

Methods for

Assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids —

Part 2: Comprehensive procedure

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- Association of Shell Boilermakers
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- Association of Consulting Engineers
- British Paper and Board Industry Federation (PIF)
- Institution of Chemical Engineers
- Institution of Mechanical Engineers
- National Industrial Fuel Efficiency Service
- Water-tube Boilermakers' Association

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Foreword

This Part of BS 845 has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee. Together with BS 845-1 it supersedes BS 845:1972 which is withdrawn.

The revised edition of BS 845 describes, in two Parts, the procedures that should be used and the data that should be collected in order to obtain an assessment of the thermal performance of steam, hot water or high temperature heat transfer fluid boilers, generally of output greater than 44 kW. The test results may be based on either the net or the gross calorific value of the fuel.

The tests described in this British Standard are for thermal performance only but are based on the assumption that boilers are operated during the tests in such a manner as to comply with relevant safety requirements and the requirements of national environmental legislation.

BS 845 is published in two separate Parts as follows:

— *Part 1: provides a concise but complete procedure and is convenient for boilers which are thermodynamically simple, i.e. having a single major source of heat input and a simple water or steam or high temperature heat transfer fluid;*

— *Part 2: provides a comprehensive procedure suitable for all boilers, including those with multiple thermal flows to and from the boiler.*

Part 2 is intended for testing boiler plant of any size burning any of the fuels available to commerce and industry. It may be used for contractual tests or for any subsequent test at full or part output and is suitable for testing all types of boiler including waste heat and electric boilers.

Allowance is made for the use of fluidized bed combustion and for the use of domestic refuse as fuel.

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 44, 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 Scope

This Part of BS 845 describes a comprehensive procedure for conducting thermal performance tests on steam, hot water or high temperature heat transfer fluid boilers to give results within a tolerance of ± 2 percentage points¹⁾ and for presenting the results in tabular form. This Part makes use of both the direct and the indirect methods of test. Test results are based on either the gross or the net calorific value of the fuel.

This comprehensive procedure is suitable for all boilers, including those with multiple thermal flows to and from the boiler.

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 Part of BS 845 the following definitions apply.

2.1

unit

a steam, hot water or high temperature heat transfer fluid boiler, generally of output greater than 44 kW, including firing equipment, together with ancillary plant or equipment, such as superheater, economizer, air heater, fans and pumps lying within the unit boundary (as indicated in Figure 1 and Figure 2)

2.2

solid fuel

any fuel in the solid state, including wastes with declared characteristics

2.3

liquid fuel

petroleum fuel oils in accordance with BS 2869 or any other fuel in the liquid state with declared characteristics

2.4

gaseous fuel

manufactured gas (first family), natural gas (second family) or LPG, i.e. propane or butane, (third family) or any other gaseous fuel with declared characteristics

2.5

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 (see 7.8, clause 8 and BS 526)

2.6

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 (see 7.8, clause 8 and BS 526)

2.7

heat input

the heat value of the fuel fired during the test based upon the net or gross calorific value (to be stated), plus the sensible heat in the fuel above the air intake temperature and any heat supplied to the unit from a separate source. In the case of waste heat and electric boilers the reference to net or gross calorific value does not apply

2.8

heat output

the heat value of the steam or hot water supplied by the unit less the heat value of any water or steam returned to the unit during the test

¹⁾ One percentage point is one hundredth of the total amount concerned, in this instance, the heat input.

2.9

radiation, convection and conduction losses

the 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

2.10

thermal efficiency

the heat output divided by the heat input expressed as a percentage

2.11

direct procedure

the determination of thermal performance from thermal input and output, based on measurement. Further measurements are taken to determine the heat losses, although one or more minor losses may be determined by difference in the heat balance

2.12

indirect procedure

the determination of thermal performance by the assessment of the thermal losses and the measured thermal input or output. Major thermal losses are determined directly from measured quantities; minor losses are determined directly, or assessed, and in the case of radiation and convection losses Appendix C gives values

3 Test preparation

3.1 Before a test, the unit shall be examined for condition and cleanliness (see clause 9).

NOTE 1 It is important that the unit is in a suitable condition for testing and in particular that it is in an acceptable state of cleanliness.

NOTE 2 Appendix D gives information concerning guiding principles for the carrying out of tests and Appendix E deals with the selection of the test method.

3.2 The unit shall be isolated from any supplies of feed water or fuel other than those passing through their respective measuring devices. Precautions shall be taken to avoid all leakages of water or steam, inwards or outwards, which will affect the results of the test. Similar precautions shall be taken with liquid or gaseous fuel. Wherever practicable unused pipes shall be blanked off or be subject to continuous supervision.

3.3 The unit shall be observed in operation for as long as may be necessary to confirm whether or not each of the following working conditions can be met.

- a) Output of hot water or steam from main boiler stop valve or flow connection.
- b) Pressure and temperature of steam or water at the unit outlet.
- c) Pressure and temperature of feed or return water entering the unit.
- d) Temperature of air at entry to the unit.
- e) Temperature and analysis of the flue gases.

It shall also be verified that the characteristics of the fuel to be burned are within the agreed range (see D.8) and that the fuel can be burned at the necessary rate (see D.7).

NOTE If such preliminary observation discloses that the required working conditions, as listed in 3.3 a) to e), cannot be met in any one or all particulars, or if the characteristics of the available fuel are different from those specified, the test may be carried out, by agreement between the parties concerned, under the working conditions shown to be feasible, and on agreement also on the resultant changes in the guarantee values.

3.4 Where circumstances require correction curves to be applied for deviations from the reference temperature of feed water temperature, temperature of steam or water and external air, as well as for deviations of steam or water throughput and fuel analysis, the method of application shall be stated. The correction shall be made to bring the maker's guarantee values to the "as tested" conditions.

NOTE The use of correction curves should be agreed between the parties concerned prior to the commencement of the test.

3.5 Boiler water shall comply with BS 2486.

3.6 In preparation for the test the unit shall be run for a sufficient time to attain equilibrium of temperature and combustion at test load conditions (see 3.7).

NOTE At this time it is also necessary to ensure that national legislation (e.g. Health and Safety at Work etc. Act 1974 and Clean Air Acts) is being complied with.

3.7 Before the test the following conditions shall prevail:

- a) the heat output shall not vary by more than $\pm 5\%$ from the value required;
- b) the extreme values of steam pressure shall not differ from one another by more than $\pm 6\%$;
- c) The extreme values of difference between the temperatures of the flue gas at the unit exit and the ambient air shall not differ from one another by more than $\pm 6\%$. That is $t_7 - t_3$ will not vary by more than 6% .

3.8 During the whole of the preliminary running the unit shall be fired with the fuel(s) that will be used for the duration of the test.

4 Minimum test duration

Having attained the steady conditions given in clause 3, a one hour control period shall be followed by the minimum test periods given in Table 1.

NOTE The control period may be counted as part of the test period only by mutual agreement between the parties concerned. Following the test a further control period may be maintained.

Table 1 — Minimum duration of tests

Direct tests, and indirect tests with fuel measured	
Solid fuel equipment giving steady burning rates	4 h
Solid fuel equipment giving possible cyclic variations in the mass of fuel present (e.g. underfeed, gravity feed stokers, hand de-ashed units) ^a	Not less than 8 h and at least one full cycle of firing or de-ashing operations, beginning and ending at the same points on the cycle
Solid fuel equipment burning domestic refuse, bagasse, and other solid fuels of variable calorific value	6 h
Liquid and gaseous fuels (including waste heat boilers)	2 h
Electric boilers	1 h
Indirect tests, fuel not measured	
Solid fuel	2 h
Liquid and gaseous fuels (including waste heat boilers)	2 h

^a If the unit has to be taken off load for de-ashing, the period between de-ashing operations is the duration of the test.

5 Test operation

5.1 Operation of equipment during test

5.1.1 During the test, the cleaning equipment shall not be operated unless there is a specific operational need to do so. If the cleaning equipment is to be operated during the test this shall be recorded in the report [see clause 9 and Appendix A c) viii)] together with the time(s) and period(s) of such operation(s).

NOTE The need to operate the cleaning equipment should be agreed between the parties concerned prior to the test.

5.1.2 During the test, the boiler shall not be blown down nor shall the timed or continuous integral ash-quenching equipment be operated unless such operations are normal functions or there is a specific operational need to do so. In the event of blow down or operation of the ash-quenching equipment during the test, allowance shall be made for the operations in the heat account (see 7.6).

NOTE The need to blow down or operate the ash-quenching equipment should be agreed between the parties concerned.

5.2 Rejection of test runs

The test shall be discontinued or rejected if excessive variations occur such as to disturb the running equilibrium (see 3.7).

NOTE Momentary variations may occur without involving the rejection of the test, providing that, taking into account the frequency, duration and time of occurrence of the variations, the parties agree that the variations are not such as to upset appreciably the equilibrium of temperature in the different parts of the unit.

5.3 Conditions at beginning and end of test

The following parameters shall correspond at the beginning and end of the test:

- a) combustion conditions;
- b) combustion air temperature;
- c) excess air;
- d) rate of feeding fuel;
- e) feed water pressure, temperature and rate of feed;
- f) steam pressure;
- g) water level;
- h) main steam and reheat steam flows.

NOTE With grate firing and, particularly during direct tests, the stock of fuel on the grate and its condition should, as far as can be reasonably ascertained, be the same at the beginning and end of the test.

With mechanical grates, the average grate velocity and the height of the fuel layer, at least during the period of one pass of the fuel on the grate, shall be the same at the beginning and end of the test. These values shall, therefore, be observed for an adequate period before commencement and after termination of the test.

NOTE In view of these conditions it is recommended that in cases where a test of long duration necessitates a change of observers during its course, the observers at the end of the test are the same as at the beginning.

6 Instrumentation

6.1 Temperature measurement

Any of the following types of thermometer shall be used for temperature measurement.

- a) High grade thermocouples used with a potentiometer or digital voltmeter of appropriate accuracy (see BS 4937-1, BS 4937-2, BS 4937-3, BS 4937-4 and BS 4937-5).
- b) Electric resistance thermometers with Wheatstone bridge or similar “null” balance instrument (see BS 1041).
- c) Mercury-in-glass solid stem thermometers with scales appropriate to the measurement to be made (see BS 593 and BS 1704).

Care shall be taken to ensure that the sensing element provides a representative reading, is of low thermal inertia so as to respond rapidly to changes, and does not gain or lose heat by radiation.

6.2 Pressure measurement

Steam and water pressures shall be measured by calibrated Bourdon-type gauges (see BS 1780), dead-weight gauges or other means.

The scale markings of the Bourdon gauges shall be of plain straight lines or dots, and a difference of 1 % of the working pressure shall be easily read on the scale.

6.3 Sampling and analysis of flue gases

Flue gases shall be sampled and analyzed using any of the following.

- a) Orsat apparatus for CO₂ and O₂ measurement.
- b) Paramagnetic or electrochemical instruments for O₂ measurement.
- c) Colorimetric apparatus such as Draeger tubes or infra-red apparatus for CO measurement.

NOTE Since new forms of portable instruments are continually becoming available, e.g. infra-red analysers and electrochemical cells for certain gas analyses, this should be borne in mind.

6.4 Measurement of steam or water flows

The feed (or return) water quantity shall be measured by any of the following methods.

- a) Tanks and suitable scales for actual weighing.
- b) Calibrated volumetric measuring tanks.
- c) A calibrated venturi meter of the precision type, nozzle or orifice plate or any meter suitable for the working conditions and having the required standard of accuracy.

The associated pipework and device for indicating the differential pressure used in conjunction with a venturi, nozzle or orifice plate shall comply with BS 1042.

6.5 Measurement of fuel flow

Quantities of gaseous fuels shall be measured using meters of the nozzle, orifice, venturi or pitot-static type complying with BS 1042 or using positive or semi-positive displacement meters. Oil fuel shall be measured by direct weighing, positive displacement meters, flow meters of the accuracy required by 7.1.1 or, where practicable, calibrated tanks. Solid fuel shall be measured by direct weighing.

6.6 Measurement of energy used by auxiliaries

Energy used by auxiliaries shall be measured using either integrating kWh meters or indicating instruments of the precision type with current and voltage transformers also of the precision type (see 7.1.4).

7 Measurement procedure

7.1 General

7.1.1 The methods of making and recording measurements shall be within the measurement tolerances given in Table 2. Unconventional methods of measurement shall only be used if their compliance with the measurement tolerances given in Table 2 can be demonstrated.

7.1.2 Calibrations shall be carried out in accordance with the manufacturer's instructions, before the tests, of all instruments and apparatus.

NOTE 1 In some cases it may be considered necessary to repeat calibrations after the tests.

NOTE 2 Where possible at no sacrifice of accuracy the use of remote indicating recording instruments is recommended and the location and grouping of all instruments, whether local or remote reading, should be considered from the standpoint of the observers, with the object of ensuring accurate measurements with the minimum of fatigue, having due regard to the agreed duration of the tests.

7.1.3 Recording instruments shall be monitored regularly, correct charts shall be fitted and the charts accurately timed especially at the start and end of the test period. Enough data to indicate the time base shall be on the chart.

7.1.4 When using indicating instruments for flow measurements, the interval between readings shall be half a minute, except where constant flow conditions are established. Water temperature readings in hot water installations shall be taken at 5 min intervals. In other cases readings shall be taken at intervals of up to 15 min provided that there are not less than 25 uniformly spaced readings and provided that there are no sudden and wide fluctuations.

NOTE 1 All readings should be taken at such frequency as may be necessary to determine the arithmetic average accurately over the test period.

NOTE 2 Where there are sudden and wide fluctuations it may be necessary to reduce the interval between readings.

NOTE 3 Intervals that are too short can result in an increase in the error due to fatigue of the observers taking the readings.

7.1.5 With respect to quantitative measurements, as far as possible the initial readings shall be taken simultaneously and the final readings shall be taken simultaneously. The steady-state values shall be read off immediately prior to the beginning of the test period.

NOTE It is recommended that major readings should be continued throughout both the initial and any final control periods.

7.1.6 The observed data shall be directly recorded by each observer on log sheets designed for the purpose, having regard to recording all data necessary for subsequent interpretation (see clause 9). The log sheets shall include the reference number of all instruments. Units and multipliers shall be included.

Table 2 — Measurement tolerances

Measurement	Tolerance (expressed as a percentage of reading except where stated otherwise)
Atmospheric pressure	± 0.5
Gas fuel pressure	± 0.5
Steam pressure	± 1
Water or fuel mass by weighing	± 0.2
Water or liquid fuel flow	± 0.5
Gaseous fuel flow	± 0.5
Steam flow	± 0.5
Time	± 0.1
Calorific value	± 0.6
Auxiliary electrical energy	± 0.5
Gas temperature	± 1
Water temperature	± 0.1 °C
CO ₂	± 0.1
CO (for the calculation of flue-gas losses)	± 10
O ₂	± 0.2
Dryness fraction of saturated steam	See 7.15

7.2 Temperature measurement

7.2.1 The temperature of steam taken from the unit and used for heating oil, or for other purposes, shall be taken in such a manner as to debit the heater with any pipe heat losses for which it may be responsible.

NOTE The usual procedure is to measure the steam temperature directly at a point that is as near as practicable to the source of supply. Where steam flow is determined other than by direct measurement, the steam temperature used should ensure a similar result.

7.2.2 The temperature of the combustion air shall be measured at the points of air entry to the unit; where there is non-uniformity in the temperature, several thermometers shall be used.

7.2.3 In measurements of the flue gas outlet temperature, the temperature measuring point shall be as close to the heat exchanger outlet as is practicable, care being taken to obtain a representative temperature.

7.3 Pressure measurement

Bourdon gauges shall be calibrated under pressure and ambient temperature conditions approximating to those obtained during the test, using standard dead-weight test gauges before and, if required, after the tests.

7.4 Sampling and analysis of flue gases

7.4.1 Sampling and analysis of the flue gases are normally carried out at a point after the final heat exchange surface of the unit but, if an alternative boundary point is taken after the induced draught fan (see Figure 2), checks shall be carried out to ensure that there is no air leakage inward at the fan.

7.4.2 Before the test the ducts where gas analyses are required shall be explored, under all conditions of load and combustion expected on the test, to ascertain the distribution of carbon dioxide or oxygen.

NOTE 1 If this reveals a point where a reliable mean exists, single point sampling may be adopted with the end of the sampling tube in this position.

NOTE 2 For large ducts it is recommended that multi-point sampling be employed and the arithmetic average taken.

NOTE 3 Care is necessary in selecting the plane of sampling of the flue gases. The difficulty may be accentuated in large cross-sectional areas. Stratification may be particularly bad after a bend and where rotating air heaters are present and there may also be considerable variation in gas analysis over the duct due to air infiltration (see BS 1756 and BS 3048).

7.4.3 Analyses shall be made at frequent intervals. Unless the analysis is to be used for reasons other than determining the discharge gas losses, the sampling point shall be as close as practicable to the point at which the exit temperature is taken.

7.4.4 Because all gases and especially SO₂ and CO₂ are soluble to some extent in water, the water in the levelling bottle of Orsat apparatus, if used (see **6.3**), shall be saturated with sample gas before taking any readings.

7.5 Measurement of steam or hot water flows

7.5.1 Steam or hot water output shall be determined by measurement of the feed (or return) water quantity or alternatively, for steam boilers, by direct measurement of steam flow.

NOTE Output should be determined preferably by measurement of water quantity. Direct measurement of steam flow should only be used where the parties agree, the duration of the test and the water content of the boiler having been taken into consideration.

Whether the determination of steam output is made by water or steam measurement, reference shall be made to BS 1042, BS 3285 and BS 3812 (see **7.15**).

7.5.2 The pressure pipework between the primary element and its associated equipment shall be arranged so that no back pressure or false pressure difference is set up (see BS 1042-1).

7.5.3 Pipeline primary elements and associated equipment shall only be used with systems incorporating centrifugal pumps providing a non-pulsating flow.

7.5.4 In no case shall vane-type meters be used in conjunction with reciprocating pumps.

NOTE If reciprocating pumps are used, the mass or volume of the feed water should be determined, if this is permissible, the oxygen absorption of the feed water in open measuring tanks having been taken into consideration.

7.5.5 Water levels in all parts of the unit shall be the same at the end of a test period as at the start unless differences are measured and taken into account.

7.5.6 All leakages at safety valves, blow-off valves, feed water heaters, pumps, joints, stuffing boxes, and through-connecting piping that may affect the test results shall either be eliminated or measured and accounted for.

NOTE For the purposes of this standard the elimination of leakages may be taken to include reduction to an amount which to the satisfaction of all parties concerned can be ignored.

Errors due to steam or water entering or leaving the equipment under test through connecting piping shall be obviated by blanking off such connections or by providing open tell-tale drains to give visible assurance that no flow exists.

7.6 Measurement of blow-down

If the boiler is to be blown down during the test, the quantity of the blow-down shall be determined, where practicable, by direct measurement of the cooling water to any blow-down cooler and of the inlet and outlet water temperature.

NOTE Blowing down during a test should be avoided wherever practicable.

7.7 Measurement of fuel

7.7.1 Solid fuel. The amount of fuel between the point of weighing and the point of combustion shall be kept as small as possible and, wherever practicable, shall be kept to the same amount at the beginning and at the end of the test. Where this is not practicable, the change in quantity of fuel so stored shall be estimated and the appropriate correction made. In the case of pulverized fuel produced by on-site milling equipment and discharged directly to the burners, the fuel shall be weighed before pulverizing.

7.7.2 Liquid fuel. The precautions referred to for solid fuel regarding storage between point of weighing and point of combustion shall be observed with fuel oil.

7.7.3 Gaseous fuel. The location and installation of nozzles, orifices, venturis or pitot-static tubes, and the connecting system between the primary element and the manometer shall be in accordance with BS 1042.

7.8 Sampling and analysis of fuel

7.8.1 Solid fuel shall be sampled and analysed in accordance with BS 1017 and BS 1016 respectively. The degree of accuracy in sampling shall be to 0.25 % in ash and moisture.

7.8.2 The following principles shall be adopted for sampling pulverized fuel from a fuel pipe for determination of size grading.

- a) The velocity of flow into the sampling nozzles shall be within ± 10 % of the velocity within the pipe at the sampling point.
- b) The sampling pipe shall be cleared of pulverized fuel before sampling is begun.

c) Sampling shall take place from a section of the fuel pipe at a sufficient distance from the pulverizer (and from the exhaust, if one is used) in a straight length of the pipe, preferably vertical, and as far away as possible from bends.

d) A traverse shall be made of the pipe section at regular intervals of time throughout the test and samples drawn off from centres of equal areas, the sampling time being the same at each point.

e) The weighted average of the individual gradings so obtained shall be used as the average result for the test unless the samples are thoroughly mixed and the grading of the mixture determined.

7.8.3 In the case of fuel mixtures such as coal and oil or relatively uniform waste materials the characteristics of each fuel component shall be determined separately and the characteristics of the mixture found from the proportions by mass of the constituents. This procedure shall also be adopted in cases where different fuels are burned simultaneously as this will enable the formulae for dry gas losses (based on flue gas analysis) to be used.

NOTE For widely varying materials such as domestic refuse, either the heat output should be determined instead of the heat input or agreement should be obtained concerning the size, frequency and method of determination of calorific value.

7.8.4 For liquid fuels a continuous sample shall be collected throughout the test at a point between the fuel conditioning station and the burners.

NOTE This may be at the fuel oil heaters for convenience.

7.8.5 For liquid fuels the ultimate analysis, including ash and water, calorific value, viscosity and density shall be determined (see BS 1469, BS 2000-12 and BS 2000-13, BS 2869 and BS 4451).

7.8.6 If gaseous fuel does not have closely controlled characteristics (e.g. is not from the public supply system) special consideration shall be given to the method of obtaining an average sample.

7.8.7 If the composition of the gaseous fuel is expected to remain constant during the test, sampling of the fuel gas shall be either by means of a continuous sample, or by samples taken at regular intervals.

NOTE If it is expected that the fuel gas composition may vary significantly during the test (for instance if the fuel gas comes from an intermittent gas-producing process), agreement should be reached on the procedure to be adopted to obtain the true weighted mean calorific value.

7.8.8 All calorific values used shall be those at constant pressure and corrected to one atmosphere standard pressure (1.013 25 bar²⁾). The standard reference temperature for the calorific values of solid and liquid fuels shall be 25 °C, and for gaseous fuels shall be 15 °C. The calorific values at constant pressure as defined in BS 526 shall be used.

7.9 Measurement of humidity

The humidity of the combustion air at entry to the unit shall be determined.

NOTE The quantity of combustion air is required for the calculation of the total amount of moisture admitted with the air. This air flow may be determined by calculation, provided that the fuel and flue gas analyses are known, or be measured using nozzles at the air inlets.

7.10 Measurement of residues

7.10.1 The masses of ash and clinker, dust, riddlings, mill rejects and any other residues shall be determined. The mass of the flue dust shall be found by carrying out representative gas sampling to obtain the dust burden (see BS 893, BS 3405 and **7.10.2**).

7.10.2 The masses of residues shall be determined on a dry basis. However, as any hot residue has to be quenched with water immediately upon its withdrawal from the unit, and as residues are often wet when discharged from the handling plant, the water content shall be ascertained in order that this may be allowed for in the calculations.

NOTE Where there is special difficulty in weighing any component, and especially where the carbon content of the component concerned is expected to be small, its mass may be estimated from the masses of the other components and of the total ash corresponding to the coal mass and analysis (see Appendix B).

7.11 Sampling of boiler residues

NOTE 1 Sampling of residues is required for two main reasons: sampling to determine heat loss, involving residue quantities, and sampling for determination of other physical characteristics such as grading, density or, for instance, fusion temperatures or corrosive qualities.

NOTE 2 The methods for sampling, which are considered in connection with the measurement of residues in accordance with **7.10**, should be agreed by the parties concerned prior to the test.

²⁾ 1 bar = 0.1 MPa.

7.11.1 Separate sample collection shall be carried out from all the relevant residue discharges of the plant.

NOTE These discharges may take the form of hoppers, chutes or pipes discharging solids or liquids or both, or may be ducts carrying dust laden gases.

7.11.2 From each discharge a quantity of material, representative of the residue leaving the unit via that discharge during the test, shall be collected.

NOTE 1 A procedure for collection of residues is given in a) and b).

a) *Ash*. Where the loss due to combustible matter in ash is known to be small, a number of increments to form a gross sample should be taken as the hoppers are being emptied after the test. Where the loss is likely to be significant, the whole of the ash should, if practicable, be treated as the gross sample and should be crushed to 13 mm and mixed thoroughly. Quantities in excess of 100 kg should be subdivided by coning and halving and quartering until the mass of the subdivided sample is reduced to between 50 kg and 100 kg. Samples of 100 kg and less should be subdivided by a mechanical sample divider, of a type approved for subdivision of coal samples down to the size of sample suitable for laboratory use (see BS 1017-1). In the event of wetting of the ash taking place, separate moisture samples should be taken unless the mass of the dry ash is being found by calculation.

b) *Other residues*. With boilers fired with pulverized fuel, if the dust burden in the flue gases is being measured, laboratory samples for combustible content should be taken from the gross sample collected, after this has been thoroughly mixed, by riffing or by means of a sample divider. If the sample is taken from a hopper which has collected the dust during the test period, periodic samples to form a gross sample should be taken as the hopper is being emptied. The gross sample should then be mixed and divided as above, to obtain laboratory samples.

Where the fly ash or dust is wetted, and this is weighed after wetting, the quantity of water added should be obtained by calculation or by direct measurement; in the latter case, representative samples should be taken both for moisture and for combustible content. In addition to the main flue dust, if significant quantities are collected in other parts of the unit, gross samples should be taken and divided by means of a riffle or sample divider.

If the quantity of mill rejects or stoker riddlings is significant, the whole quantity should be considered as a gross sample and this should be reduced by halving and quartering to form laboratory samples.

NOTE 2 The collection of residues by any other procedure should be agreed prior to the test by the parties concerned.

NOTE 3 The quantities of sample to be submitted for examination, the condition of the samples for submission and the number of replicate samples and their purpose should be agreed by the parties concerned prior to the test.

7.11.3 The samples shall be submitted for analyses (see BS 1016-14).

NOTE These analyses, as required by the purpose of the test, can relate to design or contractual requirements or to an agreement between the parties concerned prior to the test.

7.12 Sensible heat in residues or fluidized bed material

Where the sensible heat loss in the ash or carried over fluidized bed material is significant, the sensible heat shall be measured, in dry systems, by determining the temperature and specific heat. In wet systems, the sensible heat of residues shall be determined from the mass of the cooling water and its rise in temperature and/or from the mass of water evaporated.

NOTE The operation of wet systems may be modified or suspended if this enables the test procedure to be simplified [see D.8 i)].

7.13 Radiation, convection and conduction loss

The loss due to radiation, convection and conduction (i.e. the gross loss from the unit with no allowance being made for recuperation) shall be evaluated by using one of the following methods.

a) From the measurement of the surface temperature and ambient air temperatures of the unit together with heat transfer coefficients, or from measurements with a heat flux meter.

NOTE It is important to have an accurate knowledge of the area of surface to which the above temperatures or heat fluxes refer and to determine the surface area of irregular parts, particularly those which are not lagged.

b) By determining the heat entering and leaving the building or isolated section thereof, using air-flow and temperature measurement at each point of entry or exit, including the entry to the air intakes of the unit, together with an allowance for the building radiation loss.

NOTE This is only applicable where the unit, or one of a number of identical units steaming equally, can be isolated as regards air supply.

c) By adopting predetermined values for radiation convection and conduction losses.

NOTE This method of evaluation should only be used when methods a) and b) are impracticable and agreement should be reached before the test as to the value to be adopted for the radiation convection and conduction loss. Suggested values for boilers of conventional design are given in Table 4 and Table 5.

7.14 Measurement of energy used by auxiliaries

Where only the total electrical energy is to be determined, this shall be measured by appropriate metering in the main feeder, or in each feeder if there are more than one.

NOTE 1 In this case an indication of the distribution of energy may be obtained from a comparison of the ammeter, voltmeter, and power factor measurement or Watt meter readings of each motor.

Where the energy input to a particular auxiliary motor is to be determined, it shall be measured directly by a Watt meter connected in the supply to that motor.

NOTE 2 Determination of the energy consumption of auxiliaries driven by other means (such as steam, hydraulic and gas turbines) should be made as agreed by the interested parties in the light of the circumstances of the individual case.

7.15 Estimation of dryness fraction

Boilers producing saturated steam shall be tested by the indirect procedure [see E.2 f)].

NOTE 1 The dryness fraction, q , can be estimated by calculation if required (see 8.3.5, G_5), provided that the steam flow can be derived.

NOTE 2 Methods of estimating the dryness fraction of saturated steam are described in BS 3812 but accuracies are not specified.

8 Calculations

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

8.1 General

The calculations necessary to complete the assessment of thermal performance shall be in accordance with the equations given in 8.2 to 8.4.

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 clause 9 and Appendix A(d)].

The calculations shall be carried out in the following order.

- Having identified the individual heat flows relevant to the unit (see E.2), calculate the individual heat-flow rates by using the equations provided in 8.2.
- Calculate the combined heat flows G_1 to G_5 using the equations provided in 8.3.
- Calculate the thermal efficiency in accordance with 8.4.

NOTE The data required to complete the calculations are fully itemised in the test report (see clause 9 and Appendix A), which includes a tabulation of the heat account.

8.2 Calculation of heat flows

Calculate the individual heat flows using the equations given in 8.2.1 to 8.2.46.

8.2.1 Heat flow rate from calorific value in solid fuel, F_1

$$F_{1 \text{ gr}} = C_1 Q_{\text{gr,p}} \quad (1)$$

$$F_{1 \text{ net}} = C_1 Q_{\text{net,p}} \quad (2)$$

Alternatively, in the case of on-site milling, with the fuel weighed prior to milling:

$$F_{1 \text{ gr}} = W_{12} Q_{\text{gr,p}} - F_{27} \quad (3)$$

$$F_{1 \text{ net}} = W_{12} Q_{\text{net,p}} - F_{27} \quad (4)$$

8.2.2 Heat flow rate from calorific value in liquid fuel, F_2

$$F_{2 \text{ gr}} = C_1 Q_{\text{gr,p}} \quad (5)$$

$$F_{2 \text{ net}} = C_1 Q_{\text{net,p}} \quad (6)$$

8.2.3 Heat flow rate from calorific value in gaseous fuel, F_3

$$F_{3 \text{ gr}} = C_1 Q_{\text{gr,p}} \quad (7)$$

$$F_{3 \text{ net}} = C_1 Q_{\text{net,p}} \quad (8)$$

or

$$F_{3 \text{ gr}} = C_2 Q_A \quad (9)$$

$$F_{3 \text{ net}} = C_2 Q_B \quad (10)$$

In the case of waste heat

$$F_{3,1} = C_1 h_{16} \quad (11)$$

8.2.4 Heat flow rate due to preheating liquid fuel, F_4

8.2.4.1 If supplied from a separate source (as indicated by “alternative boundary” in Figure 2):

$$F_4 = C_1 f_1 (t_9 - t_3) \quad (12)$$

8.2.4.2 If supplied with steam for this purpose by the unit:

$$F_4 = C_1 f_1 (t_6 - t_3) \quad (13)$$

NOTE If the unit also supplies steam for heating fuel tanks and pipes beyond the unit boundary only the heat flow required to raise the fuel temperature from t_6 to t_9 should be treated as being for use within the unit (see 7.2.1).

8.2.5 Heat flow rate in combustion air from separate source, F_5

$$F_5 = W_{23} (h_{15} - h_{14}) \quad (14)$$

8.2.6 Heat flow rate in feed or return water, F_6

$$F_6 = W_1 (h_1 - h_5) \quad (15)$$

8.2.7 Heat flow rate in attemperor spray water (main steam), F_7

$$F_7 = W_4 (h_4 - h_5) \quad (16)$$

8.2.8 Heat flow rate in main steam or water at discharge from unit, F_9

$$F_9 = W_2 (h_2 - h_5) \quad (17)$$

or

$$F_9 = (W_1 + W_4 - W_3 - W_5 - W_{13}) (h_2 - h_5) \quad (18)$$

8.2.9 Heat flow rate in blow-down, F_{10}

$$F_{10} = W_3 (h_3 - h_5) \quad (19)$$

8.2.10 Heat flow rate in ash and clinker due to unburnt carbon³⁾, F_{11}

$$F_{11} = \frac{D_1 i_1 Q_i^a}{100} \quad (20)$$

^a Normally 33 820 kJ/kg. If the greater part of the combustibles in the unburned residue is in the form of partly distilled coal and not of carbon, then Q_i should be determined by bomb calorimeter and calculated on the dry basis of this partly distilled coal.

8.2.11 Heat flow rate in grit and dust due to unburnt carbon³⁾, F_{12}

$$F_{12} = \frac{D_2 i_2 Q_i^a}{100} \quad (21)$$

^a Normally 33 820 kJ/kg. If the greater part of the combustibles in the unburned residue is in the form of partly distilled coal and not of carbon, then Q_i should be determined by bomb calorimeter and calculated on the dry basis of this partly distilled coal.

8.2.12 Heat flow rate in fine dust due to unburnt carbon³⁾, F_{13}

$$F_{13} = \frac{D_3 i_3 Q_i^a}{100} \quad (22)$$

^a Normally 33 820 kJ/kg. If the greater part of the combustibles in the unburned residue is in the form of partly distilled coal and not of carbon, then Q_i should be determined by bomb calorimeter and calculated on the dry basis of this partly distilled coal.

8.2.13 Heat flow rate in riddlings due to unburnt carbon, F_{14}

$$F_{14} = \frac{D_4 i_4 Q_i^a}{100} \quad (23)$$

^a Normally 33 820 kJ/kg. If the greater part of the combustibles in the unburned residue is in the form of partly distilled coal and not of carbon, then Q_i should be determined by bomb calorimeter and calculated on the dry basis of this partly distilled coal.

8.2.14 Heat flow rate in carried-over fluidized bed material and ash due to unburnt carbon³⁾, F_{15}

$$F_{15} = \frac{D_5 i_5 Q_i^a}{100} \quad (24)$$

^a Normally 33 820 kJ/kg. If the greater part of the combustibles in the unburned residue is in the form of partly distilled coal and not of carbon, then Q_i should be determined by bomb calorimeter and calculated on the dry basis of this partly distilled coal.

8.2.15 Sensible heat flow rate in ash and clinker, F_{16}

$$F_{16} = D_1 f_2 (t_{10} - t_3) \quad (25)$$

³⁾ See Appendix B for pure ash account.