BRITISH STANDARD

BS 3841-2:
1994

Determination of smoke emission from manufactured solid fuels for domestic use —

Part 2: Methods for measuring the smoke emission rate

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Solid Mineral Fuels Standards Policy Committee (SFC/-) to Technical Committee SFC/11, upon which the following bodies were represented:

Association of British Solid Fuel Appliances Manufacturers
British Coal Corporation
British Foundry Association
Department of Health
Department of the Environment (Her Majesty's Inspectorate of Pollution)
Department of Trade and Industry (Warren Spring Laboratory)
Low Temperature Coal Distillers' Association of Great Britain Ltd.
METCOM
Solid Smokeless Fuels Federation

This British Standard, having been prepared under the direction of the Solid Mineral Fuels Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 May 1994

The following BSI references relate to the work on this standard:
Committee reference SFC/11
Draft for comment 92/58575 DC

ISBN 0 580 21836 8

Amendments issued since publication

Amd. No.	Date	Comments

Contents

Foreword

This Part of BS 3841 has been prepared under the direction of the Solid Mineral Fuels Standards Policy Committee. Together with BS 3841-1:1993 it supersedes BS 3841:1972 which is withdrawn.

The Clean Air Act 1956 [1], modified and extended by the Clean Air Act 1968 [2], was introduced to control air pollution in the United Kingdom.

Under Section 11 of the 1956 Act, local authorities are empowered, subject to confirmation by the Minister, to set up smoke control areas in which it is an offence to emit smoke from a building. The only defences against prosecution under the Act are that the smoke is produced from an authorized fuel, that authorized fuels are not available or that the smoke is from an exempted appliance.

An exempted appliance is defined by Section 11(4) of the 1956 Act as one which can be operated for burning a fuel other than an authorized fuel without producing any smoke or a substantial quantity of smoke.

An authorized fuel is defined in Section 34(1) of the 1956 Act as a fuel declared by regulations of the Minister to be an authorized fuel for the purposes of this Act. In 1956 a number of classes of solid smokeless fuel, both manufactured and natural, which pre-dated the Act were declared to be authorized fuels.

Subsequent development of other types of manufactured smokeless fuel for domestic purposes demonstrated the need for a standard procedure to establish their potential for smoke emission and to assess whether such fuels were suitable for authorization within the terms of the 1956 Act.

For this revision, BS 3841 has been divided into two Parts, Parts 1 covering the fuel combustion procedure and Part 2 describing the smoke measurement equipment and its use. The main technical changes form the previous edition are as follwos:

a) extension of the test procedure to cover brown coal, lignite, peat and wood fuels;

b) widening of the permitted tolerance in the second radiation peak for valid tests;

c) modification of the refuelling procedure for long briquettes;

d) provision of a suitable aerator to enable the gas ignition burner to burn natural gas;

e) inclusion of the form of test report required;

f) specification of a sampling method in a dilution tunnel as an alternative means of smoke measurement to the electrostatic precipitator (see Annex A);

g) change of organic solvent for cleaning the precipitator;

h) change of procedure for conditioning the precipitator, utilizing a constant temperature room (hot room);

i) inclusion of safety precautions relating to the use of high voltage and of organic solvent in the operation of the precipitator.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 20, 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.

0 Introduction

BS 3841-1 describes the general procedure to be adopted for measuring the smoke emissions from solid smokeless fuels. This Part of BS 3841 describes procedures for measuring the smoke emission rate (in g/h) under the combustion conditions specified in Part 1.

The electrostatic precipitator method was developed for the purpose of collecting and measuring the smoke from domestic appliances burning solid fuel. The precipitator collects the particulate matter from the total volume of flue gas produced by the fire during the test period. The total mass of smoke emitted during the test period is determined by weighing the precipitator at the beginning and end of the test.

The dilution tunnel method involves sampling isokinetically from a duct above the test chimney. This technique is widely used internationally.

Both methods have been shown to be capable of measuring in the range 0.5 g/h to 30 g/h. The two methods give results in close agreement (see Annex A).

1 Scope

This Part of BS 3841 describes an electrostatic precipitator method and a dilution tunnel method for measuring the smoke emission rate from a manufactured solid fuel tested in accordance with BS 3841-1:1994.

2 References

2.1 Normative references

This Part of BS 3841 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 3841 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This Part of BS 3841 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Electrostatic precipitator method for smoke emission rate measurement

3.1 Principle

The instrument used is an electrostatic precipitator developed for the purpose of collecting and measuring the smoke from domestic appliances burning solid fuel. It is placed on top of the laboratory test chimney and removes the smoke from the whole of the flue gas with minimal resistance to flow. The total mass of smoke emitted during a test period is determined by weighing the instrument at the beginning and the end of the test.

NOTE The precipitator has been shown to have the requisite efficiency of smoke collection for testing manufactured solid fuels in accordance with BS 3841-1 and was used in the experimental work leading to the formulation of BS 3841.

3.2 Apparatus

3.2.1 *Electrostatic precipitator*, comprising a single stage multi-tube unit, constructed as shown in Figure 1 to Figure 4. The main components of the assembly shall be as follows.

a) *Collecting electrodes*. The collecting electrodes (1) (see Figure 1) shall be made of hexagonal tube of 0.7 mm thick aluminium alloy, having external dimensions of 30 mm across the flats, assembled in a honeycomb consisting of 85 passages, as shown in the plan view. By utilizing the outside of some of the tubes as collecting surfaces, the assembly shall be made up of 66 individual tubes, 457 mm long. The ends of the tubes shall be argon-arc welded together and the tube assembly shall be welded to a 356 mm diameter base plate and 330 mm diameter top plate. Both end plates shall be flanged and shall be of 1.6 mm thick aluminium alloy. A 102 mm high aluminium alloy skirt (2) of diameter 360 mm shall be bolted to the flange on the base plate. The skirt shall contain two 6 mm swages approximately 51 mm apart, the lower one being 29 mm from the base of the skirt.

b) *Charged electrodes*. The charged electrodes (10) (see Figure 1) shall be made of hard-drawn stainless steel wire of 0.15 mm diameter, and shall pass along the vertical axis of each tube. They shall be spring loaded and shall be attached to suspension hooks (8) on a supporting framework at each end of the tube assembly.

c) *Supporting frames*. The supporting frames (4) and (5) shall be as shown in Figure 1 and Figure 2. Each frame shall be made up of 22 aluminium alloy strips of width 13 mm and thickness 1.6 mm. The strips shall be slotted together into a lattice (see Figure 2) resulting in 85 junctions at which the suspension hooks (8) clip on. The frames shall be strengthened by 12 mm × 12 mm aluminium angle of thickness 3 mm formed into a ring, butt welded and then welded round the periphery of the lattice. The top frame shall be attached to the main frame by 13 mm × 13 mm insulators, for example of compressed mica-filled phenolformaldehyde (3). For the lower supporting frame, the insulators shall be held at an angle of 45° to the vertical by mounting brackets made from 1.6 mm thick aluminium (6) and (7), the insulators passing through 32 mm diameter holes in the skirt.

NOTE Details of the method of fixing are shown in Figure 3.

The precipitator shall be positioned for smoke collection as shown in Figure 4.

A 610 mm × 610 mm mild steel sealing plate shall be attached to the top of the square section test chimney to form the base of a safety cage. In the centre of this plate a hole shall be cut, 330 mm in diameter. A locating ring of internal diameter 370 mm shall be made up from 25 mm × 3 mm mild steel strip, located centrally on the base plate and fastened by a suitable means such as tack welding. When in position for smoke collection, the precipitator shall stand inside the locating ring.

A collecting hood shall be positioned above the precipitator and connected by ducting to a fan discharging to outside air. A damper shall be provided in the extraction ducting to enable the suction exerted by the fan to be varied.

3.2.2 *Extra-high tension (EHT) power unit*, capable of providing a continuously variable output voltage of 0 kV to 12 kV at 50 mA continuous rating. The output shall be d.c. negative to earth, with a ripple content of not more than 1 %. Meters shall be provided for reading the output voltage and the current on a meter scale of approximately 125 mm. The meters shall be at the final stage of the output of the circuit in order that internal tracking current, which increases with the usage of the equipment, is not measured. An overload protection device shall be incorporated to safeguard the components of the unit against short-circuiting at the output terminals. This device shall be so designed as to switch off the mains power supply to the unit and to provide an audible warning signal; an interlock shall be provided to ensure that the overload protection device cannot be reset until the voltage control has been returned to zero.

The leads from the power unit shall be connected to the electrostatic precipitator by means of suitably sized crocodile clips, the negative conductor being attached to the top supporting frame [see **3.2.1** c)] and the positive conductor, which is at earth potential, to the top plate [see **3.2.1** a)].

WARNING. It is essential that adequate precautions be taken to prevent personnel who are operating the equipment from coming into contact with the high voltage. Suitable equipment consists of an earthed metal cage with a gate, surrounding the precipitator when in position for smoke collection. With this method a safety lock should be attached to the gate in the cage, with an interlocking arrangement to the EHT unit which ensures that the unit can be turned on only when the gate is closed.

A reliable independent earth should be provided for the collecting hood in the flue gas extraction system (see **3.2.1**) and for the safety cage described above. The EHT unit itself should be built into a totally enclosed cabinet which is also earthed.

3.2.3 *Means for discharging the precipitator*

NOTE This should preferably be an automatic shorting device, e.g. linked to the mechanism for opening the gate on the safety cage. Alternatively the precipitator may be discharged manually, a suitable design of earthing tool being shown in Figure 5.

3.2.4 *Electrically heated, thermostatically controlled oven*, for drying the precipitator and evaporating any residual solvent after cleaning (see **3.3.1**). The oven shall be fitted with a control dial that indicates the set oven temperature within a range of at least 20 °C to 120 °C, with an accuracy of ± 2 K.

NOTE 1 Essential safety precautions for the design and use of the oven are given in **3.4.1**.

NOTE 2 The most suitable size of oven depends on the number of test chimneys and the frequency of testing. It is recommended that the oven should be able to hold two precipitators per test chimney.

3.2.5 *Temperature-controlled room (hot room)*, for conditioning the electrostatic precipitator before use (see **3.3.2**). The room shall be heated by tubular electric convector heaters and shall be thermostatically controlled at an average temperature between 32 °C and 35 °C with a fluctuation of less than ± 3 K about the mean temperature.

The room shall have enough floor space for the balance specified in **3.2.6** and sufficient storage space for all the precipitators in regular use in the test laboratory.

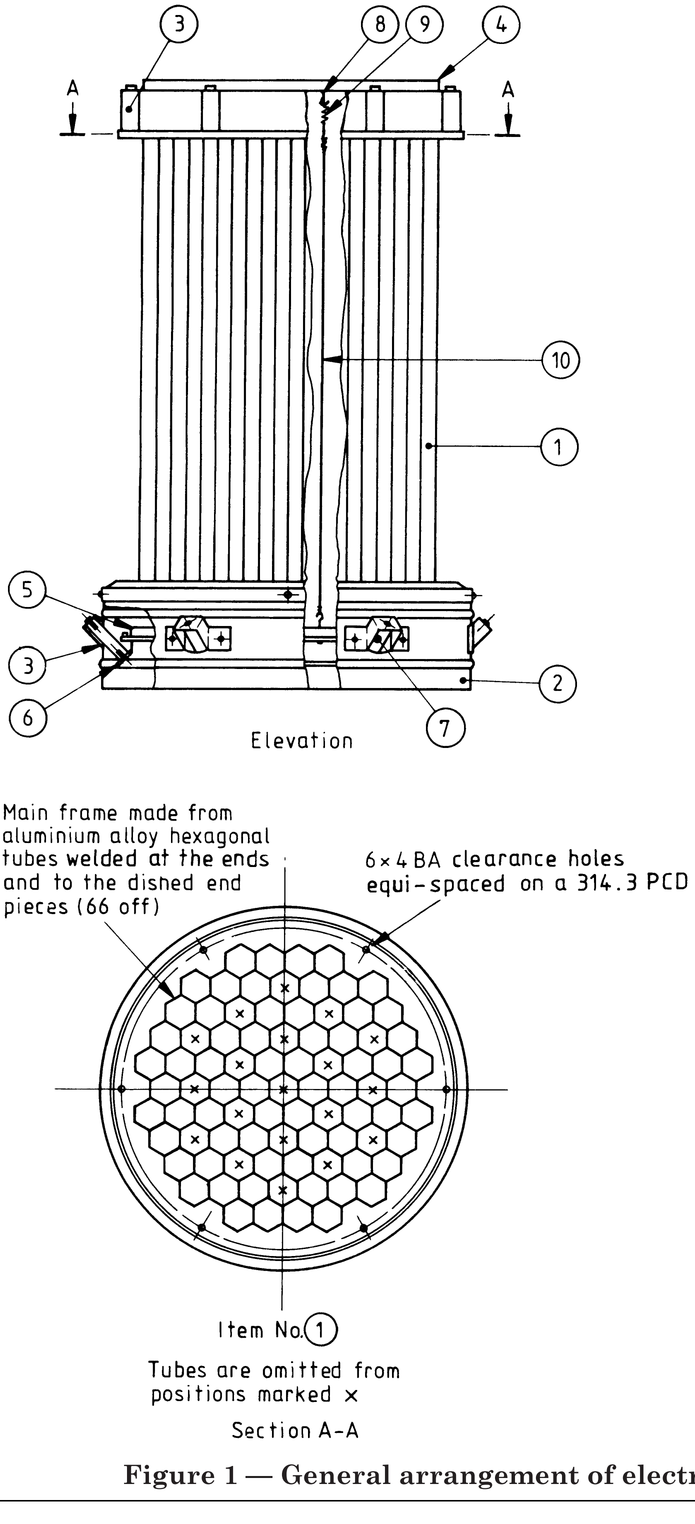
3.2.6 *Balance*, for weighing the precipitator, having a capacity of approximately 10 kg with an accuracy of ± 0.05 g. The balance shall be sited inside the hot room (**3.2.5**), in a position which is free from vibration and draughts.

3.2.7 *Pressure gauge*, capable of measuring a pressure differential with respect to atmosphere in the range 0 kPa to 0.01 kPa with a minimum accuracy of ± 0.00025 kPa.

The gauge shall be connected to a static pressure tapping point in the flue just below the precipitator (see Figure 4).

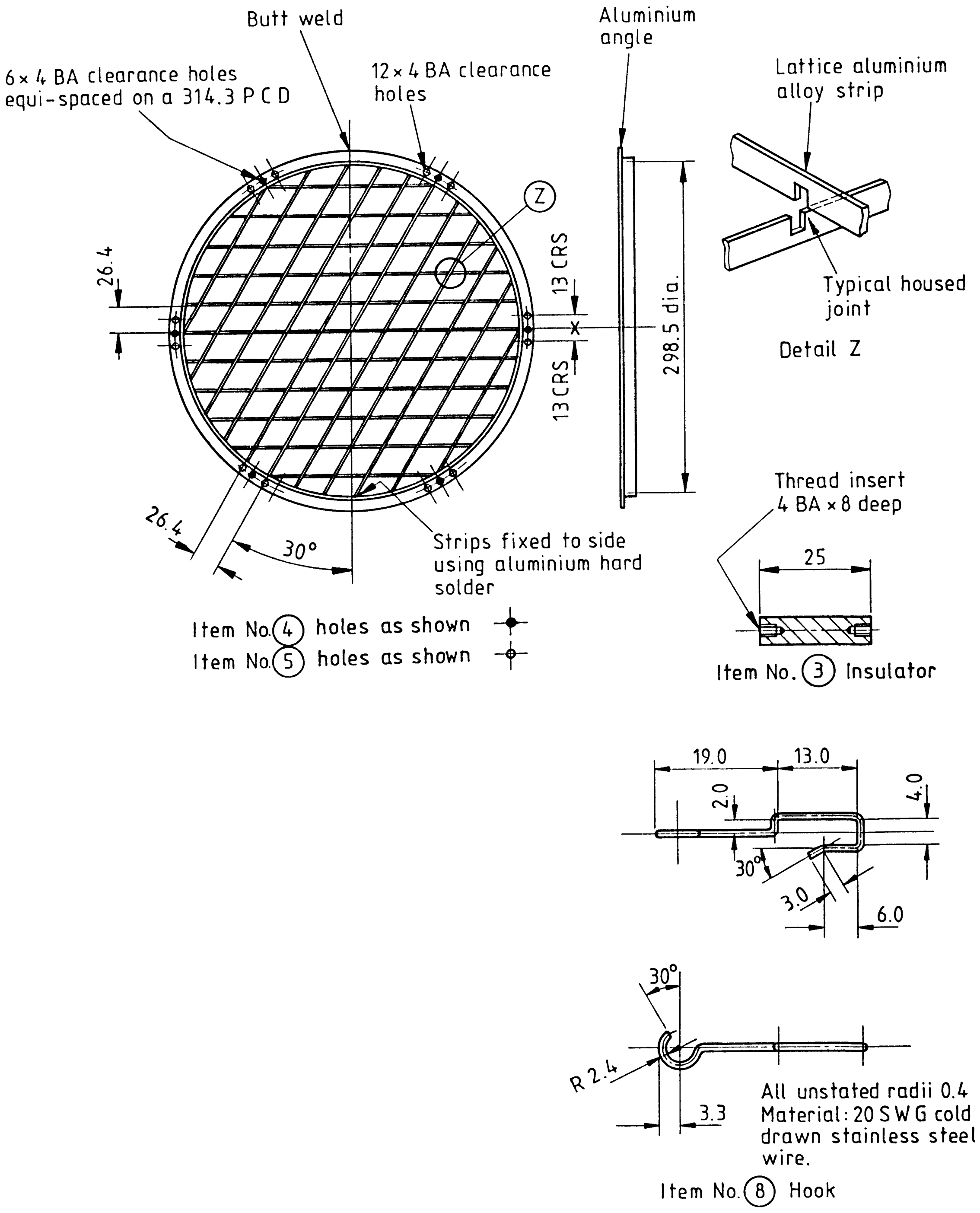
3.2.8 *High pressure water lance*, for cleaning the precipitator.

NOTE A suitable design operates at approximately 7 000 kPa with a jet angle of 30° and has facilities for injecting detergent into the stream, the precipitator being washed on a sloping surface draining to waste.



Key:
1 Collecting electrodes
2 Skirt
3 Insulators
4 Upper end frame (see Figure 2)
5 Lower end frame (see Figure 2)
6 Inner mounting bracket
7 Outer mounting bracket
8 Suspension hook
9 Tension spring
10 Charged electrodes (spring-loaded stainless steel wire)

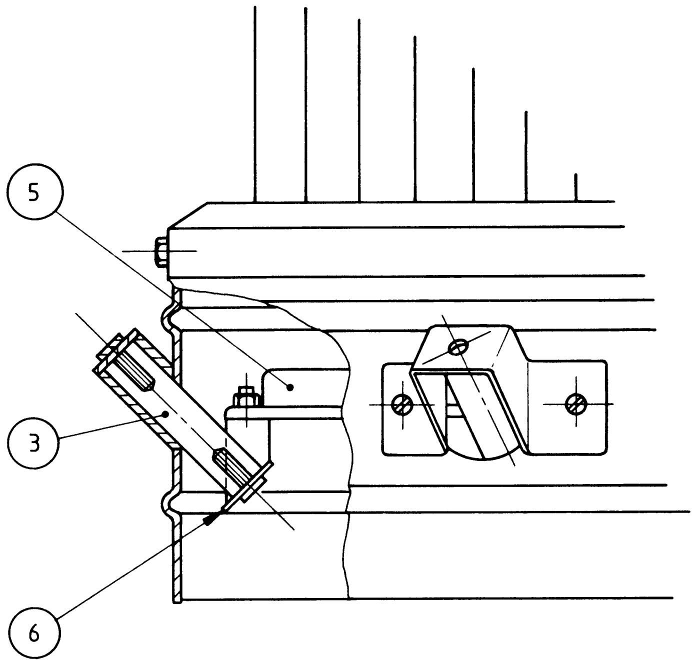
Figure 1 — General arrangement of electrostatic precipitator



NOTE 1 Lattice arrangement ensures that when frames are in position, the junctions are in line with the centres of the precipitator tubes.

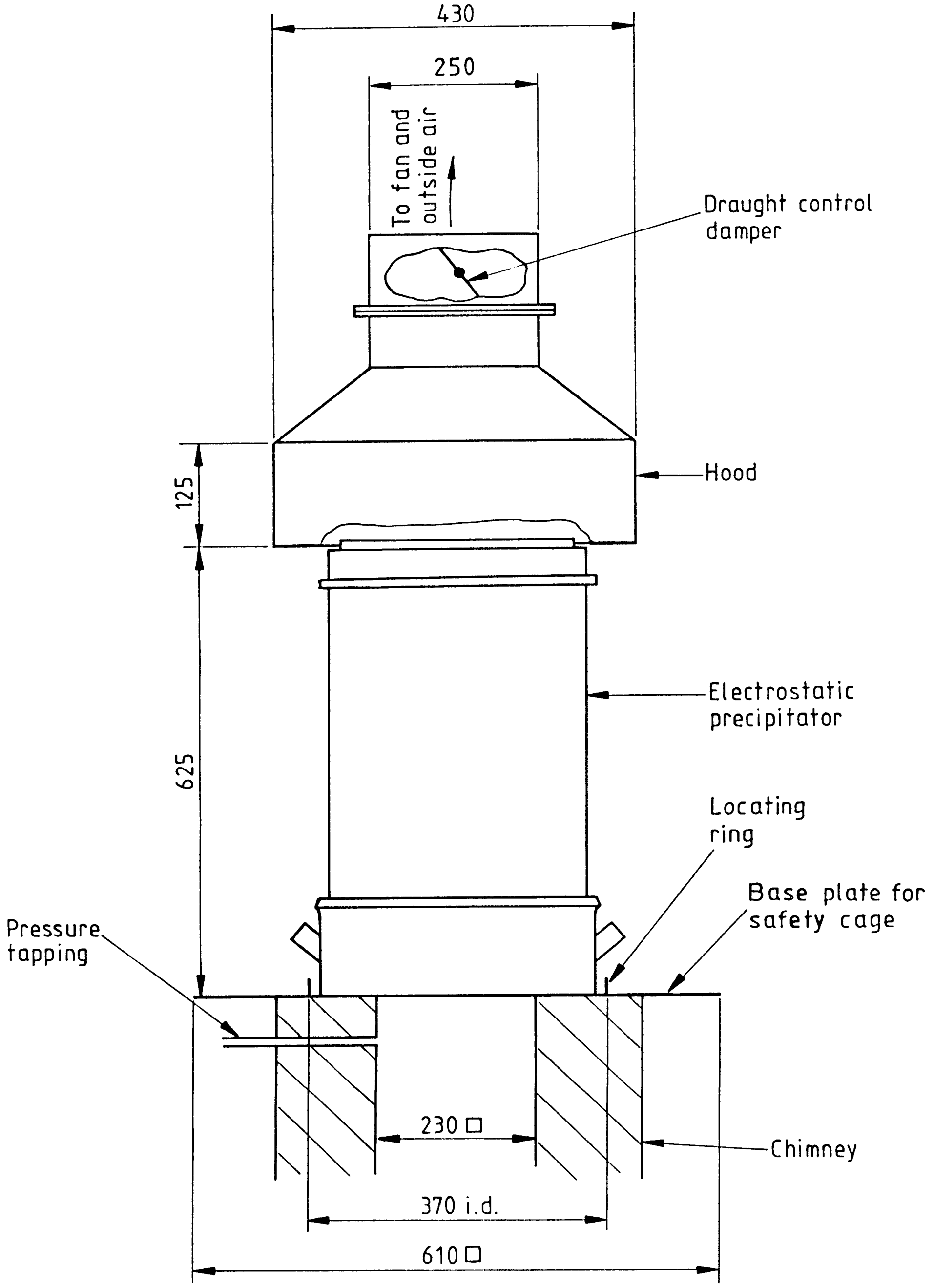
NOTE 2 See Figure 1 for key.

Figure 2 — Supporting frame of electrostatic precipitator



NOTE See Figure 1 for key.

Figure 3 — Section through skirt of electrostatic precipitator (at bracket position)



All dimensions are in millimetres.

Figure 4 — Electrostatic precipitator positioned for smoke collection

Key:

1 Handle } High voltage
2 Shields } insulating material
3 Copper earthing probe
4 Sheathed cable
5 Nipple connecting cable to probe
6 Eyelet connector to earth

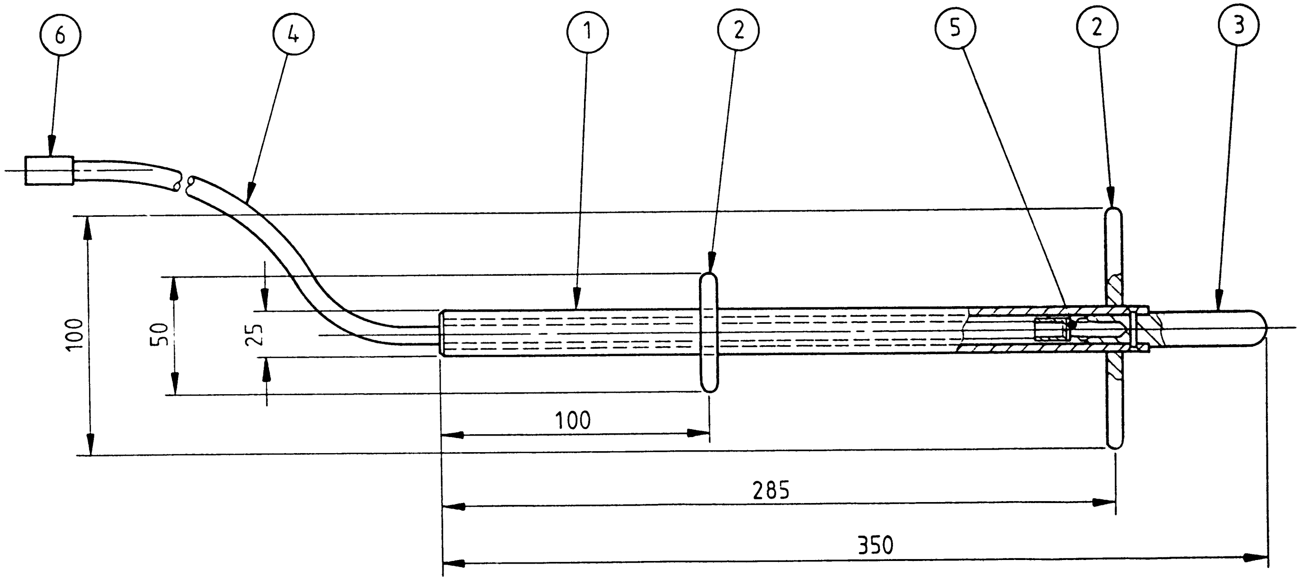


Figure 5 — Earthing tool for electrostatic precipitator

3.3 Preparation of precipitator

3.3.1 *Cleaning the precipitator*

Before each determination, clean the precipitator of all deposited smoke in the following manner.

a) Remove loose particulate matter by means of the high pressure water lance (**3.2.8**).

b) Remove tarry material by placing the precipitator in a bath containing dichloromethane with a water seal, sufficient in depth for the precipitator to be totally immersed in the dichloromethane. Leave the precipitator in the bath for 1 h to 2 h, depending on the deposit, then place it for about 10 min on a tray draining back into the bath. Rinse the precipitator with the high pressure water lance.

NOTE Commercial degreasing fluids based on dichloromethane with a water seal are available and contain various additives that make them more effective than dichloromethane/water alone.

c) Dry the precipitator and remove any residual traces of solvent or tarry material by heating the precipitator in the oven (**3.2.4**) for a minimum of 4 h at a temperature of 100 °C to 105 °C.

WARNING. The solvent dichloromethane is highly volatile and its vapour is harmful if inhaled. Great care should be exercised in its use and any safety precautions prescribed by the supplier should be adhered to. The following precautions should be taken when cleaning the precipitator.

1) A separate room, preferably in an out-building, should be set aside for cleaning the precipitators in baths of solvent.

2) The baths should be sited in a fume cupboard and should preferably be recessed into the floor for ease of access.

3) Suitable safety clothing should be provided for the personnel handling the precipitators within the room.

4) The electrically heated oven (**3.2.4**) for evaporating residual solvent should be sited in a different room from that containing the baths of solvent.

5) To prevent possible accumulation of vapours within the oven, the oven should be designed or set so that there is no re-circulation of the air flow through it.

6) A ventilation hood should be placed above the outlet from the oven, connected by ducting to a fan discharging at high level to outside air.

3.3.2 *Conditioning the precipitator*

NOTE Before each smoke emission determination, the precipitator is conditioned to minimize errors arising from differences in the amount of moisture absorbed on its surface at the beginning and end of the test.

After cleaning the precipitator in accordance with **3.3.1**, remove it from the oven and transfer it immediately to the hot room (**3.2.5**). Allow the precipitator to stand in the room for at least 2 h, after which time it is ready for use in the smoke emission determination.

3.3.3 *Adjustment of suction from flue gas extraction system*

NOTE When operating the precipitator during a smoke emission determination, the damper in the ducting of the flue gas extraction system above the precipitator (**3.2.1**) is adjusted until there is just sufficient suction to prevent flue gas leaking through the holes in the bottom skirt of the precipitator and to ensure that the combustion of the fuel is not affected by an induced draught in the chimney.

Immediately after the precipitator has been placed on the chimney and before the voltage has been applied, observe the static pressure in the flue using the pressure gauge (**3.2.7**) and adjust the damper in the extraction ducting until the pressure is between 0.0025 kPa and 0.0035 kPa below atmospheric pressure. During the course of a test the static pressure varies. Note the value at least once every hour and keep the pressure within the limits of 0.0015 kPa to 0.0045 kPa below atmospheric pressure, by adjustment of the damper as required.

3.4 Operation of precipitator during smoke emission determination

3.4.1 *Ignition period*

NOTE See **10.3.2** of BS 3841-l:1994.

After the first radiation peak, monitor the radiation heat output and estimate the approximate time in which the radiation heat output will fall to the specified value at which the first refuelling will be performed.

Approximately 10 min before the expected time of the first refuelling, weigh the precipitator on the balance (**3.2.6**) inside the hot room and record its mass. Place the precipitator in position at the top of the chimney (see **3.2.1**), connect the EHT supply (**3.2.2**) and, if a safety cage is fitted, close the gate.

Set the suction in the flue gas extraction system in accordance with **3.3.3.**

At the end of the ignition period, immediately after the fly-ash from the de-ashing operation has cleared the chimney, apply the voltage to the precipitator. Set the operating current to 35 mA.

3.4.2 *Test period*

NOTE See **10.3.3** of BS 3841-1:1994.

During the test period, maintain the operating current for the precipitator at 35 mA except for the de-ashing operation prior to the second (and, where applicable, the third) refuelling, when the current shall be reduced to 20 mA from 20 s before to 20 s after the period of de-ashing.

At hourly intervals during the test period, check and, if necessary, adjust the suction in the flue gas extraction system in accordance with **3.3.3**.

At the end of the test period switch the EHT unit off and discharge the precipitator before removing it from the chimney (see **3.2.3**).

Remove the precipitator from the chimney, taking care that none of the smoke deposit is dislodged, and transfer it immediately to the hot room. Allow the precipitator to remain there for at least 2 h. Weigh it within the room and record its mass.

NOTE If it is impossible to avoid dislodging some of the smoke deposit during the transfer, a suitable tray, previously conditioned and weighed in the same manner as the precipitator, should be used and then weighed with the precipitator.

Calculate the total mass in grams of smoke collected on the precipitator from the difference between its mass at the beginning and its mass at the end of the determination.

3.5 Calculation of results

Calculate the smoke emission rate for each determination from the following equation:

$$S = \frac{m}{t} \tag{1}$$

where

S is the smoke emission rate (in g/h);

m is the total mass of smoke emitted during the test period (see **3.4.2**) (in g);

t is the duration of the test period (in h).

4 Dilution tunnel method for smoke emission rate measurement

4.1 Principle

The flue gas from the top of the test chimney is mixed with ambient air in a dilution tunnel. A sample of the diluted flue gas is withdrawn through the sampling train in which the particulate matter is collected on a glass fibre filter maintained at 70 °C. The mass of particulate matter collected is determined. The smoke emission rate is then calculated in grams per hour using the volume of gas sampled and the volume flow rate of the tunnel gas.

4.2 Apparatus

NOTE Figure 6 shows a schematic arrangement of the apparatus sited above the top of a test chimney. The components are as described in **4.2.2** to **4.2.12**.

4.2.1 *Ordinary laboratory apparatus*

4.2.2 *Filter housing*, constructed of stainless steel and capable of retaining the filters described in **4.3.1**. The housing shall be heated to 70 °C to prevent condensation of moisture and the temperature shall be controlled to within ± 2 K with a thermocouple and thermostat. The filter shall be supported on a grid or on perforated discs to prevent distortion. Seals shall be incorporated to prevent sample gas bypassing the filter and to prevent air ingress to the filter housing.

NOTE The apparatus shown in Figure 7 has the required performance.

4.2.3 *Sampling probe*, constructed of stainless steel, 200 mm long × 9 mm internal diameter. It shall be insulated to prevent the condensation of moisture. The probe shall be provided with a series of nozzles of different inlet diameter d and of the design shown in Figure 8.

NOTE The suggested range of nozzle inlet diameters is 3.5 mm to 8.5 mm in steps of 1 mm.

4.2.4 *Dry gas meter*, capable of measuring the volume sampled to the nearest 0.001 m^3. It shall have a calibration traceable to national standards.

4.2.5 *Drying system*, comprising three 250 ml Dreschel bottles connected in series and filled with anhydrous calcium sulfate, calcium chloride or magnesium perchlorate. It shall be capable of drying the sample gas stream to less than 1.5 % (*V*/*V*) moisture prior to the dry gas meter (**4.2.4**).

NOTE The Dreschel bottles may need to be changed during the test depending on the moisture content of the flue gas.

4.2.6 *Pump*, capable of maintaining a flow rate of 0.04 m^3/min through the sampling train. The pump shall be airtight.

NOTE A diaphragm pump is preferable to avoid an excessive pressure drop across the sampling train which might cause damage to the filter.

4.2.7 *Flow control valve*

4.2.8 *Pitot static tube*, at least 300 mm long and conforming to BS 1042-2.1:1983, to be used in conjunction with the differential pressure measuring device (**4.2.10**).

4.2.9 *Temperature measuring devices*, with an accuracy of ± 2 K for measurement of the temperature of the diluted flue gas in the dilution tunnel and the dry gas meter inlet temperature.

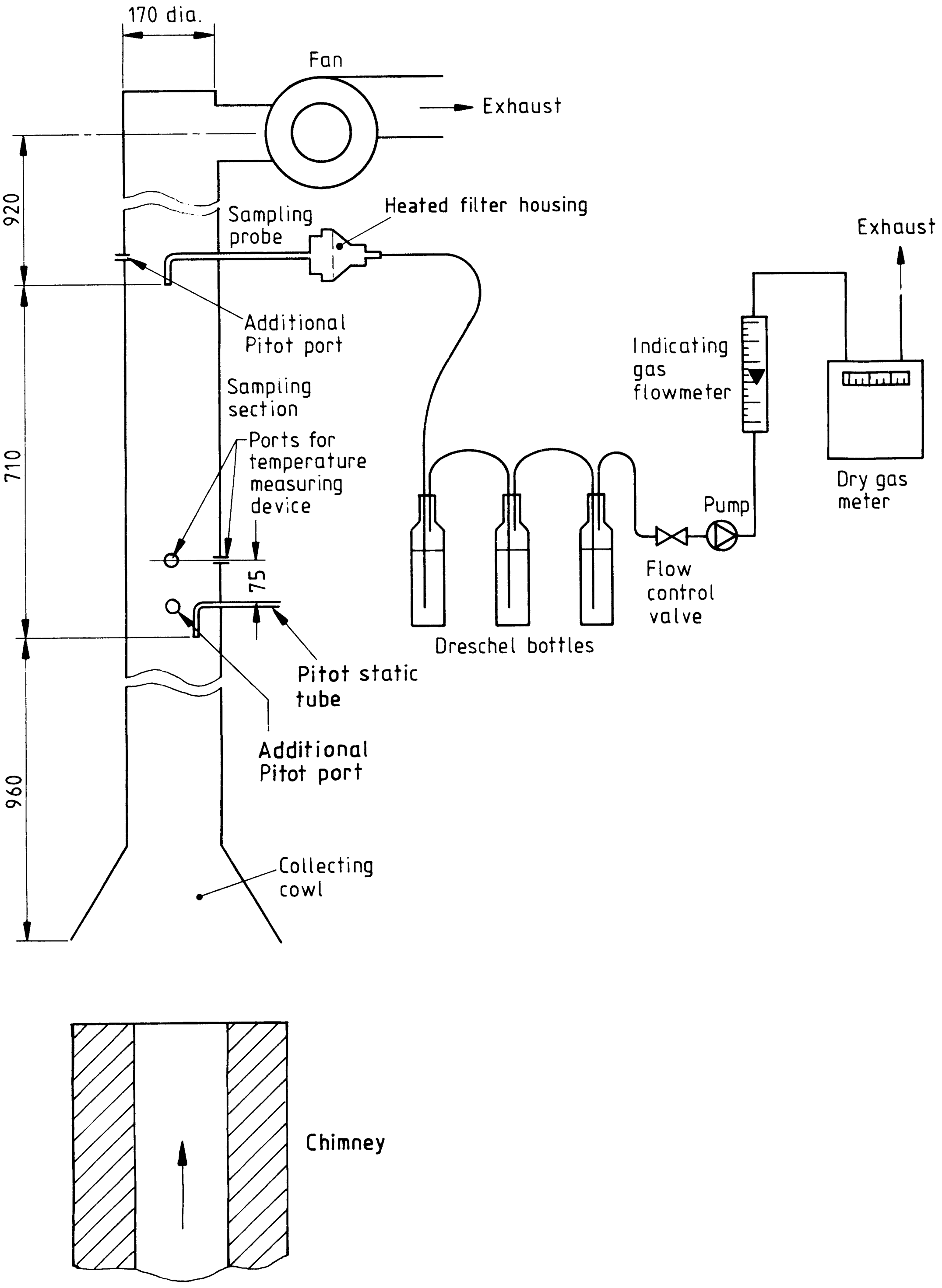
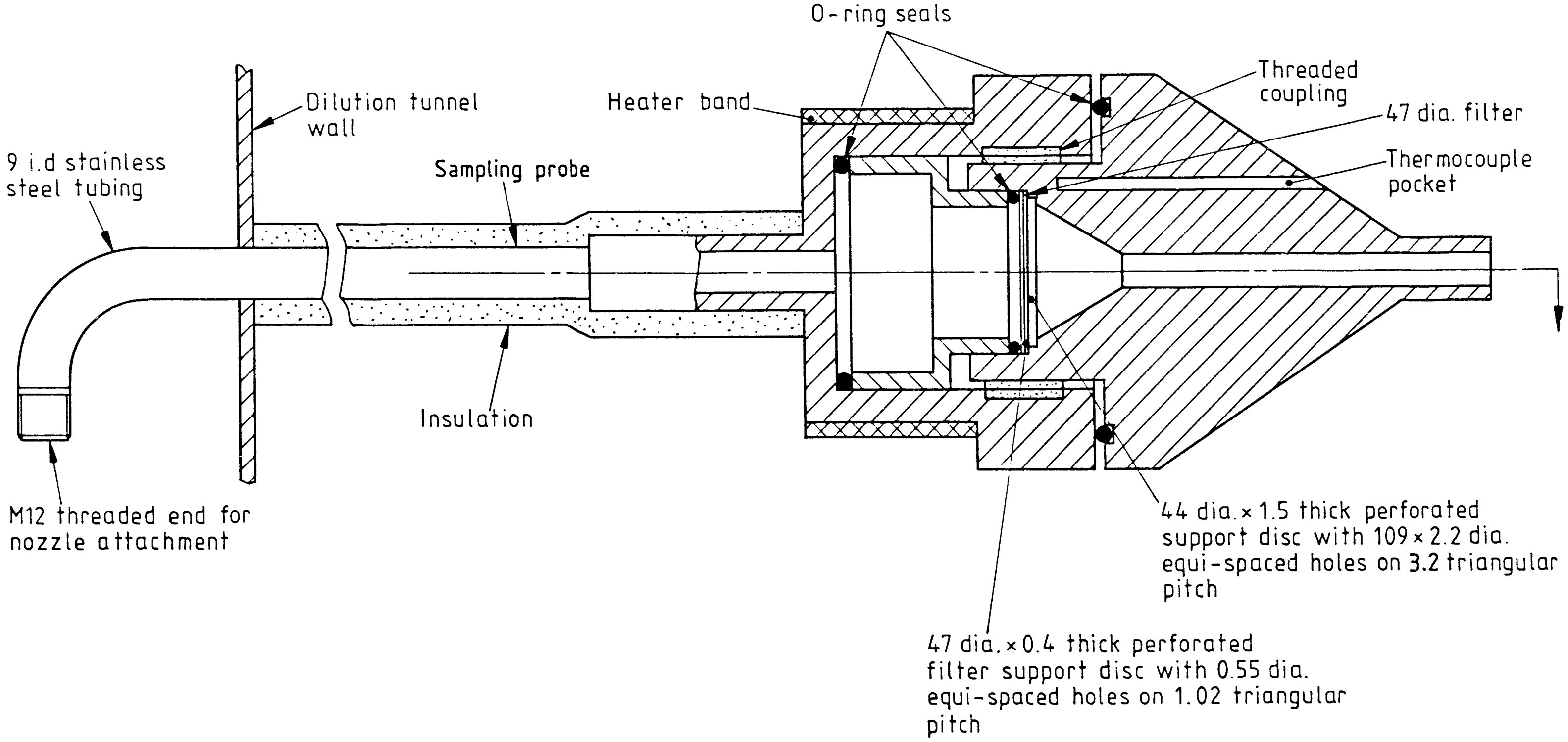


Figure 6 — General arrangement of dilution tunnel and sampling train



All dimensions are in millimetres.

NOTE The sample nozzle, probe and filter housing material is stainless steel.

Figure 7 — Suggested arrangement of dilution tunnel filter housing

4.2.10 *Differential pressure measuring device*, such as an inclined-tube manometer, capable of measuring pressure in the range 4 Pa to 300 Pa with a sensitivity of not less than ± 1 Pa, for use in conjunction with the Pitot static tube.

4.2.11 *Dilution tunnel*, as shown in Figure 6 and consisting of the following components.

a) *Collecting cowl*, designed to collect the total emission from the chimney of the standard test setting described in BS 3841-1:1994. The tapered inlet shall have a diameter of 450 mm. The cowl shall be constructed of stainless steel and shall taper to the diameter of the sampling section with an angle not greater than 45°.

b) *Sampling section*, in the form of a straight section of stainless steel ducting of 170 mm ± 2 mm diameter. Sampling ports shall be provided at the positions shown in Figure 6:

1) for insertion of the sampling probe (see **4.2.3** and **4.4.4.6**);

2) for insertion of the Pitot static tube (**4.2.8**) diametrically opposite the sampling probe port [item b 1)], to measure the velocity in the sampling probe head position, so that isokinetic sampling may be achieved (see **4.4.3**);

3) for insertion of the Pitot static tube (**4.2.8**) to determine the average volume flow during a test (see **4.4.4.3**): two ports set mutually at 90° are required, to enable a preliminary traverse to be made (see **4.4.2**);

4) for insertion of the temperature measuring device: two ports set mutually at 90°, just above those for the Pitot static tube, are required.

NOTE The Pitot static tube in position 3) is sited well below the sampling probe.

c) *Extraction fan*, capable of drawing 0.4 m^3/s of diluted flue gases through the dilution tunnel, with an adjustable damper for control of the volume flow.

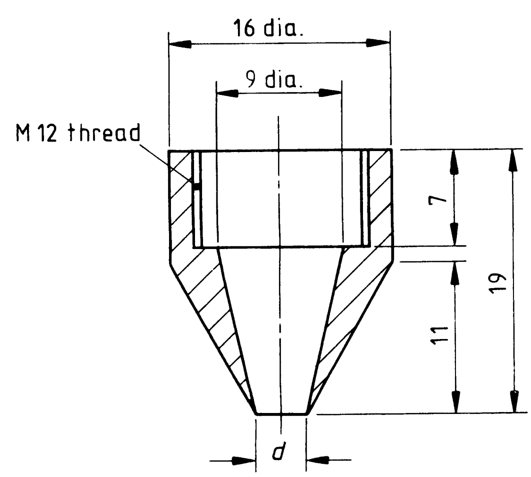


Figure 8 — Design of sample nozzle

4.2.12 *Indicating gas flowmeter*

NOTE If there are likely to be problems with pulsating flow, it is advisable to include a large, airtight bottle in the sampling train immediately before the flowmeter.

4.2.13 *Balance*, capable of weighing to the nearest 0.01 mg.

4.3 Reagents and materials

4.3.1 *Glass fibre filters*. The filter material shall be binder-free and shall have a collection efficiency of at least 99 %.

NOTE It is recommended that filters with a diameter of 47 mm and having a collection efficiency of around 99.5 % for 0.3 μm particles be used.

4.3.2 *Acetone*, general purpose reagent grade.

4.3.3 *Desiccant*. Anhydrous calcium sulfate, calcium chloride, silica gel (with indicator) or magnesium perchlorate shall be used.

4.4 Procedure

NOTE The diluted flue gas in the dilution tunnel is hereafter referred to as the tunnel gas.

4.4.1 *Preparation*

4.4.1.1 *Dilution tunnel*

Prior to each series of determinations, and prior to the adjustment of the air inlet plate described in **10.1** of BS 3841-1:1994, carry out the following procedures for commissioning of the dilution tunnel (**4.2.11**).

a) Before lighting a fire, locate the dilution tunnel cowl centrally over the chimney terminal, switch on the tunnel extraction fan and adjust the fan damper to obtain an air velocity of 8 m/s to 10 m/s in the tunnel, measured at a position 40 mm from the wall of the duct using the Pitot static tube (**4.2.8**).

b) Measure the draught induced by the tunnel on the test chimney, approximately 1 m above the top of the fireplace opening (see BS 3841-1:1994). Adjust the distance between the inlet to the tunnel and the chimney terminal so that the induced draught is less than 1.25 Pa.

c) Light a fire using the same type of fuel as for the determination and then check visually that cowl is collecting all of the smoke emitted from the chimney terminal. If it is not, reposition the collecting cowl until no smoke escapes. If the cowl is moved repeat the draught test described in item b).

4.4.1.2 *Filters*

Condition the filters (**4.3.1**) by drying them in an oven at 70 °C for 1 h and allowing them to stablize for at least 2 h in a desiccator containing the desiccant (**4.3.3**). Remove and weigh them, within 1 min, to the nearest 0.01 mg using the balance (**4.2.13**). Prepare and weigh a control filter alongside the test filters in order to correct for humidity.

4.4.2 *Preliminary velocity measurements*

If the diameter of the sampling section is not known accurately, measure the diameter across the plane containing each of the sampling ports [see **4.2.11** b) 3)], and calculate the diameter using the average of the two measurements.

During the ignition period of each determination (see BS 3841-1), operate the dilution tunnel. Insert the Pitot static tube (**4.2.8**) through one of the lower sampling ports to the centre of the tunnel and measure temperature and pressure, when the velocity is constant. Then carry out a nine-point traverse as shown in Figure 9, measuring the tunnel gas temperature and the Pitot static tube differential pressure at each of the points. Insert the Pitot static tube through the other sampling port and carry out a further nine-point traverse, making the same measurements. Also measure the atmospheric pressure and the static pressure of the tunnel gas.

For each point, record the readings and calculate the velocity using the following equation:

$$v_t = 39.48\sqrt{\left\{h\left(\frac{101.3}{p - p_t}\right)\left(\frac{273 + T_t}{273}\right)\right\}} \quad (2)$$

where

v_t is the velocity of the tunnel gas at the measurement point (in m/s);

h is the Pitot static tube differential pressure (in kPa);

T_t is the tunnel gas temperature at the measurement point (in °C);

p is the atmospheric pressure (in kPa);

p_t is the static pressure of the tunnel gas below atmospheric (in kPa).

NOTE If p_t is less than 0.5 kPa then its value can be neglected in equation (2).

Calculate the mean value of the velocity over the eighteen points.

If the mean velocity of the tunnel gas is outside the range 8 m/s to 10 m/s adjust the extraction fan damper to give this velocity and repeat the checks described in **4.4.1.1** b) and **4.4.1.1** c).

Identify the point where the measured velocity is equal to the mean velocity in the sampling section, using interpolation if necessary, and locate the head of the Pitot static tube in this position. Locate the temperature measuring device in the corresponding position just above it for the remainder of the determination.

4.4.3 *Velocity measurements for isokinetic sampling*

4.4.3.1 Measure the Pitot static pressure at the sampling point in the dilution tunnel specified in **4.2.11** b) 2), using the Pitot static tube (**4.2.8**) and pressure measurement device (**4.2.10**). Then remove the Pitot static tube ready for insertion of the sampling probe.

4.4.3.2 Measure the tunnel gas temperature T_t using the temperature measuring device (**4.2.9**).

4.4.3.3 Calculate the tunnel gas velocity using equation (2) and determine the sampling rate necessary to achieve isokinetic sampling by the method described in **4.4.4.4**.

4.4.4 *Sampling*

4.4.4.1 Weigh the Dreschel absorption bottles then assemble the sampling train in a clean area to ensure that it does not become contaminated.

NOTE The sampling train comprises the sampling probe (**4.2.3**), the filter housing (**4.2.2**), the drying system (**4.2.5**), the flow control valve (**4.2.7**), the pump (**4.2.6**), the indicating gas flowmeter (**4.2.12**) and the dry gas meter (**4.2.4**).

Select an identified and labelled filter and make sure that it is not damaged. Using filter paper tweezers insert the filter in the filter housing making sure that it is properly centred on the support grid or perforated discs and in relation to the sealing ring. Check that the filter has not been damaged during the insertion procedure before reassembling the filter housing.

4.4.4.2 Check that all connections are secure and that the system is leak-free.

4.4.4.3 Determine the velocity within the sampling section of the dilution tunnel at the position of mean velocity determined as in **4.4.2**.

NOTE The relationship between the mean velocity and the velocity at the central sampling position will be known from the measurements made in accordance with **4.4.2** and **4.4.3**. A Pitot static tube permanently mounted at the position of mean velocity may then be used to monitor the flow in the sampling section and can therefore be used to adjust to isokinetic conditions during the test if necessary.

4.4.4.4 Fit the sample probe with a nozzle of the type shown in Figure 8, having an inlet diameter d of 6.5 mm. Calculate the sample volume flow rate for isokinetic sampling from the following equation:

$$Q_\mathrm{s} = \frac{\pi d^2}{4} v_\mathrm{p} \left(\frac{273 + T_\mathrm{m}}{273 + T_\mathrm{t}}\right) \times \left(\frac{p - p_\mathrm{t}}{p + p_\mathrm{m}}\right)\left(1 - \frac{M}{100}\right) \tag{3}$$

where:

Q_s is the sample volume flow rate for isokinetic sampling (in $\mathrm{m^3/s}$);

d is the nozzle inlet diameter (in m);

v_p is the gas velocity at the sampling point as determined from Pitot static tube readings (see **4.4.3**) (in m/s);

T_m is the temperature of the gas at the inlet to the gas meter (in °C);

T_t is the temperature of the tunnel gas (in °C);

p_m is the static pressure of the gas above atmospheric at the inlet to the gas meter (in kPa);

p_t is the static pressure of the tunnel gas below atmospheric (in kPa);

p is atmospheric pressure (in kPa);

M is the moisture content of the tunnel gas, expressed as % (V/V) [see equation (6)].

NOTE 1 If either p_m or p_t is less than 0.5 kPa then its value can be neglected in the above equation.

Adjust the flow rate through the sampling train to this value.

NOTE 2 It is not sufficient to obtain the sample volume flow rate from flowmeter readings. It should be determined by noting the time taken for 40 l of gas to pass through the dry gas meter as indicated by the display, and corrected for its calibration factor. The flowmeter may then be used to maintain the flow rate constant at the required level.

After each preliminary test for adjustment of the air inlet plate, carry out a preliminary firing test in accordance with BS 3841-1:1994. If the smoke emission is such that more than four filter changes are required during the course of the test, select a smaller diameter nozzle and recalculate the sample volume flow rate for isokinetic sampling.

4.4.4.5 Mount the assembled sampling train close to the sampling position, switch on the heating system and allow to warm up to a temperature of 70 °C ± 2 K.

4.4.4.6 Immediately prior to the start of the test, insert the sampling probe into the sampling port until the nozzle is at the centre of the duct, taking care that the nozzle does not touch the side.

NOTE Damage to the nozzle introduces inaccuracies because of divergence from isokinetic sampling conditions.

Do not allow the nozzle to be contaminated with dust from the side of the sampling port.

4.4.4.7 At the start of the test note the reading of the dry gas meter (**4.2.4**) to the nearest 0.001 $\mathrm{m^3}$ and the time to the nearest minute.

4.4.4.8 Switch on the sampling pump and adjust the flow rate to the isokinetic condition calculated in **4.4.4.4**.

4.4.4.9 During the test period record the tunnel gas temperature, Pitot static pressure and sample volume flow rate readings at regular intervals of 15 min or less. Maintain the sample volume flow rate constant, unless the Pitot static pressure changes by more than ± 5 % of its original value, in which case recalculate the sample volume flow rate required for isokinetic sampling. Record the atmospheric pressure, static pressure in the dilution tunnel and dry gas meter inlet temperature and pressure at regular intervals of 30 min or less.

4.4.4.10 When it is no longer possible to maintain the sample volume flow rate for isokinetic sampling change the filter. In any case change the filter just prior to refuelling in the firing cycle.

4.4.4.11 To change the filter switch off the sampling pump, note the dry gas meter reading to the nearest 0.001 $\mathrm{m^3}$ and the time to the nearest minute, part the filter housing, carefully remove the exposed filter with tweezers and transfer it to a clean, dry Petri dish and insert a new filter into the holder. Re-assemble the filter assembly and repeat the procedure described in **4.4.4.7** and **4.4.4.8**. Confirm that the sampling train is leak-free. Complete the filter changing operation in less than 5 min.

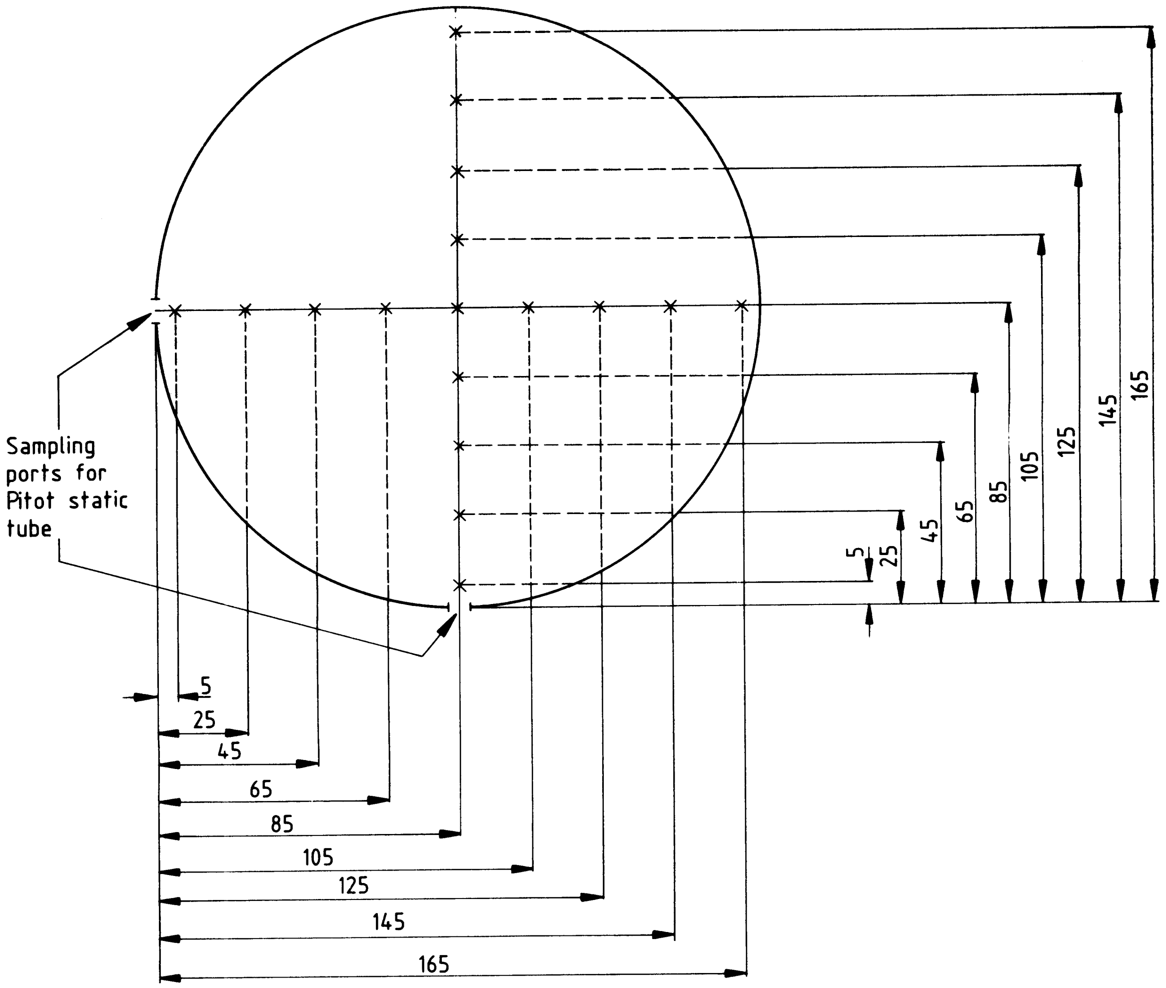


Figure 9 — Section through dilution tunnel showing measurement positions for nine-point traverses

Alternatively, a second filter assembly may be used to make the filter changing step easier. In this case, switch off the sampling pump, note the dry gas meter reading to the nearest 0.001 m^3 and the time to the nearest minute, remove the filter assembly from the end of the probe and replace it with a second filter assembly which has been prepared previously and preheated. Repeat the procedure described in **4.4.4.7** and **4.4.4.8**.

NOTE It may be necessary to change the filter up to four times during the course of a single determination (see **4.4.4.4**).

4.4.4.12 At the end of the determination switch off the sampling pump, note the dry gas meter reading to the nearest 0.001 m^3 and the time to the nearest minute. Check that the equipment is still leak-free; if it is not, the determination is invalid and shall be repeated. Remove and weigh the Dreschel bottles. Carefully dismantle the filter holder, remove the filter as described in **4.4.4.11** and place it in an identified, clean, dry Petri dish.

4.4.5 *Probe cleaning*

4.4.5.1 When the sampling probe is cool, wipe the external surfaces of the probe and nozzle to make sure that particulate material cannot contaminate the sample during the subsequent probe cleaning procedure. Rinse the inside of the probe and nozzle with acetone from a wash bottle, brush the inside of the probe with a clean nylon bristle brush then rinse the inside of the probe and the nylon bristle brush with acetone. Rinse the inlet part of the filter holder with acetone. Collect all acetone washings into an identified, clean, dry screw-top container.

4.4.5.2 Make sure that all visible internal surfaces of the probe, the nozzle and the filter holder inlet are free from particulate material. If they are not, repeat the acetone rinse sequence. Transfer any subsequent washings to the container containing the first set of washings.

4.4.6 *Determination of sample masses*

4.4.6.1 *General*

Determine the sample masses using the same balance (**4.2.13**) as was used to determine the initial masses of the filters.

4.4.6.2 *Filters*

4.4.6.2.1 Transport the filters, including the control, from the test area to the balance room in the covered Petri dish.

4.4.6.2.2 Dry the filters at 70 °C for 1 h, allow them to stabilize for at least 2 h in a desiccator containing the desiccant (**4.3.3**) and weigh them to the nearest 0.01 mg within 1 min of removal from the desiccator.

4.4.6.2.3 Record the mass of the deposit on each filter and the change in mass of the control filter.

4.4.6.3 *Acetone washings*

4.4.6.3.1 Dry a clean 100 ml glass beaker at 70 °C for 1 h, allow it to stabilize for at least 2 h in a desiccator containing the desiccant (**4.3.3**) and weigh it, using the balance (**4.2.13**), to the nearest 0.01 mg, within 1 min of removal from the desiccator.

4.4.6.3.2 Transfer the contents of the screw-top container (see **4.4.5**) to the 100 ml beaker, using the acetone (**4.3.2**) from a wash bottle to rinse out the container. Note the final volume of liquid in the beaker. Evaporate to dryness, taking care not to boil.

4.4.6.3.3 When the acetone has evaporated to dryness, cool the beaker in the desiccator and weigh it as described in **4.4.6.3.1**.

4.4.6.3.4 Evaporate to dryness the same volume of clean acetone as in **4.4.6.3.2** and repeat the procedure described in **4.4.6.3.3** to determine the mass of the acetone blank.

4.5 Calculations

4.5.1 *Volume of gas sampled*

4.5.1.1 *Dry gas sample*

Calculate the volume of dry gas sample, expressed at standard temperature and pressure, from the following equation.

$$V_\mathrm{d} = V_\mathrm{m} F \left(\frac{273}{273 + T_\mathrm{m}}\right) \left(\frac{\bar{p} + \bar{p}_\mathrm{m}}{101.3}\right) \tag{4}$$

where

V_d	is the volume of dry gas sample, expressed at 0 °C and 101.3 kPa (in m^3);
V_m	is the volume of dry gas sample, as indicated by the dry gas meter (in m^3);
F	is the calibration factor of the dry gas meter (dimensionless);
$\bar{p}$	is the mean atmospheric pressure over the test period (see **4.4.4.9**) (in kPa);
$\bar{p}_\mathrm{m}$	is the mean static pressure above atmospheric recorded at the inlet to the dry gas meter over the test period (see **4.4.4.9**) (in kPa);
$\bar{T}_\mathrm{m}$	is the mean sample gas temperature recorded over the test period at the dry gas meter (see **4.4.4.9**) (in °C).

NOTE If $\bar{p}_\mathrm{m}$ is less than 0.5 kPa then its value may be neglected in equation (4).

4.5.1.2 *Wet gas sample*

Calculate the volume of moisture in the gas sample from the following equation:

$$V_\mathrm{M} = \frac{22.4m}{1800} \tag{5}$$

where

V_M	is the volume of moisture in the gas sample, expressed at 0 °C and 101.3 kPa (in m^3);
m	is the increase in mass of the absorption bottles (in g).

Calculate the moisture content of the wet gas sample M, expressed as a percentage by volume, from the following equation:

$$M = \frac{100V_\mathrm{M}}{V_\mathrm{M} + V_\mathrm{d}} \tag{6}$$

Calculate the volume of wet gas sampled, at the temperature and pressure of the diluted flue gas in the tunnel, from the following equation:

$$V_\mathrm{t} = V_\mathrm{d} \left(\frac{273 + \bar{T}_\mathrm{t}}{273}\right) \left(\frac{101.3}{\bar{p} - \bar{p}_\mathrm{t}}\right) \left(\frac{100}{100 - M}\right) \tag{7}$$

where

V_t	is the volume of wet gas sampled, at $\bar{T}_\mathrm{t}$ °C and $(\bar{p} - \bar{p}_\mathrm{t})$ kPa (in m^3);
V_d	is the volume of dry gas sample, expressed at 0 °C and 101.3 kPa (in m^3);
$\bar{T}_\mathrm{t}$	is the mean temperature of the tunnel gas over the test period (see **4.4.4.9**) (in °C);

$\bar{p}$ is the mean atmospheric pressure over the test period (see **4.4.4.9**) (in kPa);

$\bar{p}_t$ is the mean static pressure below atmospheric of the tunnel gases over the test period (see **4.4.4.9**) (in kPa);

M is the moisture content of the flue gases, as determined from equation (6) [expressed as % (V/V)].

NOTE If $\bar{p}_t$ is less than 0.5 kPa then its value may be neglected in equation (7).

4.5.2 *Volume flow rate of tunnel gases*

Calculate the mean velocity of the tunnel gas over the test period from the Pitot tube measurements using the following equation:

$$\bar{v}_t = 39.48x\sqrt{\left\{\left(\frac{101.3}{\bar{p} - \bar{p}_t}\right)\left(\frac{273 - \bar{T}_t}{273}\right)\right\}} \qquad (8)$$

where

$\bar{v}_t$ is the mean velocity over the test period of the tunnel gas at temperature $\bar{T}_t$ °C (in m/s);

x is the mean value of the square roots of the Pitot static tube differential pressures over the test period (see **4.4.4.9**) (in $\text{kPa}^{0.5}$);

$\bar{T}_t$ is the mean temperature of the tunnel gas over the test period (see **4.4.4.9**) (in °C);

$\bar{p}$ is the mean atmospheric pressure over the test period (see **4.4.4.9**) (in kPa);

$\bar{p}_t$ is the mean static pressure below atmospheric of the tunnel gas over the test period (see **4.4.4.9**) (in kPa).

NOTE If $\bar{p}_t$ is less than 0.5 kPa then its value may be neglected in equation (8).

Calculate the mean volume flow rate of tunnel gas during the test, expressed at the tunnel gas conditions of temperature, pressure and moisture content, from the following equation:

$$\bar{Q}_t = \bar{v}_t A_t \qquad (9)$$

where

$\bar{Q}_t$ is the mean volume flow rate of the tunnel gas over the test period (in m^3/s);

A_t is the cross-sectional area of the duct in the plane of the Pitot static measurement (in m^2);

$\bar{v}_t$ is the mean velocity of the tunnel gas over the test period, as calculated in equation (8) (in m/s).

4.5.3 *Total particulate mass*

Calculate the total particulate mass from the following equation:

$$m_s = m_1 + m_2 \qquad (10)$$

where

m_s is the total mass of particulate material (in mg);

m_1 is the mass of particulate material collected on the filters, making due allowance for the change in mass of the control filter (see **4.4.6.2.3**) (in mg);

m_2 is the mass of particulate material in the acetone washings, making due allowance for the change in mass of the acetone blank (see **4.4.6.3.4**) (in mg).

4.5.4 *Particulate concentration*

Calculate the average particulate concentration during the test, under the actual temperature and pressure conditions of the dilution tunnel gases, from the following equation:

$$C_t = m_s/V_t \qquad (11)$$

where

C_t is the particulate concentration in the dilution tunnel (in mg/m^3);

m_s is the total mass of particulate material determined from equation (10) (in mg);

V_t is the volume of wet gas sample determined from equation (7) (in m^3).

NOTE C_t is the particulate concentration in the dilution tunnel: it is not the concentration of the undiluted gases in the chimney (see Annex B).

4.5.5 *Smoke emission rate*

Calculate the smoke emission rate from the following equation:

$$S = 3.6C_t\bar{Q}_t \qquad (12)$$

where

S is the smoke emission rate (in g/h);

C_t is the particulate concentration in the dilution tunnel determined from equation (11) (in mg/m^3);

$\bar{Q}_t$ is the mean volume flow rate of the tunnel gas determined from equation (9) (in m^3/s).

Annex A (informative) Comparison of results obtained by the dilution tunnel and electrostatic precipitator methods

Work has been carried out to compare the dilution tunnel method with the electrostatic precipitator method. The results of this work on two manufactured fuels for open fire use are given in Table A.1 and Table A.2.

Results for the two methods were obtained during separate tests, but the mean second peak radiant output levels were in very close agreement as shown.

The mean results and standard deviation show very good agreement between the two methods.

Table A.1 — Comparison of results obtained with fuel A

Electrostatic precipitator method			Dilution tunnel method		
Determination number	**Smoke emission rate** g/h	**Second radiation peak** kW	**Determination number**	**Smoke emission rate** g/h	**Second radiation peak** kW
1	4.72	2.18	6	4.98	2.07
2	4.54	2.02	7	4.92	2.04
3	4.65	2.02	8	4.13	1.97
4	4.22	1.93	9	3.94	2.16
5	4.02	2.02	10	4.26	1.90
	Mean = 4.43 Standard deviation = 0.299	Mean = 2.03 Standard deviation = 0.090		Mean = 4.45 Standard deviation = 0.474	Mean = 2.03 Standard deviation = 0.099

Table A.2 — Comparison of results obtained with fuel B

Electrostatic precipitator method			Dilution tunnel method		
Determination number	**Smoke emission rate** g/h	**Second radiation peak** kW	**Determination number**	**Smoke emission rate** g/h	**Second radiation peak** kW
1	1.75	2.05	6	1.87	2.07
2	2.49	2.04	7	1.90	2.07
3	2.09	2.19	8	1.75	2.04
4	1.84	2.23	9	1.96	2.15
5	1.99	2.05	10	2.31	2.10
	Mean = 2.03 Standard deviation = 0.288	Mean = 2.11 Standard deviation = 0.091		Mean = 1.96 Standard deviation = 0.211	Mean = 2.09 Standard deviation = 0.042

Annex B (informative) Calculation of in-stack concentration

In the dilution tunnel method, the smoke emission rate is calculated from the particulate concentration in the dilution tunnel and the volume flow rate of the tunnel gas (see **4.5.5**). Under certain circumstances it may be necessary to determine the actual concentration of particulate material in the chimney itself. This concentration may be calculated from the concentration determined in the dilution tunnel provided that certain additional measurements are made. The additional measurements are required to measure the dilution ratio. The dilution ratio is estimated by measuring the concentration of carbon dioxide or carbon monoxide in the undiluted flue gas and in the dilution tunnel.

Calculate the particulate concentration in the tunnel gas at 0 °C and 101.3 kPa from the following equation:

$$C_s = C_t \left(\frac{273}{273 + \bar{T}_t}\right)\left(\frac{\bar{p} - \bar{p}_t}{101.3}\right) \tag{B.1}$$

where

C_s is the mean particulate concentration in the tunnel gas at 0 °C and 101.3 kPa over the test period (in mg/m^3);

C_t is the mean particulate concentration in the tunnel gas at the tunnel gas temperature and pressure over the test period, calculated from equation (11) (see **4.5.4**) (in mg/m^3);

$\bar{T}_t$ is the mean temperature of the tunnel gas over the test period (see **4.4.4.9**) (in °C);

$\bar{p}$ is the mean atmospheric pressure over the test period (see **4.4.4.9**) (in kPa);

$\bar{p}_t$ is the mean static pressure below atmospheric of the tunnel gas over the test period (see **4.4.4.9**) (in kPa).

When carbon dioxide is the measured gas, the concentration of particulate material in the undiluted flue gas is given by

$$C_u = C_s \frac{[CO_2]_u}{[CO_2]_t} \tag{B.2}$$

where

C_u is the particulate concentration in the undiluted flue gas at a temperature of 0 °C and a pressure of 101.3 kPa (in mg/m^3);

C_s is the particulate concentration in the dilution tunnel at a temperature of 0 °C and a pressure of 101.3 kPa, determined from equation (B.1) (in mg/m^3);

$[CO_2]_u$ is the carbon dioxide concentration in the undiluted flue gas [expressed as % (*V*/*V*) or in cm^3/m^3];

$[CO_2]_t$ is the carbon dioxide concentration in the dilution tunnel [expressed as % (*V*/*V*) or in cm^3/m^3].

blank

List of references

Normative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 1042, *Measurement of fluid flow in closed conduits.*
BS 1042-2, *Velocity area methods.*
BS 1042-2.1:1983, *Method using Pitot static tubes.*
BS 3841, *Determination of smoke emission from manufactured solid fuels for domestic use.*
BS 3841-1:1994, *General method for determination of smoke emission rate.*

Informative references

[1] GREAT BRITAIN. Clean Air Act 1956. London: HMSO.
[2] GREAT BRITAIN. Clean Air Act 1968. London: HMSO.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: 020 8996 7002. Fax: 020 8996 7001.

Copyright

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

If permission is granted, the terms may include royalty payments or a licensing agreement. Details and advice can be obtained from the Copyright Manager.
Tel: 020 8996 7070.

BSI
389 Chiswick High Road
London
W4 4AL