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Draft for Development

Methods of type testing heating boilers for thermal performance

Part 2. Indirect method

Projet à développer

Méthodes d'essai de type du rendement thermique des chaudières

Partie 2. Méthode indirecte

Entwurf zur weiteren Ausarbeitung

Verfahren für die Baumusterprüfung der Wärmeleistung von Heizkesseln

Teil 2. Indirektes Verfahren

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This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature because the procedures described herein require testing facilities that may not be generally available at the present time.

In addition, certain of the procedures may subsequently need modification in the light of practical experience. It should be applied on this provisional basis, so that information and experience of its practical applications may be obtained.

A review of this Draft for Development will be carried out

not later than two years after its publication. Notification of the start of the review period, with a request for the submission of comments from users of this Draft for Development will be made in an announcement in the appropriate issue of *BSI News*. Observations which it is felt should receive attention before the official call for comments will be welcomed.

According to the replies received, the responsible BSI Committee will judge whether the Draft for Development can be converted into a British Standard or what other action should be taken.

Documents

Foreword

This Part of this Draft for Development has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee and makes use of the indirect method of test to give results with tolerances as prescribed in 4.3. Part 1 of this Draft for Development describes the direct method of test.

The type testing outlined applies to manufacturers' ranges of standard boilers. This Draft for Development sets down methods of test for manufacturers and others concerned and ensures that measurements of the performance of heating boilers are carried out by uniform procedures and under uniform conditions, so that measurements conducted by different manufacturers or in different test laboratories and statements of performance quoted in manufacturers'

literature will be on a properly comparable basis to the benefit of both user and manufacturer. Attention is drawn to the purpose of this Draft for Development which does not conflict with that of BS 845 relating to the acceptance of individual installations.

Where there are common purposes in Parts 1 and 2, the procedure, formulae and constants in Part 2 may contain minor differences from those used in Part 1 but harmonization will be carried out when the two Parts are produced in the form of a British Standard.

This Draft for Development is not concerned with levels of performance and does not give maximum or minimum operating conditions.

Draft for Development

Methods of type testing heating boilers for thermal performance

Part 2. Indirect method

1. Scope

1.1 This Part of the Draft for Development describes the indirect method of performance testing for boilers having an output rating of 44 kW and above for central heating and indirect hot water supply, and fired with solid, liquid or gaseous fuels.

1.2 It is not applicable to category 2 boilers as defined in Part 1 nor to those with built-in hot water generators. Tests to be undertaken at the working conditions specified for the heat carrier are prescribed and are based on the gross or net calorific value of the fuels.

2. References

The titles of the standards publications referred to in this Draft for Development are listed on the inside back cover.

3. Definitions

For the purposes of the Draft for Development the following definitions apply.

3.1 General boiler terminology

3.1.1 rated heat output to heat carrier. The maximum useful heat output to the heat carrier in unit time specified by the manufacturer of which the boiler is continuously capable.

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

3.1.3 minimum output. The minimum useful heat output in unit time of which the boiler is capable with the continuous operation of the firing equipment at the turn down ratio specified in 3.1.2.

3.1.4 ancillary energy. The electrical (or other) energy required for mechanical draught, firing equipment, oil pumping, gas boosting, solid fuel and ash handling and also for feed water supply to steam boilers, circulation in hot water boiler flow/return bypasses and boiler controls.

NOTE. The energy for oil heating is included in the calculations.

3.1.5 convertible boilers (solid, liquid and gaseous fuels). Boilers designed to burn more than one 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.

3.1.6 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. The swivelling of oil and gas burners is acceptable.

3.1.7 radiation, convection and conduction losses. The heat flow from the boiler and firing equipment to their surroundings.

3.2 Hot water boiler terminology

3.2.1 maximum operating water pressure. That pressure, measured at the lowest point of the boiler, for which the boiler has been constructed.

3.2.2 water-side resistance. The pressure loss that 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.

3.2.3 maximum permissible water flow temperature. The maximum flow temperature specified by the manufacturer.

3.2.4 minimum permissible return temperature. The minimum return temperature specified by the manufacturer.

3.3 Firing equipment terminology

3.3.1 boiler flue-gas outlet. The location between the boiler gas passes and the flue-gas duct where measurements of the flue-gas temperature, composition and pressure are carried out. The pressure will be negative (-), zero or positive (+).

3.3.2 gas-side resistance of the boiler. The pressure difference created across the boiler by the flow of combustion gases.

NOTE. This is obtained by subtracting the boiler flue-gas outlet pressure (see 3.3.1) from the furnace pressure (see 3.3.3).

3.3.3 pressure requirements in furnace. The pressure acceptable to the firing equipment for satisfactory operation.

For equipment designed to operate with a draught, this will be a negative pressure created by chimney pull or mechanically by an induced draught fan. A negative, zero, or positive pressure will occur at the outlet under natural or mechanical draught according to the point of balance for equipment operating at a positive pressure.

3.3.4 volume of furnace. The space provided in the design of the boiler, in which combustion takes place.

3.3.5 air ratio. The relationship between the amount of air fed to the firing equipment and that required for stoichiometric combustion.

3.4 Test terminology

3.4.1 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.

A distinction is made between:

(a) *gross calorific value*, in the determination of which the water produced by the combustion of the fuel is assumed to be completely condensed and its latent heat released; and

(b) *net calorific value*, in the determination of which the water produced by the combustion of the fuel is assumed to remain as a vapour.

3.4.2 indirect method of test. The determination of thermal performance by the assessment of the thermal losses and the subtraction of the sum of these from the measured thermal input.

3.4.3 thermal input. The quantity of heat based on the amount of fuel burnt per hour and its calorific value.

3.4.4 thermal efficiency. The ratio between the heat output to the heat carrier and the heat input to the boiler. It is equivalent to the heat input minus the sum of losses, divided by the heat input.

NOTE. Thermal efficiency is expressed as a percentage.

3.4.5 steady state. The stable operating condition of the boiler that exists when, at the required rate of firing, the temperature of the gases leaving the boiler, their CO₂ (or O₂) content and the temperature of the combustion air entering the boiler do not change beyond the limits set in 7.2.4.

4. Test objectives

4.1 The objectives of the test procedures described are the determination, calculation and presentation of the data as given in clause 10.

4.2 The intention is for every design and size of boiler to be tested, but in the case of boilers in a range of unchanged design characteristics, which are operated with the same type of fuel, it is sufficient to test only the smallest and the largest boiler if the output ratio between the largest and the smallest boiler is not more than 1.6 : 1. However, if within the same design this ratio exceeds 1.6 : 1, sufficient intermediate sizes should be tested to ensure that the ratio of larger and smaller boilers as tested does not exceed this figure.

4.3 The thermal efficiency determined should have a tolerance of not more than ± 2 percentage points for boilers fired by solid fuels with mechanical stoking or by liquid or gaseous fuels and not more than ± 4 percentage points for hand fired boilers.

5. Test facilities and considerations

5.1 General

5.1.1 Test room ventilation. The test room should be ventilated so that all firing units are supplied with sufficient fresh air for normal combustion when all test rigs are being used at maximum capacity.

5.1.2 Provision for boiler draught. The individual test rigs should be built and arranged in such a way that the required draught is provided at the boiler outlet and maintained during the test with as little variation as possible. Draught control devices may be required.

5.1.3 Test rig accuracy. The test rigs should be arranged and equipped with measuring instruments detailed in clause 8 in such a way that the requirements specified in clause 4 can be achieved.

5.1.4 Heat losses. Test rigs should be constructed with floors or supporting walls for boilers such that heat losses occurring during the test are comparable with those expected to occur in practice.

5.2 Test rigs

NOTE. The test rigs described in this clause and illustrated in figures 1 and 2 indicate general arrangements. The figures are diagrammatic and alternative layouts may be used provided that the basic concept of each is maintained.

Boiler fittings and mountings are omitted in the figures.

5.2.1 Test rig for hot water boiler (see figure 1). This test rig should be arranged so that water at a constant and measured temperature appropriate to the designed return temperature for the boiler is available at the boiler return connection. The quantity of water so delivered should be monitored by a flow-measuring device to assist in control and manually or automatically adjusted. This can be achieved by means of a bypass pump delivering hot flow water into the cool return. The method of sizing this pump is described in appendix A. To avoid unnecessary condensation in the boiler and flue ducts, the temperature of the heat carrier should be brought up to its working level as quickly as possible; this is facilitated by the bypass. The water from the source should be filtered and, if necessary, treated against excessive scale forming and corrosive properties. This is important in the event of prolonged testing.

The flue-gas outlet from the boiler should be provided with access ports to enable gas analysis and temperature measurement to be conducted (see 5.3). Where dust and grit sampling apparatus is to be used, additional ports of suitable size should be provided in accordance with BS 3405.

5.2.2 Test rig for steam boiler (see figure 2). The steam generated in the boiler may be vented to atmosphere, in which case a silencer may be needed, employed in space heating or passed to a condenser.

The water is supplied from a feed pump to the boiler in which the level is kept constant by manual or automatic control.

5.3 Correction of flue-gas temperature for change in heat carrier temperature. If it is preferred to test a boiler at a flow temperature or steam pressure different from that at which it will be used, the flue-gas temperature should be corrected in the proportion of 0.75 K for each 1 K change in heat carrier temperature, or alternatively the method given in appendix B may be used if the gas temperature at the inlet to the convection pass can be identified and measured by suction pyrometer.

5.4 Flue-gas measuring devices

5.4.1 General. It is essential that the measurement of flue-gas temperatures and the analysis of these flue gases are carried out as accurately as possible.

5.4.2 Flue-gas temperature measurement and sampling. A fine bare-wire thermocouple should be used in conjunction with a potentiometric recorder or digital indicator of high internal resistance. The thermocouple should be supported in and electrically insulated from a

tube through which the flue-gases are sampled. This assists in the traversing process described below and ensures that at each station flue-gas temperature and sample are taken in the same location. The bore of the tube should be as small as practicable, consistent with freedom from obstruction by deposits from the gases. A 5 mm bore should be adequate for gas or gas-oil firing but 15 mm may be needed for heavy fuel oil or coal. The probe should be of sufficient length to traverse the duct.

A hole just sufficient in size to accommodate the probe is drilled in the flue-gas duct as near as practicable to the final heat transfer surfaces of the boiler. The probe is inserted into the hole, any gap being effectively sealed. The flue-gas duct should be insulated for at least one duct diameter upstream and downstream from the hole using 50 mm thick rock wool blanket or similar material.

Readings of flue-gas temperature and composition should be taken at the centre of the cross section of the duct and at a minimum of four other representative points, the mean values being taken as representing the temperature and composition of the bulk gases. If it is found that readings taken at a single point represent these mean values, such a point may be used for subsequent observations provided that the firing conditions remain unaltered. Using figure 3, the flue-gas temperature should be corrected to allow for heat radiated from the thermocouple top. Alternatively a calibrated suction pyrometer may be used, in which case the correction is unnecessary.

5.4.3 Inlet air temperature measurement. The inlet air temperature is measured at the inlet to the firing equipment or fan. The temperature measuring device should be shielded against direct radiation from hot boiler or burner parts.

5.4.4 Particulate matter in the flue gases. With solid fuel firing, and to a lesser extent with residual grades of oil, e.g. BS 2869, classes F and G, there will be a heat loss in suspended solids in the flue gases. The carbon content should be determined by analysis and the quantity emitted during each test should be measured in the case of solid fuels and, where considered necessary, in the case of residual fuel oils.

Some solid fuel fired boilers are fitted with packaged grit arrestors of known efficiency and these may be used for the measurement of suspended solids. In other cases the apparatus and method described in BS 3405 should be used.

5.5 Measurement of fuel input

5.5.1 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, should be suspended freely from the weighing tank (see figure 4). The return pipe should be bent into the horizontal plane at the lower end so that the discharge does not cause any additional downward force.

Where the fuel consumption is measured volumetrically, it is necessary to determine the temperature of the fuel oil. This temperature should be maintained within a range of $\pm 5^\circ\text{C}$ of the initial setting.

5.5.2 Gaseous fuels. To determine the volume of gas consumed during the test a gas meter having a capacity appropriate to the maximum input is inserted into the supply pipe. Suitable equipment is required to measure gas temperature, dew point and pressure as well as atmospheric pressure. As an aid to maintaining the

measurement tolerances specified in table 1, the meter should be recalibrated at intervals not exceeding six months.

5.6 Measurement of water-side resistance in hot water boilers. A differential pressure gauge of range appropriate to the expected pressure loss should be connected between flow and return connections on the boiler. To avoid errors in measurement the pressure tapings should be de-burred and made flush with the internal wall of the connections.

6. Test preparations

NOTE. Attention is drawn to relevant national legislation such as the Health and Safety at Work, etc. Act and the Clean Air Acts. It is essential that these regulations are not contravened.

6.1 Installation of boiler under test

6.1.1 The boiler and combustion equipment should be installed and adjusted in accordance with the manufacturer's instructions and a hydraulic test carried out.

6.1.2 Where the test is not carried out at the boiler manufacturer's premises, it is recommended that he or his authorized representative should participate in the erection, hydraulic testing and preliminary running of the boiler, giving instructions as necessary.

6.1.3 After completion of the commissioning and final adjustment, the boiler should be cleaned and closed up to the satisfaction of the manufacturer. No further cleaning or adjustment should be carried out during the tests, unless the full test series is repeated. Cleaning and adjustment are permitted in convertible boilers upon a change of fuel.

6.2 Fuels. The tests should be carried out with the fuel(s) (of appropriate grades and characteristics) specified by the manufacturer. With liquid fuels requiring preheating, the temperature of the oil at the inlet to the firing equipment should be as specified by the manufacturer.

6.3 Boiler draught. During the tests the draught at the boiler exit should be maintained within the limits specified by the manufacturer.

7. Test procedure

7.1 Basis of output tests

7.1.1 For all boilers the test should be carried out at or within 5 % excess of the rated output or outputs.

7.1.2 In addition to the requirement in 7.1.1, boilers with firing equipment providing 'high/low' firing rates should be tested also at the low rate. In the case of the firing equipment being fully modulating over a range, the additional tests should be at the lowest and middle firing rates. Such tests should be carried out within $\pm 5\%$ of the intended output.

7.2 Settings prior to tests

7.2.1 General. During the preliminary running of hot water boilers, settings of flow rate, flow and return temperatures, draught at the boiler exit, primary and secondary air, etc, as required in 7.1.1 and 7.1.2 should be made to establish a steady state prior to the commencement of the test.

For steam boilers, steam flow, pressure and feed water temperature require setting in place of hot water flow rate and flow and return temperatures.

Additionally for solid fuel fired boilers 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. These conditions should be attained 1 h before the test period and maintained for 1 h after the test, but see also 7.4.2.

If blowdown of the boiler is unavoidable during the test, the mass and temperature should be determined and the heat content included in the heat account.

7.2.2 Hot water boilers. For tests on hot water boilers, the flow and return temperatures should be set as specified in the appropriate performance standard.

7.2.3 Steam boilers. For tests on steam boilers, the pressure should be set as specified in the appropriate performance standard.

7.2.4 Steady state. The steady state exists when at the required rate of fuel input the following variations are not exceeded over four consecutive readings taken at 15 min intervals:

- (a) temperature of gases leaving the boiler is within 15 °C of mean value;
- (b) temperature of air entering the boiler is within 4 °C of mean value;
- (c) CO₂ (or O₂) content of gases leaving the boiler is within 0.4 percentage points of mean value.

7.3 Constant conditions during tests. The efficiency values to be determined apply to the continuous operation of the boiler under the constant conditions established prior to the test as given in 7.2.

7.4 Duration of tests

7.4.1 Oil fired and gas fired boilers. The test should last sufficiently long for at least three complete sets of flue-gas temperatures and gas analyses to be carried out, the readings of which should be within the variations permitted in 7.2.4.

7.4.2 Solid fuel fired boilers. For solid fuel combustion appliances giving a steady heat release rate (e.g. chain grate and coking stokers) a test lasts at least 6 h. For appliances that give cyclic variations in heat release due to periodic re-fuelling and/or de-ashing operations (e.g. hand fired units and underfeed or gravity feed stokers) a test lasts at least 24 h and begins and ends at corresponding points on the first and last cycles covered by the test period. The test should be repeated, and if the thermal efficiencies vary by more than ±2 %, testing should be continued until the permissible variation between two successive test periods is not exceeded.

7.5 Running of tests

7.5.1 General

7.5.1.1 During a test no manual interference with combustion settings should occur. With automatic 'high/low' or fully modulating firing equipment, no interference should be permitted between tests at rated output and lower firing rates.

7.5.1.2 For changeable boilers, consecutive tests should be undertaken with each of the fuels with no intermediate cleaning being permitted. Additional tests with cleaned boiler flue ways should be undertaken with the fuels used in reverse order. Adjustments to the burner at changeover should not be permitted.

7.5.2 Solid fuel fired boilers

7.5.2.1 Before the test is started, the boiler should be de-ashed and subsequent ash removal carried out in accordance with the manufacturer's instructions. If de-ashing causes cyclic variations in heat release, the periods between de-ashing operations should be kept constant during the course of the test.

The combustion residues produced during the test period are weighed and sampled for analysis. Weighing of the refuse should take place preferably in the dry state. If water is used to quench burning refuse or to facilitate handling, the water content should be ascertained in order that this may be allowed for in the calculations. Where a grit arrestor is fitted, the grit should be weighed and sampled for analysis.

7.5.2.2 In the case of hand firing, the refuelling technique specified in the manufacturer's technical literature should be used throughout the tests and quoted in the test report.

NOTE. The boiler manufacturer's claims regarding recovery from banking and response to kindling controls should be made the subject of separate tests outside the scope of this Draft for Development; these tests should be agreed between the parties concerned.

8. Measurements and determinations

8.1 Measurement tolerances. Only measuring devices having the tolerances specified in table 1 and that comply with the requirements of the following clauses should be used. They should be selected so that the boiler efficiency can be determined within the prescribed tolerances (see 4.3).

Table 1. Instrument tolerances

Measurement	Instrument tolerance
Atmospheric pressure	± 0.05 mbar*
Gas fuel pressure	± 0.05 mbar
Steam pressure	± 2 %
Fuel mass solid and liquid fuels gaseous fuels	± 0.1 % by mass ± 0.5 % by volume
Time	± 0.1 %
Ancillary electrical energy	± 3 %
Flue-gas temperature	± 5 °C
Ambient and combustion air temperature	± 1 °C
CO ₂	± 0.1 percentage point
CO, for the calculation of flue-gas losses	± 0.2 percentage point
O ₂	± 0.1 percentage point

*1 mbar = 10² N/m² = 100 Pa.

8.2 Water temperature. The points where the measuring instruments should be fitted are shown in figure 1.

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Proper fitting of the instruments for the temperature measurement of the heat carrier is of particular importance. Probes should preferably be fitted into elbow joints against the direction of flow. If immersion sleeves are used for the measurement of the heat carrier temperature, 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. Thermometers for the measurement of the ambient temperature should be fitted with a protective shield against radiant heat.

8.3 Radiation, convection and conduction losses. The radiation, convection and conduction heat loss to be used in the calculations should be determined from appendix C in relation to the appropriate construction and rate of firing of the boiler.

8.4 Fuel 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 chemical composition.

Table 2. British standards for sampling and analysis of fuels

	Fuel		
	Solid	Liquid	Gaseous
Sampling	BS 1017	—	—
Analysis	BS 1016	BS 2869	BS 3156 : Parts 1, 2 and 4 BS 3804 : Part 1

8.5 Combustion residues from solid fuel. Samples of the refuse from the ashpit and grit arrestor should be taken in order to determine the combustible contents. The sensible heat content is taken as 0.3 % of heat input.

8.6 Flue-gas composition. The measured carbon dioxide, $V_{CO_2,m}$ (i.e. $CO_2 + SO_2$) and measured carbon monoxide $V_{CO,m}$ (i.e. $CO + H_2$) contents of the dry flue gases should be measured within the tolerance shown in table 1. If preferred the oxygen content may be measured instead of $V_{CO_2,m}$. This has the advantage of having the same meaning, in terms of excess air, for all fuels.

8.7 Smoke number. During the tests, measurements on the Ringelmann or Bacharach scale, as appropriate, should be made for solid and liquid fuel firing respectively.

8.8 Dryness fraction. For steam boilers, the dryness fraction should be determined for information only, in accordance with BS 3812. (See 5.3.1.1 of DD 65 : Part 1 : 1979.)

9. Calculations

9.1 General. These calculations are based on either the gross or the net calorific value of the fuel. The calculated efficiency is based on either the gross or the net calorific value or on both values and the basis should be stated on the test report.

9.2 Symbols, definitions and units

Symbol	Definition	Unit
a_1	Combustible content in ash residues removed from boiler	%
a_2	Combustible content in grit and dust removed from grit arrestor	%
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	Total heat in steam above fuel temperature	kJ/kg
H	Hydrogen content of fuel	%
k_1	Constant in unburnt gas loss formula, appropriate to fuel	
k_2	Constant appropriate to solid and liquid fuels in dry flue gas loss formula	
L	Total losses (gross or net)	%
$L_{1,gr}$	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	%
$L_{2,gr}$	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	%