} + 0.010\right)(t_7 - t_8)$ (24)

11.4.6.2 *For third family gases*

11.4.6.2.1 *LPGC, propane*

Gross calorific value	Net calorific value
$L_{7,gr} = \left(\frac{0.400}{V_{CO}} + 0.008\right)(t_7 - t_8) + 7.85$ (25)	$L_{7,net} = \left(\frac{0.434}{V_{CO_2}} + 0.008\right)(t_7 - t_8)$ (26)

11.4.6.2.2 *LPGA, butane*

Gross calorific value	Net calorific value
$L_{7,gr} = \left(\frac{0.405}{V_{CO_2}} + 0.007\right)(t_7 - t_8) + 7.45$ (27)	$L_{7,net} = \left(\frac{0.438}{V_{CO_2}} + 0.008\right)(t_7 - t_8)$ (28)

11.5 Calculation for the heat emitted from the surface of the boiler and other unmeasured losses

11.5.1 *Solid and liquid fuels*

Gross calorific value	Net calorific value
$L_{8,gr} = 100 - (E_{gr} + L_{1,gr} + L_{2,gr} + L_{4,gr} + L_{5,gr} + L_{6,gr})$ (29)	$L_{8,net} = 100 - (E_{net} + L_{1,net} + L_{3,net} + L_{4,net} + L_{5,net} + L_{6,net})$ (30)

11.5.2 *Gaseous fuels*

Gross calorific value	Net calorific value
$L_{8,\,gr} = 100 - (E_{gr} + L_{7,\,gr})$ (31)	$L_{8,\,net} = 100 - (E_{net} + L_{7,\,net})$ (32)

11.6 Calculation of thermal efficiency

Gross calorific value	Net calorific value
$E_{gr} = 100\ \dfrac{Q_c}{Q_{i,gr}}$ (33)	$E_{net} = 100\ \dfrac{Q_c}{Q_{i,net}}$ (34)

11.7 Calculation of pressure losses

11.7.1 The gas-side resistance of the boiler, p_g, is derived as follows:

$p_g = p_c - p_f$

11.7.2 The water-side resistance of the boiler, p_w, is derived as described in **4.3.4**.

12 Report

The report shall include the data set out in Appendix A.

Table 3 — Symbols, definitions and units

Symbol	Definition	Unit
a_1	Combustible content in ash, dry basis	%
a_2	Combustible content in grit and dust, dry basis	%
c	Specific heat of water [4.2 kJ/(kg·K)]	kJ/(kg·K)
C	Carbon content of fuel by mass	%
C_f	Specific heat of liquid fuel	kJ/(kg·K)
E_{gr}	Thermal efficiency, based on gross calorific value	%
E_{net}	Thermal efficiency, based on net calorific value	%
H	Hydrogen content of fuel by mass	%
k_{gr}	Constant appropriate to solid and liquid fuels in dry flue gas loss formula, based on gross calorific values	—
k_{net}	Constant appropriate to solid and liquid fuels in dry flue gas loss formula, based on net calorific values	—
k_1	Constant appropriate to solid and liquid fuels in unburnt gas loss formula	—
$L_{1,\,gr}$	Loss due to sensible heat in dry flue gases, related to thermal input based on gross calorific value	%
$L_{1,\,net}$	Loss due to sensible heat in dry flue gases, related to thermal input based on net calorific value	%

Table 3 — Symbols, definitions and units

Symbol	Definition	Unit
$L_{2,\ gr}$	Loss due to sensible and latent heat in water vapour in flue gases related to thermal input, based on gross calorific value	%
$L_{3,\ net}$	Loss due to sensible heat in water vapour in flue gases, related to thermal input based on net calorific value	%
$L_{4,\ gr}$	Loss due to unburnt gas in the flue gases, related to thermal input based on gross calorific value	%
$L_{4,\ net}$	Loss due to unburnt gas in the flue gases, related to thermal input based on net calorific value	%
$L_{5,\ gr}$	Loss due to combustible matter in ash residues, related to thermal input based on gross calorific value	%
$L_{5,\ net}$	Loss due to combustible matter in ash residues, related to thermal input based on net calorific value	%
$L_{6,\ gr}$	Loss due to combustible matter in grit and dust, related to thermal input based on gross calorific value	%
$L_{6,\ net}$	Loss due to combustible matter in grit and dust, related to thermal input based on net calorific value	%
$L_{7,\ gr}$	Losses (total) in flue gases, related to thermal input based on gross calorific value of fuel	%
$L_{7,\ net}$	Losses (total) in flue gases, related to thermal input based on net calorific value of fuel	%
$L_{8,\ gr}$	Loss due to heat emitted from surface of boiler, and other unmeasured losses, related to thermal input based on gross calorific value	%
$L_{8,\ net}$	Loss due to heat emitted from surface of boiler, and other unmeasured losses, related to thermal input based on net calorific value	%
L_9	Loss due to heat emitted from surface of test equipment (calculated or measured)	kW
m_{H_2O}	Moisture content of fuel by mass	%
M_1	Mass of water entering bleed circuit system in test period	kg
M_3	Mass of ash residues collected in test period	kg
M_4	Mass of grit and dust collected in test period	kg
M_f	Mass or volume of fuel burned in test period	kg or m^3
p_g	Gas-side resistance of the boiler	mbar
p_w	Water-side resistance of the boiler	mbar
p_a	Atmospheric pressure	mbar
p_c	Total pressure over firebed or in flame space	mbar
p_f	Total flue gas pressure at boiler outlet	mbar
p_m	Pressure of the gas supply measured at the meter	mbar
p_v	Partial pressure of the water vapour in the gas within the meter	mbar
Q_{gr}	Gross calorific value of the fuel, at constant pressure. (For gas, the standard condition is 15 °C and 1013.25 mbar, dry basis.)	kJ/kg MJ/m^3
Q_{net}	Net calorific value of the fuel, at constant pressure. (For gas the standard condition is 15 °C and 1013.25 mbar, dry basis.)	kJ/kg MJ/m^3
$Q_{i,\ gr}$	Rate of heat supply by fuel, based on gross calorific value	kW
$Q_{i,\ net}$	Rate of heat supply by fuel, based on net calorific value	kW
Q_c	Heat output to water	kW

Table 3 — Symbols, definitions and units

Symbol	Definition	Unit
t_1	Temperature of water entering the boiler	°C
t_2	Temperature of water leaving the boiler	°C
t_3	Temperature of bleed water entering circuit	°C
t_4	Temperature of cooling water entering the heat exchanger	°C
t_5	Temperature of cooling water leaving the heat exchanger	°C
t_7	Temperature of flue gases at the boiler exit	°C
t_8	Temperature of air entering combustion system	°C
t_f	Temperature of liquid fuel at inlet to firing equipment	°C
t_g	Temperature of gas fuel at the meter	°C
T	Test period	s
V_{CO}	Proportion of carbon monoxide in flue gas, dry basis	%
V_{CO_2}	Proportion of carbon dioxide in flue gas, dry basis	%
$V_{CO_2 s}$	Proportion of CO_2 in stoichiometric products of combustion, dry basis	%
V_{O_2}	Proportion of oxygen in flue gas, dry basis	%
V	Flow rate of gaseous fuel corrected to standard conditions (15 °C and 1013.25 mbar, dry basis)	m^3/s
V_m	Flow rate of gaseous fuel	m^3/s

Appendix A Report data

NOTE The data shown are the minima required to carry out the thermal performance assessment.

a) Equipment under test

(1) *Boiler*

Manufacturer .....

Manufacturer's model and type number .....

Form of construction .....

Rated heat output to heat carrier ..... kW

Volume of combustion space ..... m^3

(2) *Firing equipment*

Manufacturer .....

Manufacturer's model and type number .....

(3) *Fuel (manufacturer's general requirements)*

NOTE This information is provided only for guidance in selecting a test fuel. Test results relate only to the fuel actually used in the test.

Solid fuel

Classification .....

Washed or untreated .....

Grade or size range ..... (% < 3 mm =) .....

Ash content (range) .....

Ash fusion temperatures (in semi-reducing atmosphere):

- Deformation temperature ..... °C
- Hemisphere temperature ..... °C
- Flow temperature ..... °C

Moisture ..... %

Volatile matter ..... %

Liquid fuel

Class (BS 2869) .....

Temperature at which oil is to be supplied ..... °C

Gaseous fuel

Family .....

Pressure ..... mbar

b) Test fuel

(1) *Solid fuel*

Type .....
Classification .....
Colliery or preparation plant .....
Washed or untreated .....
Grade or size range ..... (% < 3 mm =) .....

Proximate analysis
- Moisture (air-dried sample) ..... %
- Volatile matter ..... %
- Fixed carbon ..... %
- Ash ..... %

Calorific values
- Gross calorific value at constant volume ..... kJ/kg
- Gross calorific value at constant pressure ..... kJ/kg
- Net calorific value at constant pressure ..... kJ/kg

Ash fusion temperature in semi-reducing atmosphere
- Deformation temperature ..... °C
- Hemisphere temperature ..... °C
- Flow temperature ..... °C

(2) *Liquid fuel*

Class (BS 2869) .....
Density at 15 °C ..... kg/L
Viscosity at 40/100 °C ..... mm^2/s
Water content, by mass ..... %
Ash content, by mass ..... %
Gross calorific value at constant volume ..... kJ/kg
Net calorific value at constant pressure ..... kJ/kg

(3) *Gaseous fuel*

Family .....
Gross calorific value ..... MJ/m^3
Net calorific value ..... MJ/m^3
Relative density .....
Wobbe number (on gross basis) .....

c) Thermal input

Item	Unit	Test number		
		1	2	3
Test period	s			
Fuel burned in test period	kg or m^3			
Temperature of liquid fuel as fired	°C			
Atmospheric pressure	mbar			
Gas pressure at meter	mbar			
Partial pressure of water vapour in gas at meter	mbar			
Corrected fuel burned in test period	m^3			
Fuel burned in unit time	g/s or m^3/s			
Fuel burned per square metre of grate area in unit time	$g/(m^2\ s)$			
Heat release per cubic metre of combustion space in unit time	kW/m^3			
Thermal input based on gross calorific value	kW			
Thermal input based on net calorific value	kW			

d) Thermal output

Item	Unit	Test number		
		1	2	3
Mean boiler house temperature	°C			
Measured losses from test equipment	kW			
Mass of water entering bleed circuit system in test period	kg			
Inlet temperature of make-up water	°C			
Temperature of boiler return water	°C			
Temperature of boiler flow water	°C			
Heat output to water	kW			

e) Losses

Item	Unit	Test number		
		1	2	3
CO_2 in dry flue gas	%			
CO in dry flue gas	%			
Flue gas temperature	°C			
Entering air temperature	°C			
Grit and dust collected	kg			
Combustible content of grit and dust	%			
Flue gas losses:				
Dry gas	%			
Total heat in water vapour (gross calorific value only)	%			
Sensible heat in water vapour (net calorific value only)	%			
Unburnt CO	%			
Loss due to combustibles in grit and dust	%			
Ash collected in test period	kg			
Combustible content of ash	%			
Loss due to combustibles in ash	%			
Surface heat losses, and other unmeasured losses	%			
Total power consumed by combustion equipment and all necessary ancillaries	kW			

f) Characteristics

Item	Unit	Test number		
		1	2	3
Thermal efficiency — gross calorific value	%			
Thermal efficiency — net calorific value	%			
Gas-side resistance	mbar			
Water-side resistance	mbar			

g) Details for certification purposes

Tests carried out by: .....

On behalf of: .....

Date: .....

Appendix B Test rig

Examples of test rigs for testing hot water boilers are given in Figure 1(a) and Figure 1(b).

In these figures, the flow and return of the boiler are connected by a short pipe containing a circulating pump and the boiler circuit control valve (item 11). Cold water at temperature t_3 is fed into the pipe on the boiler return side of this valve from a raised tank with overflow which maintains a constant head. An equivalent quantity of water at the flow temperature, t_2, flows out of the system via a vented constant head discharge tank. The water flow rate to give the desired flow temperature at the preset output is regulated by means of the cold water bleed control valve (item 7). The desired temperature difference ($t_2 - t_1$) is set by means of the boiler circuit control valve. The bleed water supply valve (item 17) is so adjusted that some water always overflows. Items 6, 15 and 16 are included only when it is desired to cool the heated bleed water prior to discharge or recirculation.

The water throughput is weighed or measured by a flow meter. When weighing it is advisable always to fit a flow rate indicator as shown in order to allow spot checks of the water flow rate. The weighing tank(s) are sufficiently large to accommodate at least the amount of water flowing out in 5 min, so as to keep the error in the time measurement as small as possible. Alternatively the weighing apparatus may be arranged to weigh inlet water to item 3, in which case the overflow is returned to the weighing tank(s) or to item 8.

The boiler output to the water is determined by measuring the water throughput and determining the temperature difference ($t_2 - t_3$).

The pipework is insulated as shown hatched in Figure 1. The heat losses from this pipework and its components, L_9, should be calculated or determined experimentally. If these heat losses exceed 0.1 % of the particular thermal input to the boiler, account of them should be taken when the output to the water is calculated.

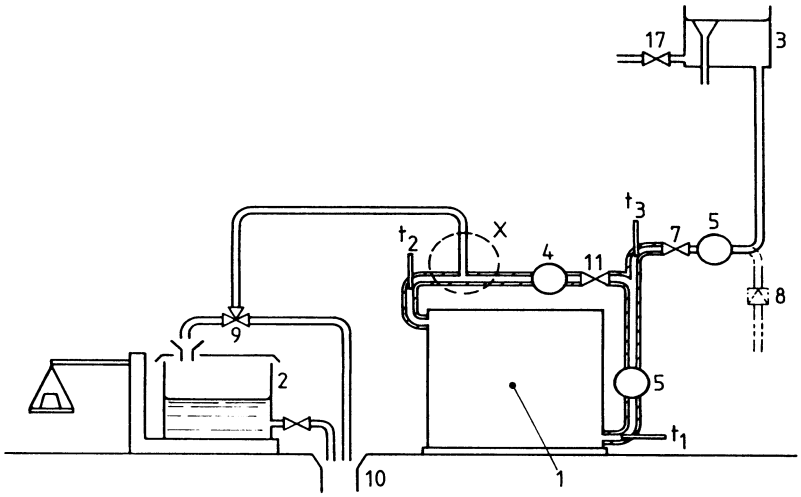
Experimental determination of heat losses (L_9) can be achieved conveniently by installing, in place of the boiler, an electrically-powered heat generator to match the heat losses and measuring the energy consumption. A part of this heat input will, in this case, be diverted to the cooling water to maintain the feed and return temperatures in the pipework as for the actual test. The heat diverted to the cooling water is measured and subtracted from the energy input.

The important characteristics of the rigs are as follows.

a) The temperature difference ($t_2 - t_3$) (from which the boiler output is determined) is larger than the temperature rise across the boiler itself ($t_2 - t_1$). This is conducive to high accuracy in the determination of the heat output to the water, and hence in the determination of the thermal efficiency.

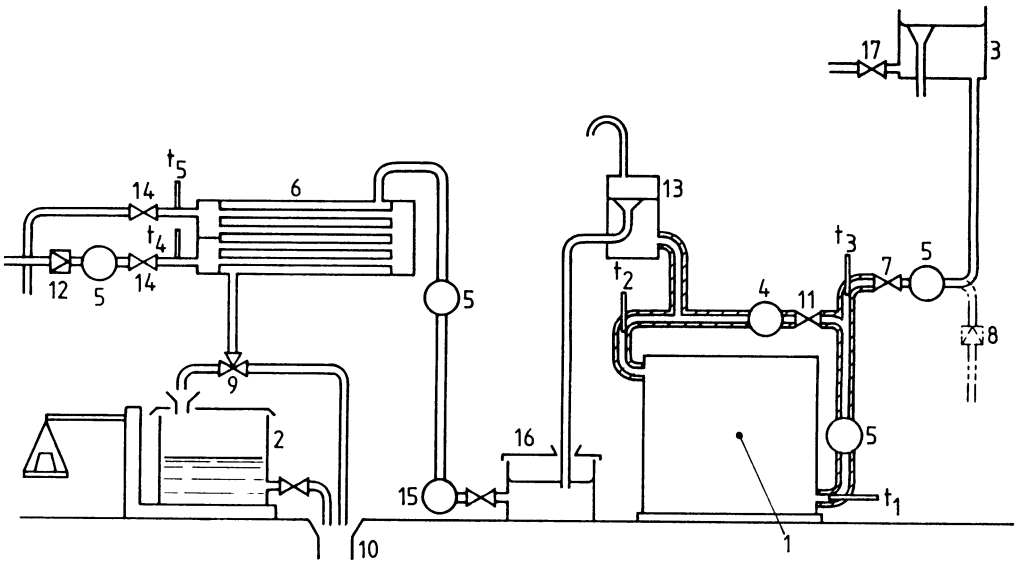
b) Thermal capacity is comparatively low and so steady state conditions are quickly obtained.

c) Surface heat losses from the rig are small. If determined experimentally, comparatively little electrical power is required.



NOTE An air separator (located at point X) may be necessary, depending on the rig layout.

a) With discharge of bleed water



NOTE The constant head discharge tank (item 13) acts as an air separator and vent.

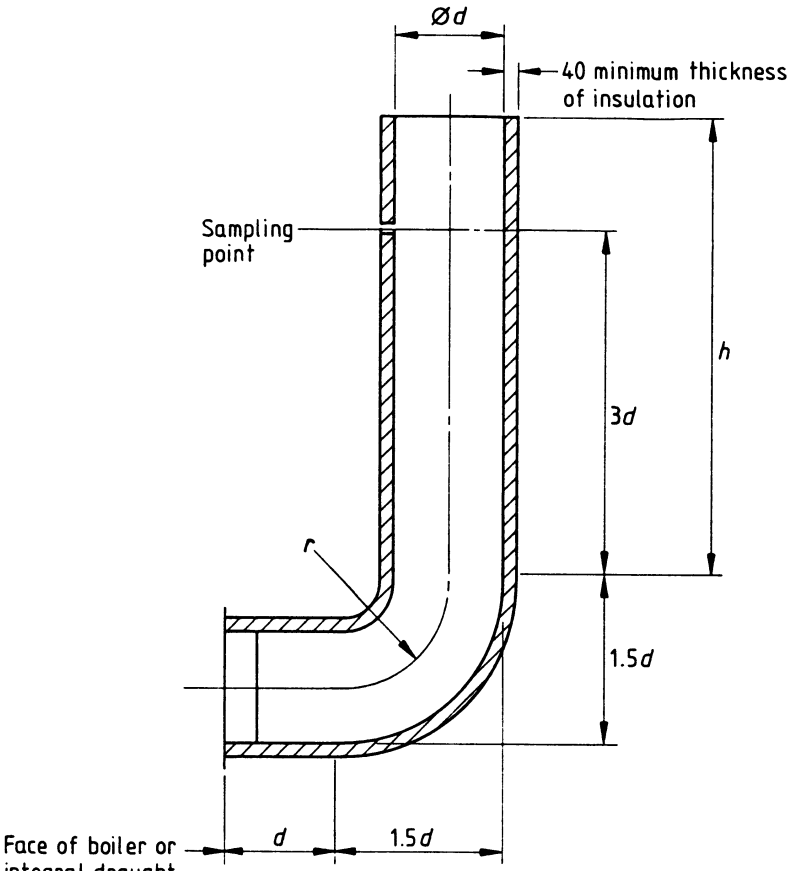
b) With cooling of bleed water via a heat exchanger and recirculation where appropriate

1. Boiler under test
2. Weighing tank(s)
3. Constant head tank
4. Circulating pump
5. Flow rate indicators[a]
6. Heat exchanger
7. Bleed water control valve
8. Water supply at constant pressure (alternative to 3)
9. Three-way valve
10. Recirculation via 17 or 8, or discharge
11. Boiler circuit control valve
12. Water supply at constant pressure
13. Constant head discharge tank
14. Heat exchanger cooling water control valve(s)
15. Bleed water hotwell pump
16. Bleed water hotwell
17. Water supply

Temperature measuring points t_1, t_2, t_3, t_4[a], t_5[a]

[a] For operation convenience only.

Figure 1 — Test rigs for hot water boilers operating below a temperature of 100 °C

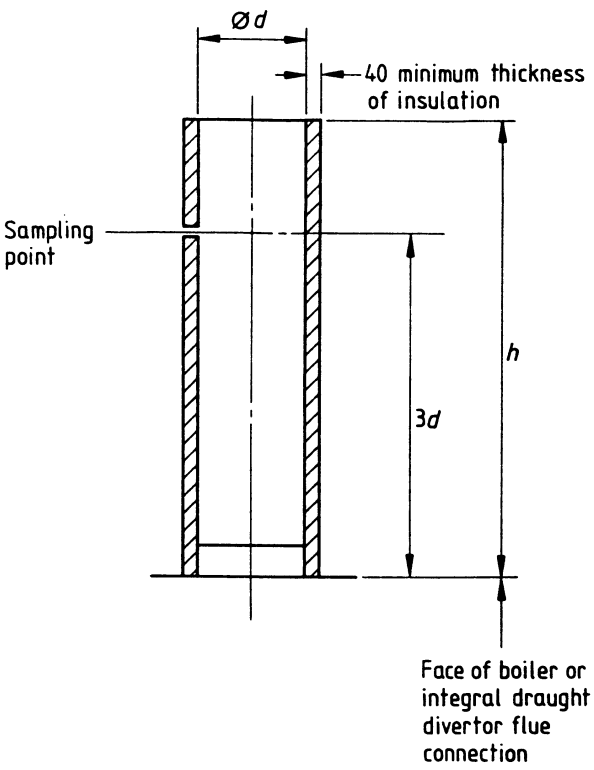


where:

r is the radius of the make-up bend;
d is the nominal diameter of the boiler flue outlet;
h is the height of test flue (see **4.3.1.4**).

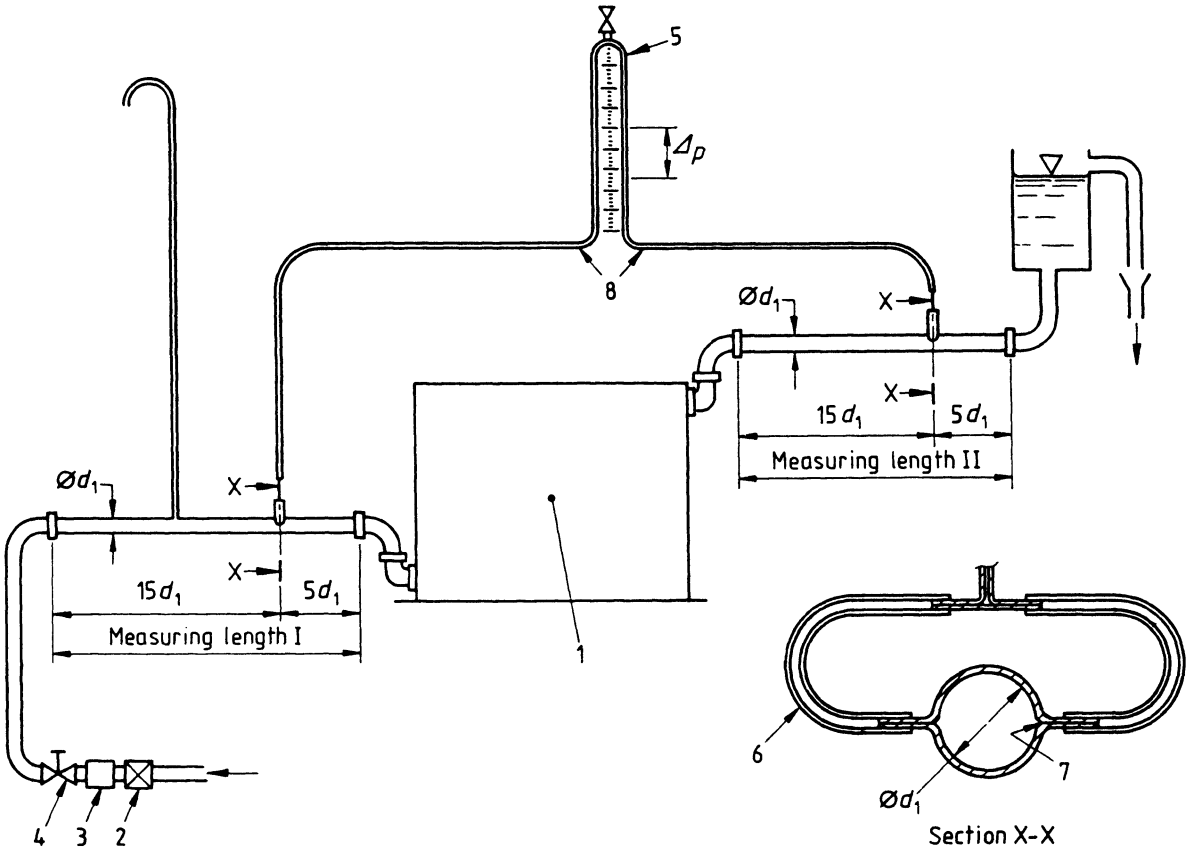
(a) Boilers with horizontal flue outlets

All dimensions are in millimetres.



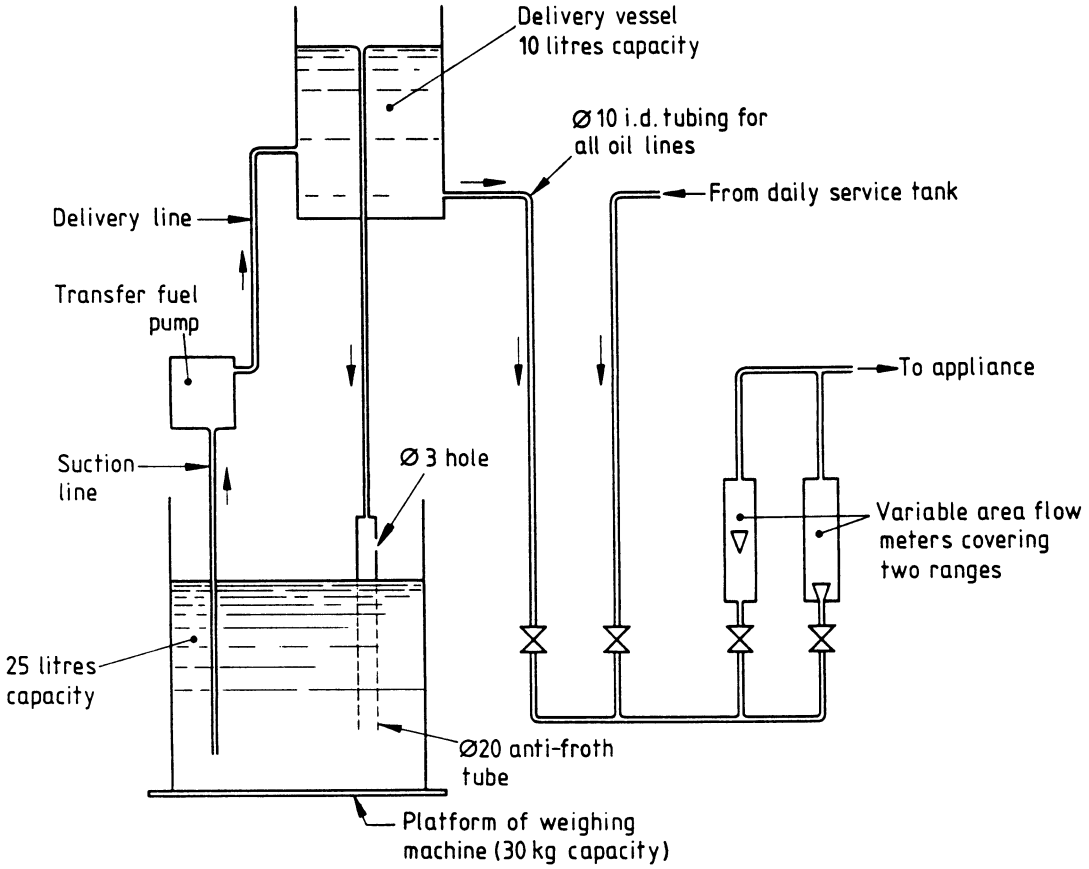
(b) Boilers with vertical flue outlets

Figure 2 — Test flues



1. Boiler
2. Pressure regulator
3. Water meter
4. Pressure control valve
5. Differential gauge (Δp being the gauge differential pressure)
6. Connecting tubes
7. Bore 3 mm inside deburred

Figure 3 — Equipment for determination of water-side resistance



All dimensions are in millimetres.

NOTE 1 Dimensions and capacities shown are suitable for appliances of rated outputs up to 300 kW. The capacities of the fuel containers should be increased in accordance with the rated duty of the appliance under test to achieve the necessary accuracy of measurement.

NOTE 2 The daily service tank for the appliance should be at the same static height as the delivery vessel and should be within the test room area. This will ensure similar temperatures for the fuel delivered to the appliance under test and assist in the setting up for steady state conditions.

Figure 4 — Measurement system for distillate fuel oils

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Publications referred to

BS 526, *Definitions of the calorific value of fuels (withdrawn).*

BS 845, *Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids.*

BS 845-1, *Concise procedure*[3)].

BS 845-2, *Comprehensive procedure*[3)].

BS 1016, *Methods for analysis and testing of coal and coke.*

BS 1017, *Methods for sampling of coal and coke.*

BS 2000, *Methods of test for petroleum and its products.*

BS 2000-12, *Heat of combustion of liquid hydrocarbon fuels.*

BS 2869, *Specification for fuel oils for oil engines and burners for non-marine use.*

BS 3156, *Analysis of fuel gases.*

BS 3156-1, *General analysis.*

BS 3156-3, *Combustion characteristics.*

BS 3156-4, *Gas chromatographic analysis.*

BS 3804, *Methods for the determination of the calorific value of fuel gases.*

BS 4876, *Specification for performance requirements for domestic fluid oil burning appliances (including test procedures).*

BS 4947, *Specification for test gases for gas appliances.*

BS 5978, *Safety and performance of gas-fired hot water boilers (60 kW to 2 MW input).*

[3)] Referred to in the foreword only.

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