
Code of practice for

Flues and flue structures in buildings

Code de bonne pratique relatif aux cheminées et structures de cheminées dans les bâtiments

Richtlinien für Abzüge und Abgasstrukturen in Gebäuden

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Contents

	Page		Page
Foreword	1	Figures	
Cooperating organizations	Back cover	1. Air leakage through brickwork	32
Code of practice		2. Schematic diagram of design procedure	33
1. Scope	2	3. Examples of free-standing linings	35
2. References	2	4. Examples of integral linings	36
3. Definitions	2	5. Acid corrosion rate of surfaces in contact with flue gases	39
4. Symbols	3	6. The effect of temperature on the pressure distribution of gases	39
5. Design requirements and procedure	4	7. Conversion of actual flue gas velocity to velocity pressure	40
6. Forms and materials of construction	6	8. Theoretical buoyancy due to flue gas temperature	41
7. Building services design	8	9. Temperature gradient across the flue structure	41
8. Structural design of linings	11	10. Surface coefficient of heat transfer	42
9. Steel liners	14	11. Typical layouts at chimney entry	43
10. Workmanship	15	12. Suggested support for brickwork lining at intermediate levels where access cannot be achieved from below	45
Appendices		13. Suggested design of lateral locators for steel liners	46
A. Derivation of design values	20	14. Typical construction at top of chimney	46
B. Calculation of design data: worked example using liquid fuel	20	15. Relation between q/θ and c/θ for $d_t/r = 0$	48
C. Calculation of design data: worked example using gaseous fuel	24	16. Relation between q/θ and c/θ for $d_t/r = 0.25$	48
D. Theory for calculation of stresses in brittle flue lining materials (using design charts)	25	17. Relation between q/θ and c/θ for $d_t/r = 0.5$	49
E. Sample calculations for diatomaceous brick linings	26	18. Relation between q/θ and c/θ for $d_t/r = 0.75$	49
Tables		19. Relation between q/θ and c/θ for $d_t/r = 1.0$	50
1. Lining operating temperature limitations	27	20. Relation between q/θ and c/θ for $d_t/r = 1.25$	50
2. Material properties	28	21. Relation between q/θ and c/θ for $d_t/r = 1.5$	51
3. Acid resistance of mortars	29	22. Typical courses for inner ring of lining (shown in 114 mm brick)	52
4. Insulating materials	29	23. Typical courses for inner ring of lining (shown in 152 mm brick)	53
5. Properties of liquid fuels	29	24. Bonding of circular brickwork linings using 114 mm or 152 mm bricks	53
6. Average properties of typical industrial solid fuels	30	25. Bonding of circular brickwork linings using 229 mm bricks	54
7. Typical properties of gaseous fuels	30	26. Static pressure distribution in flue system as used in the example in appendix B	55
8. Reduction factor β for permissible axial stresses	31	27. Temperature gradient across the lining	56
9. Striking of formwork (minimum times)	31		

Foreword

Several premature failures of flue linings that have occurred during the last few years have emphasized the need for a more rigorous approach to the whole design process of flue linings, using more comprehensive materials data, and a much closer liaison between the structural and building services engineers.

Therefore, this code of practice presents the latest informa-

tion on available lining materials: it brings together full design data for the building services engineer; it examines the lining from a structural viewpoint when subjected to self-weight, wind and thermal loading; it demonstrates the areas of design where collaboration between the structural engineer and building services engineer is necessary; and it gives recommendations for construction.

British Standard Code of practice for

Flues and flue structures in buildings

1. Scope

This code of practice gives recommendations for the design and construction of flue linings and flue structures serving appliances (boilers and air heaters) of 45 kW output and above, burning solid, liquid or gaseous fuels.

The recommendations contained in this code may be used for the design of a flue serving an incinerator, which should be provided with its own individual flue.

Prior approval of the height of the chimney by the local authority is required by Section 6 of the Clean Air Act 1968 where the appliance(s) served by the chimney burn(s) (a) pulverized fuel or (b) 45 kg or more of solid fuel per hour or (c) liquid or gaseous fuel at a rate of 366 kW or more if:

- (1) a new chimney is erected to serve a new or existing installation; or
- (2) an installation (e.g. of boilers, incinerators) served by an existing chimney is enlarged, e.g. its combustion capacity is increased, or an additional appliance is added to the system; or
- (3) an appliance served by an existing chimney is removed and replaced by one having a larger combustion capacity.

The official publication *Chimney heights. Second edition of the 1956 Clean Air Act Memorandum*,* subsequently referred to in this code of practice as the 'Chimney Height Memorandum', gives guidance for the calculation of heights likely to be suitable in most instances for solid or liquid fuel appliances.

Useful information to facilitate calculation of possible chimney heights for gaseous fuel is contained in the *CIBS Guide, Volume B, Section B13* (1970)†.

This code applies to:

- (a) linings that are built within a space enclosed by a building;
- (b) linings that are built as an integral part of the building.

This code does not, in general, apply to linings within a freestanding or independent chimney, but many of the conditions and criteria are applicable.

The design of flue linings and flue structures in buildings is subject to increasing knowledge and experience, and should be undertaken only by those competent to evaluate the many aspects of satisfactory construction and performance. This code provides the building services engineer and the structural engineer with design criteria, suggested procedures and methods of design, recommendations for construction, and basic guidance data for the selection of lining materials.

The code also seeks to augment the skills of experienced designers who will need to interpret the information and examples with appropriate professional expertise, giving due consideration to all the relevant issues involved.

The examples and calculations in this code are given as one form of use of the data provided. They do not preclude other methods of computing satisfactory designs.

Where appropriate, detailed information has been put in appendices.

2. References

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

3. Definitions

For the purposes of this British Standard, the following definitions apply.

3.1 access. Provision for entry to flues to facilitate inspection and repair.

3.2 access door. A door, normally at the base of the flue, to provide access and/or to permit the removal of flue dust and allow cleaning of the flue.

3.3 acid dew-point. The temperature at which acid present in the flue gases condenses.

3.4 basic material property. The material property that is obtained from data from tests performed on new materials at normal temperatures in a dry condition.

3.5 chimney. The part of a structure that contains one or more flues.

3.6 corbel. A unit cantilevering from a wall surface to form a bearing.

3.7 cowl. A conical or dished cap fitted to the top of the chimney to prevent or minimize the ingress of rainwater.

3.8 dead leg. A section of flue in which the main flue gas flow does not take place; commonly, the extension of a vertical flue below the flue gas entry.

3.9 design material property. The material property to be used in design. It is the basic material property modified due to the effects of moisture content and operating temperature.

3.10 downwash. The tendency for flue gases to travel a short distance down the outside of the chimney in the negative pressure area created on its leeward side by wind. It tends to reduce the effective height of the chimney.

3.11 drain points. Locations provided for the removal of water from the duct or flue.

* Published by Her Majesty's Stationery Office (HMSO).

† Published by the Chartered Institution of Building Services.

3.12 draught stabilizer. A device designed to reduce the amount of natural draught available by diluting flue gases with cold air.

3.13 efflux velocity. The velocity of hot flue gases passing from the flue to the atmosphere.

3.14 expansion joint. A joint that allows relative movement between parts of the lining or between the lining and the surrounding structure.

3.15 explosion door. A device that allows the release of excess pressure in the flue system.

3.16 fan-diluted flues. A fan-operated system used to dilute flue gases with air, reducing the carbon dioxide content to about 1 % before final discharge, usually at low level.

3.17 flue. The shaped passageway through which flow the products of combustion.

NOTE. It is desirable to restrict the term 'flue' to its aerodynamic context, i.e. the term 'flue' should not be used if the meaning 'lining' is intended, although the term 'flue lining' is acceptable.

3.18 flue gas. Gaseous products of combustion.

3.19 freestanding lining. A lining or part of a lining that is not bonded throughout its height to the main structure.

3.20 integral lining. A lining or part of a lining that is bonded throughout its height to the adjacent structure.

3.21 inversion. The entry of cold air into the individual section of a lining discharge point.

3.22 liner. A metal or reinforced plastics tube serving as a lining.

3.23 lining. The membrane or structure incorporating the boundary of the shaped passageway for the flue gases and providing containment for those gases.

3.24 lining height. The dimension of a lining to be used for calculating the slenderness ratio.

3.25 mid-feather. A partition between adjacent flues.

3.26 negative pressure. When referred to a flue, the pressure inside the flue is less than the pressure outside the flue.

3.27 positive pressure. When referred to a flue, the pressure inside the flue is greater than the pressure outside the flue.

3.28 smuts. A general term describing agglomerated soot or ash particles discharged to the atmosphere in waste gases. Their size range is typically 1 mm to 10 mm diameter. They originate from the deposits on lining surfaces and may include acid and corrosion materials, e.g. iron sulphates, where those surfaces operate below the acid dew-point temperature of the flue gases.

3.29 turn down ratio. The relationship between the maximum fuel input and the minimum fuel input.

4. Symbols

Symbol	Definition	Units
A	Cross-sectional area of flue	m^2
A_s	Inner surface area of the flue lining through which thermal transmittance takes place	m^2
B	Appliance rating (output)	MW
C_p	Specific heat of flue gas or air at constant pressure	$\text{J}/(\text{kg K})$

Symbol	Definition	Units
C_v	Gross calorific value of fuel	MJ/kg or MJ/m^3
c	Maximum longitudinal compressive stress at inside of lining at the location considered	MPa
d	Internal diameter of circular flue	mm
d_t	Thickness of lining material	mm
E	Young's modulus of elasticity	MPa
f	Coefficient of friction (from <i>CIBS Guide, Volume B, Section B13</i> (1970))	—
f_t	Modulus of rupture of lining material	MPa
G	Volume flow rate of flue gas	m^3/s
g	Acceleration due to gravity	m/s^2
H	Chimney height	m
H_b	Draught required at boiler outlet	Pa
H_d	Theoretical draught available due to chimney effect	Pa
H_f	Total pressure loss due to friction of fluid flowing through section under consideration	Pa
H_{fr}	Static pressure change	Pa
H_{fv}	Change in velocity pressure across the section under consideration	Pa
H_v	Vertical length of the column of the flue gases	m
h	Surface coefficient of heat transfer	$\text{W}/(\text{m}^2 \text{ K})$
h_i	Surface coefficient of heat transfer to the inner surface of the flue lining	$\text{W}/(\text{m}^2 \text{ K})$
h_r	Surface coefficient of heat transfer from the outer surface of the complete flue structure to the adjacent space	$\text{W}/(\text{m}^2 \text{ K})$
K_s	Surface roughness	mm
k_1, k_2 , etc.	Thermal conductivities of lining components	$\text{W}/(\text{m K})$
k_a, k_b , etc.	Velocity pressure factors (from <i>CIBS Guide, Section B13</i> (1970) and <i>Section C4</i> (1977) in which these factors are denoted by ζ)	—
L_1, L_2	Thickness of component parts of composite lining	m
L_o	Lining length between lateral supports	m
m_r	Mass flow rate of flue gas	kg/s
n	Number of air changes per second	s^{-1}
p	Perimeter of flue	m
Q	Rate of heat transfer	W
q	Stress due to self weight and flexure (modified by slenderness in the absence of cracking)	MPa
R_a	Lining air cavity resistance	$\text{m}^2 \text{ K/W}$
R_e	Reynolds number	—
r	Internal radius of flue	mm
r_y	Radius of gyration of flue	m
S	Sulphur content of fuel	% mass/mass

Symbol	Definition	Units
T_a	Ambient temperature (absolute)	K
T_f	Flue gas temperature (absolute)	K
t_1, t_2 , etc.	Component interface temperatures	°C
t_{ai}	Air temperature at base of flue	°C
t_{ao}	Air temperature at top of flue	°C
t_f	Flue gas temperature (Celsius)	°C
t_{fi}	Flue gas temperature at flue entry	°C
t_{fo}	Flue gas temperature at flue exit	°C
t_r	Air temperature under consideration	°C
Δt	Temperature drop across flue lining	°C
U	Thermal transmittance	W/(m ² K)
V_r	Room volume. Adjacent air space volume	m ³
v	Velocity of flue gas at a point under consideration	m/s
v_p	Velocity pressure	Pa
W_m	Rate of fuel consumption	kg/s
w	Percentage load factor for stress design calculation	%
X_1	Fuel constant	—
y	Depth from inside face of lining to the root of a crack	mm
Z	Length of flue	m
z	Length of flue under consideration	m
α	Coefficient of linear expansion	K ⁻¹
β	Reduction factor for permissible axial stresses	—
γ	Stress factor derived from w	—
δ	$= d_t/r$ (see appendix D)	—
η	Appliance efficiency based on C_v	%
ϵ	$= y/r$ (see appendix D)	—
θ	$\frac{E \alpha \Delta t}{1 - \sigma}$ (see appendix D)	—
μ	Absolute viscosity of fluid	kg/(m s)
ρ	Density of fluid	kg/m ³
σ	Poisson's ratio	—
ν	$= 1 - \frac{\epsilon}{\delta}$ (see appendix D)	—

5. Design requirements and procedure

5.1 Function of chimney. The principal function of a chimney is to convey products of combustion from the appliance(s) to the atmosphere and to discharge them at such a height as to ensure dispersal over a large area, thereby reducing the ground level concentrations to an acceptable level.

5.2 Operating conditions in flue. Compliance with the Clean Air Act 1968 (see clause 1) produces certain conditions in the flue that may differ from those normally found in the older, large diameter, natural draught flues; see the following examples.

- (a) High flue gas velocities may cause the frictional pressure drop to be greater than the pressure head available due to the buoyancy of the flue gases. This

may produce positive pressure in the flue so that any waste gas leakage would be outwards, and gases may condense, causing extensive corrosion.

- (b) The heights of chimneys are now considerably greater, and there is the need to examine the lining from a structural viewpoint with regard to dead weight, wind and temperature stresses, and overall stability.

- (c) High flue gas velocities tend to cause any smuts, formed on the lining surfaces, to be entrained and discharged to the atmosphere.

5.3 Structural considerations

5.3.1 Design for replacement and repair. Careful consideration should be given, in the initial design, to the possibility of a lining having to be repaired or replaced in the future. The following are general recommendations that should be considered.

- (a) Each flue should have access facilities for inspection and cleaning.

- (b) All expansion joints should, if possible, be capable of being remade and recaulking, from outside the flue.

- (c) Linings should be independently supported at different levels to allow easy replacement of damaged sections.

5.3.2 Lining in materials other than steel. The structural behaviour of flue linings should be analysed under all forms of loading. A method of analysis is given (see appendix D) that predicts the behaviour of brittle lining materials under dead weight, flexural and thermal conditions; the effects of slenderness ratio of the lining are also incorporated.

Flue linings usually support only their self-weight, and hence, by definition, they are not structural load-bearing brickwork, but it is recommended that, where possible, the structural principles of CP 111 : Part 2 should be applied.

The method has been generalized (see appendix D) to cover conditions where tensile cracking occurs; however, a design should permit tensile cracking only under exceptional circumstances.

5.3.3 Steel liners and steel chimneys. The structural performance of steel liners is outlined in clause 9 and table 1. Steel chimneys are not included. Relevant information on these can be found in BS 4076.

5.3.4 Choice of flue lining material. The available materials of which flue linings can be made are given in clause 6 of this code. The derivation of material properties is given in appendix A and the 'basic' and 'design' values are given in table 2. Since more information is continually becoming available, the designer may wish to use such information where it augments or replaces that given in table 2.

5.4 Containment of flue gases

5.4.1 Flue gas leakage. Flue gas leakage into a flue, out of a flue, or through a mid-feather wall between flues should be avoided in order to prevent the occurrence of corrosion, as well as to ensure that flue gases do not escape into adjacent spaces. Leakage can occur in the following locations:

- (a) access doors, expansion joints, etc.;
- (b) joints between intermediate lifts, flue entry positions and at the base of a lining;
- (c) construction joints in the lining. These can, for example, be at the joints between precast insulating units of diatomaceous concrete which are placed on top

of one another; at the flanged or lap joints between two sections of a steel liner, etc.

5.4.2 Inherent leakage in brick linings. A pressure differential across a brick lining will cause ingress of air, or egress of flue gases. Figure 1 indicates values for new, well constructed brickwork. Most leakage occurs through the joints. This leakage can be considerably reduced by plastering, as can be seen from figure 1.

Air ingress across a brick lining may lower the flue gas temperature by up to 50 °C, possibly with consequent condensation problems.

Conversely, flue gas egress through the lining wall can pass significant volumes of flue gas into the cavity and may pose ventilation problems. Any condensed acid/water within the brickwork may result in deterioration and ultimate failure of the lining.

5.5 Operational life

5.5.1 General. Design of a lining should take account of potential corrosion, thermal shock, expansion, contraction and erosion. The effects of these should be minimized by careful choice of materials and forms of construction. The main cause of deterioration is usually corrosion.

5.5.2 Onset of corrosion. Corrosion in flue structures is mainly limited to those connected to plant giving off sulphur dioxide, although some corrosion and erosion may occur in an incinerator flue structure. Corrosion occurs when the temperature of the surfaces in contact with the flue gases falls below acid dew-point, usually between 100 °C and 140 °C. Resistance to acid attack depends on the material used for the flue lining. The emphasis in this code is on design for prevention of corrosion; otherwise the lining should be designed to be replaced.

Various acids will condense on the flue lining if the latter operates at a temperature below the relevant acid dew-point temperature.

The process of corrosion in steel linings is well understood, the thickness of the lining being gradually reduced due to the formation of complex ferrous and ferric oxides and salts. (For further information, see BS 4076.)

With brickwork linings, acid attack occurs primarily in the jointing material rather than in the bricks themselves. However, as the material corrodes, the expansion which occurs can cause flaking of the bricks and thus a general deterioration of the lining ensues.

Where acid condensation occurs in such quantities that the face of the lining is saturated and running with acid, the corrosion occurs more by a general 'leaching-out' process. Concretes and mortars are particularly affected in this way.

Gases will diffuse through most building materials if there is a difference of pressure across them. In the case of water vapour, if the dry bulb temperature falls below the dew-point temperature, interstitial condensation can occur*. If oxides of sulphur are also present in the flue gas, these can dissolve in the condensate and form acids.

5.5.3 Prevention of corrosion. Under normal operating conditions the temperature of the surfaces in contact with the flue gases should be maintained above the acid dew-point temperature. Omission of any of the following points may result in corrosion of the lining internally, or

corrosion of parts of the structure external to the flue, as well as producing smuts.

(a) The lining insulation should be adequate to maintain its temperature above acid dew-point temperature under all boiler operating conditions other than those during the short period after light-up.

(b) Often the summer load requirements of the boiler plant are so low that a boiler may be continually cycling on and off even on the full turn-down setting, thereby not allowing the lining to reach dew-point temperature. In such circumstances, the number of boilers and their individual outputs should be reviewed.

(c) The extent of flue gas leakage should be minimized. If leakage occurs, then under negative pressure conditions, inward leakage may lower the lining temperature below the acid dew-point temperature. Under positive pressure conditions, flue gases will pass through a permeable lining, and acid will condense where a surface temperature falls below the acid dew-point.

5.6 Outline of design procedure. To assist in the overall design, and to illustrate the relation between the work of the building services engineer and the structural engineer, the suggested design stages are set out in 5.6.1 to 5.6.3.

5.6.1 Building services engineer

5.6.1.1 Obtain the following essential information: Clean Air Act 1968 (Section 6) and also the Chimney Height Memorandum; overall dimensions of the building; boiler power required in winter and summer; type of fuel to be used for incinerators; the thermal capacity and system of operation; any effects that phased construction may have on the boiler use.

5.6.1.2 Calculate the mass flow, the velocity of flue gases, and the dimensions of the chimney.

5.6.1.3 Select the lining materials and calculate the flue gas temperatures (for acid dew-point considerations) and the temperature gradient across the lining and adjacent structure.

5.6.1.4 Calculate pressure drops in the flue system and relate this to the available draught.

These steps are illustrated in appendices B and C.

5.6.2 Structural engineer

5.6.2.1 With the selected flue lining materials, calculate the deadweight and flexural stresses and check that, under the design conditions, tensile cracking does not occur.

5.6.2.2 Modify the stresses due to the slenderness ratio of the lining. With the known temperature drop across the lining, calculate the maximum resultant stress in the lining for deadweight, flexural and thermal loading. Check this against permissible stresses.

5.6.2.3 Calculate the movements for expansion joint design.

5.6.3 Liaison between the building services engineer and structural engineer. The design procedure relies on considerable exchange of information between the building services engineer and the structural engineer, and it is evident that the design may need to be revised more than once before a satisfactory design is obtained.

The foregoing design procedure has been reproduced in schematic form in figure 2 for ease of reference.

*See the CIBS Guide A10.

6. Forms and materials of construction

6.1 Alternative forms of construction. This clause gives a selection of some typical flue layouts that should act as a guide for the flue designer. While the figures indicate forms of construction that are possible, it is not intended to cover every combination of flue arrangement and all the flue details. Several linings of modular form and construction are available and in use. This code does not deal with such forms of construction nor does it in any way exclude them. They should be considered on their merits in the context of the relevant principles outlined in this code, and should always be constructed in accordance with the manufacturer's recommendations.

All dimensions given in figures 3 and 4 are recommended minima; however, the thickness of the diatomaceous concrete or brickwork may have to be increased above these minima for other design conditions.

Figure 3. Examples of free-standing linings

- (a) Rectangular precast diatomaceous concrete linings in a reinforced concrete (or a brickwork) casing.
- (b) Circular steel liners insulated with mineral wool in a reinforced concrete (or a brickwork) casing.
- (c) Circular steel liners insulated with perlite in a reinforced concrete (or a brickwork) casing.
- (d) Rectangular precast diatomaceous concrete linings in a casing that has three sides of reinforced concrete and the fourth side in common brickwork.

Figure 4. Examples of integral linings (linings normally used as permanent shuttering for reinforced concrete casing)

- (a) Separate rectangular precast diatomaceous concrete linings in a reinforced concrete casing.
- (b) Rectangular precast diatomaceous concrete linings in a reinforced concrete casing.
- (c) Separate diatomaceous brickwork linings in a multiple rectangular reinforced concrete casing.
- (d) Separate diatomaceous brickwork linings in a reinforced concrete casing.
- (e) Separate diatomaceous brickwork linings in a common brickwork casing rendered externally.
- (f) Separate diatomaceous brickwork linings in a casing with three sides of reinforced concrete and the fourth side in common brickwork.

6.2 Description of lining materials (see tables 1 and 2)

6.2.1 Properties of materials. Physical and chemical properties of the different lining materials are given in table 2, where two values are given for each property for the different materials. The first value is the 'basic' property which is obtained from data from tests performed on new materials at normal temperatures and in a dry condition, where applicable. The other value tabulated is the 'design' material property which is the value that should be used in design. It differs from the 'basic' material property due to the effects of moisture content and operating temperature which may have a deleterious influence on the basic material properties.

In appendix A, information is given which shows how these 'design' properties have been obtained and the factors upon which they depend. The designer may be able to derive his own material properties when additional or alternative information is available.

6.2.2 Lining materials

6.2.2.1 Diatomaceous brickwork. Diatomaceous bricks are manufactured from clay containing diatomaceous deposits. They are jointed to form brickwork using proprietary mortars based on Portland, high alumina, or potassium silicate cements. They are suitable for temperatures up to 800 °C, but they are of low strength and are not recommended for abrasive conditions. Similarly, because of their high porosity, they are not recommended for wet operating conditions. This type of material has a very low coefficient of expansion and good resistance to damage from rapid temperature changes.

6.2.2.2 Diatomaceous concrete. Diatomaceous concrete is formed from aggregate made from crushed diatomaceous brick and it is mixed with either Portland cement for medium temperature application, or with high alumina cement for high temperature use. It may be used for in situ, gunned or precast applications, or in conjunction with diatomaceous bricks. A more controlled product is obtained by using it for precast lining segments.

6.2.2.3 Firebricks. Firebricks are used for high temperature work: they have a higher porosity than vitrified clay and are generally used only above the acid dew-point temperature. Special care should be taken in designing linings and chimneys to accommodate the high thermal stresses in linings carrying gases over 400 °C. For other properties see BS 1758.

6.2.2.4 Fireclay aggregate (refractory) concrete. Castable refractory concrete is formed from refractory firebrick aggregate and high alumina cement and may be used for monolithic linings. High density linings in this material are particularly suitable for both abrasive and high temperature conditions.

6.2.2.5 Vitrified clay brick. Generally complying with the requirements of BS 784 in respect of acid resistance, this brick is suitable for temperatures below 250 °C, particularly where abrasive conditions occur. In certain cases vitrified clay bricks are resistant to temperatures of 500 °C, but specialist advice should be sought before employing such materials at this temperature. This material is unsuitable where sharp fluctuations of temperature are expected.

6.2.2.6 Carbon steel fabricated linings. Carbon steel linings are used where gas tightness is essential. They should comply with the relevant requirements of BS 4076.

6.2.2.7 Stainless steel fabricated linings. Stainless steel linings may also be used where gas-tightness is essential, and either at a higher temperature than low carbon steel allows, or for aesthetic reasons.

It is recommended that steels of grades 316S12 and 301S16 of BS 1449 : Part 2, be used for this purpose. Stainless steel is considerably more expensive than carbon steel, but is little better in so far as its resistance to acid attack is concerned. It is often used, however, for the tops of linings because of its resistance to external weathering.

6.2.2.8 Asbestos cement. Asbestos cement, referred to in BS 835 (heavy quality), can be used for gaseous fuels and is suitable for temperatures up to 260 °C. The material is fairly resistant to effects of condensation. Supports should be provided at every pipe socket.

6.2.2.9 Aluminium. High purity aluminium is suitable for gaseous fuels, where condensation is low and the tempera-

ture of the flue gases does not exceed 300 °C. The material used should comply with the requirements of BS 1470.

6.2.2.10 Reinforced plastics. This material is not normally recommended for flue linings principally because most of such materials are combustible, but see table 1. Overheating and ignition of a plastics lining can result from:

- (a) elevated flue gas temperature;
- (b) ignition of soot deposits within the flue system.

6.2.3 Gunned linings. Gunned linings are not often used for flue linings within buildings, and their most common usage is for lining separate free-standing steel chimneys.

Gunned linings can function as any or all of the following:

- (a) thermal insulators;
- (b) gas-tight membranes;
- (c) acid resistant linings.

The choice and application of the most suitable material should comply with the requirements of BS 4207.

6.2.4 Mortars. The choice of mortar type is generally governed by the required degree of resistance to chemical attack by flue gases and by the choice of brick or block, which, by implication, generally determines the temperature suitability. In addition, mortars should be chemically compatible with the lining materials and should be used strictly according to the manufacturer's recommendations. For the latter reasons it may be advisable to use prepared proprietary mortars.

Table 3 describes mortar types in relation to their acid resistance.

6.2.5 Insulating materials (non-structural). Non-structural insulating materials (see table 4) function as a thermal barrier only: they do not have to satisfy any structural requirements. Since most granular insulating materials flow freely, surfaces containing these materials should preclude leakage. Long term settlement of granular insulation may occur and topping-up should be performed as necessary.

6.3 Principal considerations for selection of chimney and lining materials

6.3.1 Type of equipment. Consideration should be given to the type of plant for which a chimney is used, in order to select a type of lining that can handle flue gases of the composition, temperature and pressure involved. The following factors should therefore be taken into account.

6.3.1.1 Boiler plant. Cognizance should be taken of the relevant fuels on which the boiler will operate, the type of firing equipment and the pressure requirements of the furnace.

6.3.1.2 Industrial process and incinerator plant. The type and concentration of any specially corrosive elements in the flue gases of industrial plant should be taken into account.

It is necessary to know whether the flue gases carry any solid particles out of the furnace and, if so, the level of erosion. (It may be necessary to install grit arrestors.)

6.3.2 Multiple or single flue system

6.3.2.1 Where there is more than one appliance in an installation, there are alternative flue arrangements: single or multiple flues.

6.3.2.2 The designer should consider the long term need for inspection and maintenance of flue linings. Where access is intended or can be obtained from inside the flue(s), 750 mm is generally considered to be the minimum practicable internal dimension.

6.3.2.3 Until about 1963, chimneys were predominantly of the single flue type operating under natural draught conditions. During the mid 1960s the multi-flue arrangement became more popular as the easiest way of satisfying requirements for minimum outlet velocities.

6.3.2.4 Before the decision is made to adopt a separate flue for each boiler or item of plant, consideration should be given to using a single, well-insulated flue. With a reasonable base load, the designer can ensure that the temperature of the inside face of the lining of the single flue seldom falls below the acid dew-point temperature.

6.3.2.5 If a single flue construction incorporates devices that control efflux velocity at any given load, careful design to include fail-safe interlocking mechanisms, and also access for maintenance, is essential if reliable operation is to be achieved.

6.3.3 Integral or free-standing linings. The decision whether a lining is to be free-standing or integral will depend upon many factors, and the following points give a brief indication of some of these.

6.3.3.1 Cost. Costs should take account of capital expenditure relative to operating life, anticipated maintenance and ultimate removal.

6.3.3.2 Materials of construction (see 6.2.2). Steel or reinforced plastics liners are almost always free-standing. Linings in brickwork or precast insulating units can be either free-standing or integral.

NOTE. Free-standing brickwork linings have to be supported with intermediate lifts at intervals not exceeding 10 m, which entail intermediate supporting corbels, joints, etc. Integral brickwork linings do not require intermediate supports. Where free-standing precast concrete linings require intermediate supports, these are normally at about 20 m intervals. (See 8.2.2(a)(2).)

6.3.3.3 Pressure conditions in flue. Whether the pressure in a flue is negative or positive, it is preferable that brickwork linings should be integral, so that the inherent leakage in brickwork is minimized. Under positive pressure conditions, brickwork linings should always be used as permanent shuttering if the external casing is concrete. Under positive pressure conditions, where the casing is brickwork, the lining should be integral with the brickwork and keyed in at regular intervals. The external face of the casing should be treated with a suitable sealant to prevent leakage of waste gases. The thermal expansions of the lining material and the surrounding structure should be checked to ensure that they are similar.

6.3.3.4 Maintenance policy. When considering the maintenance policy that would be adopted for a lining, if the only access is from the top and bottom, brickwork linings should be of integral construction, to avoid the danger of collapse during repairs. Because of the difficulty and undesirability of rebuilding large areas of brick linings within an existing casing, consideration should be given to a possible need to remove the brickwork and insert a suitably insulated steel liner, if temperature conditions allow (see table 1). Precast diatomaceous concrete linings can possibly be replaced from the top of a chimney if they are free-standing and constructed as a single lift.

6.3.3.5 Building policy and site work. Sometimes the building programme or site conditions may influence the choice of whether a lining is free-standing or integral, e.g. it may be convenient to use a lining as a permanent shuttering for a concrete casing. Alternatively, it may be more convenient to lower precast units or steel liner sections into a core area after the entire height of the core wall has been

constructed, because of the availability of the site crane. In the case of a diatomaceous brick lining, three sides of a reinforced concrete casing would be fully constructed, and the lining then built integrally (with regular keying to the concrete casing) from the access provided by the fourth side.

6.3.4 Physical aspects. Depending on the physical conditions to which the lining will be subjected, only some of the materials available will prove suitable. The following points should be considered in deciding which lining materials to use.

- (a) Normal range of flue operating temperatures. Table 1 indicates suitable materials for different temperature conditions. An analysis of the flue gases should, however, be studied before selecting the material for the lining.
- (b) Maximum operating gas temperature at entry for deciding the thickness of the insulation required and the temperature gradient through the lining.
- (c) Minimum operating gas temperature throughout the full height of the flue in relation to the acid dew-point temperature.
- (d) Frequency of start-up for consideration of acid deposition.
- (e) Pressure of the gases in the flue for consideration of the integrity of the lining to prevent gas leakage.
- (f) Grit and dust burden for consideration of erosion. Abrasive conditions make the use of thin liners such as steel and reinforced plastics less desirable. If the flue gas velocity produced by gases with abrasive content exceeds 15 m/s, then the effects of abrasion should be considered.
- (g) Flue gas volumes relating to temperature under (a) to (c).
- (h) Flue gas efflux velocities to prevent downwash, and to satisfy the requirements of the Chimney Height Memorandum, where it applies.

7. Building services design

7.1 The appliance and the lining

7.1.1 General requirements. The flue and the mechanical plant cannot be considered as separate entities. They are both part of the same system designed to produce, convey and discharge, to atmosphere, the products of combustion. The mechanical plant can be either of two basic types:

- (a) boilers and air heaters;
- (b) incinerators.

In each case the equipment incorporates a furnace in which combustion takes place, but the primary purpose is different, and this can influence the design of the associated flue.

In boilers and air heaters, fuel is burnt as efficiently as possible, and the products of combustion are cooled by heat transfer to other media, e.g. air or water.

In an incinerator, the primary aim is waste disposal by combustion and, to assist this end, a large amount of excess air is supplied. Heat is not normally extracted from the flue gases when using standard equipment, and this means that flue gas temperatures are normally much higher with incinerators than with boiler plant.

A lining should be able to withstand all the demands of temperature, chemical attack and erosion that will be made on it, whilst fulfilling the functions previously stated.

7.1.2 Chemical attack. It is essential that account be taken of any specially aggressive compounds in the waste gases and their effect on lining or jointing materials. In most instances the inner surface temperature of the lining is the criterion, e.g. where there is sulphur in the fuel, surfaces in contact with the flue gases should be above the acid dew-point to avoid condensation and corrosion. Figure 5 illustrates the relationship between surface temperature and corrosion of steel due to sulphuric acid in the flue gases.

7.1.3 Flue gas temperature. The exit temperature of most appliances will be within the range of 120 °C to about 650 °C (for incinerators), and accurate information should be obtained from the appliance manufacturer.

High flue gas velocities cause high rates of heat transfer to the lining which may give rise to the following effects:

- (a) excessive thermal stress in some lining materials;
- (b) uncomfortable conditions in areas adjacent to the chimney, if the outside surface of the chimney becomes too hot;
- (c) the temperature of the flue gases can fall below the relevant dew-point temperature with possible detrimental effects on the lining.

Any fully automatic boiler plant will cycle on and off repeatedly under low load conditions, and the lining temperature may fall below, and rise above, the dew-point. The design of the plant and the arrangement of the control systems should be such that the period in which this can occur is kept to a minimum (see 5.5.2 and 7.7).

7.1.4 Erosion. With modest flue gas velocities below 15 m/s this is not normally a problem. Above these velocities the presence of abrasive particles in the flue gases may require special design considerations, e.g. at bends. The thickness of a material and its resistance to erosion are important factors for consideration.

7.1.5 Gas-tightness. For the reasons given in 5.4, leakage outwards cannot be permitted, and it is essential that a flue designed to operate at a positive pressure be gas-tight.

If a flue designed to operate at a negative pressure is not gas-tight, air leakage inwards can result in the flue gases being cooled to below their dew-point. An assessment should therefore be made of the amount of in-leakage which can be expected under normal conditions, and the necessary calculations made to ascertain the final flue gas temperature. Devices that control excessive draught by bleeding cold air into flues should not be used where condensation problems could result; the use of a furnace pressure controller, suitably interlocked, should be considered.

7.2 Flue gas flow rates. The calculation of flue gas flow rates requires a knowledge of the fuel analysis, its calorific value, the amount of excess air required and the fuel firing rates. Data are given in tables 5, 6 and 7 and worked examples in B.5 and B.6.

7.3 Cross-sectional area of flues. The cross-sectional area should be selected to obtain the required design velocity of the flue gases. The design velocity selected is determined by the parameters of unacceptably high friction losses and unacceptably low lining temperatures.

In addition, the efflux velocity will normally be in line with the recommendations of the Chimney Height Memorandum where this is relevant. In most instances the efflux velocity will be the velocity of the flue gases in the flue.

tively a coned section may be fitted to some linings to accelerate the flue gases at the point of discharge. In some instances, the natural draught available from the chimney may not be sufficient to obtain the intended velocities.

Having determined the desirable flue gas velocity, it is now possible to calculate the cross-sectional area:

$$A = \frac{G}{v}$$

where

- A is the cross-sectional area of flue (in m^2)
- G is the volume flow rate of gas within the flue (in m^3/s)
- v is the velocity of gas flowing within the flue (in m/s)

7.4 Chimney height. If the chimney height is to be approved by a local authority under Section 6 of the Clean Air Act 1968 and the minimum height is based on the rate of sulphur dioxide (SO_2) emission, the latter should be calculated first.

$$\text{Quantity of } \text{SO}_2 = \frac{2000 BSX_1}{C_v \eta}$$

where

- B is the appliance rating (in MW)
- S is the percentage of sulphur content in fuel (% mass/mass)
- X_1 $\left\{ \begin{array}{l} \text{is the factor 0.9 for solid fuel} \\ \text{is the factor 1.0 for all other fuels} \end{array} \right.$
- C_v is the gross calorific value of fuel (in MJ/kg)
- η is the efficiency of appliance based on C_v (%)

If the local authority's approval of the chimney height is not based on the sulphur dioxide emission, other guidelines should be considered (see the *CIBS Guide, Volume B, Section B13* (1970)).

The height determined by either of these methods requires to be formally approved by the local authority.

If the proposed chimney height does not require approval by the local authority under Section 6 of the Clean Air Act 1968 (e.g. an oil fired installation for which aggregate energy input to the furnace(s) is less than 366 kW) it should be calculated by combustion draught requirements, subject to the requirements of the Building Regulations. These provide that the chimney should terminate not less than 1 m above any nearby structure, i.e. terminating in a location with minimal downdraught potential.

7.5 Pressure conditions in a flue. The pressures calculated in this clause may demand careful choice of lining material (see 5.4). If the flue is to operate in a satisfactory manner, there should be sufficient motive force available to carry the products of combustion from the furnace and discharge them at the top of the chimney at a suitable velocity. This can be achieved by any one of several methods.

7.5.1 Natural draught. In the case of natural draught, the motive power is provided by the difference in density between the hot flue gases and the ambient air. The system stabilizes itself at an equilibrium condition in which the pressure drop created by the flow of the flue gases exactly equals the buoyancy which the flue gases themselves create. It is normal practice to design the system so that there is excess buoyancy available and fine control can then be provided by a damper. In some cases the draught created by natural means will be inadequate and one of the mechanical methods stated in 7.5.2 to 7.5.4 will have to be utilized.

7.5.2 Forced draught. The forced draught method utilizes a fan to provide an air supply at positive pressure for combustion. The amount of air supplied is normally regulated by a damper and the fan may overcome an additional resistance imposed by the flue system. Where there is such additional resistance, the combustion space is kept at a positive pressure relative to the boiler house. Consequently, this method should not be used if the boiler is not completely gas-tight, e.g. Lancashire boiler with brick flues or traditional cast iron sectional boilers.

7.5.3 Induced draught. The induced draught method utilizes a fan to extract the products of combustion from the appliance and discharge them to the flue. A damper or variable speed fan is used to regulate the negative pressure in the furnace. With this method the combustion space is kept at a negative pressure and all leakage is inwards.

7.5.4 Balanced draught. As the name implies, the balanced draught method is one in which an attempt is made to maintain the static pressure in the combustion space as close as possible to that in the plant room and minimize air/flue gas leakage. It utilizes a forced draught fan and an induced draught fan working in series, the former overcoming the resistance to the air entering the combustion space and the latter overcoming the combined flue and appliance resistance.

7.5.5 General comments. Many modern burners designed to burn oil or gas are capable of being used 'over pressure' to provide forced draught, when used with appliances of a suitable type. Most non-gas-tight appliances can be fitted with induced draught fans and automatic dampers. Balanced draught has proved useful with older types of boiler, but it is now only applicable to larger installations such as water-tube boilers.

7.5.6 Calculation of pressure gradient and pressure drop. If the lining is to be constructed of permeable material, it will be necessary to check that the internal static pressure remains negative relative to that on the outside of the lining. This means that the pressure gradient will have to be analysed.

The relationship between static pressure, velocity pressure and total pressure is the same as it would be for any fan system, but it is necessary to emphasize in this case the differences created by the high temperature of the flue gases.

Figure 6(a) shows a simple boiler and flue arrangement. The dotted line shows the position of the chimney rotated to the horizontal to simplify the graphical representations shown underneath. The first of these graphs, figure 6(b), shows the distribution of pressure with cold air passing through a forced draught system. When the flue gases are heated, the effect is to distort the basic pressure datum as shown in figure 6(c) by an amount equivalent to the static lift of the flue gases. This static lift is equal to the difference in density of the vertical column of the flue gas at the point in question, and the overall effect when combined with the system pressure distribution is shown in figure 6(d).

There will always be a *total* pressure at the discharge point higher than the atmospheric pressure, or the gases will not flow out and, with flues operating at high gas velocities, the entire flue can have a positive internal static pressure.

In a flue designed for natural draught operation, the major portion and, in most cases, all of the flue, will be under a negative static pressure.

When carrying out a *static* pressure analysis it is best to start at the discharge point (i.e. the top of the chimney), as this is the point at which the static pressure is equal to atmospheric pressure and a known relationship therefore exists.

The next step is to divide the flue into sections and calculate the static pressure drop in each individual section. These are then added and a running total kept of the static pressure at each point in the system. The static lift or negative pressure at each point due to flue gas buoyancy is then calculated, and the answers added together algebraically to give the actual static pressure at each point in the system under operating conditions.

Each of the components bounded by the chosen points may be either a straight length of flue or a fitting.

The pressure drop, H_f (in Pa), through a straight section of parallel-sided flue may be calculated using the formula:

$$H_f = \frac{pzfv_p}{A}$$

NOTE. H_f is the total pressure loss (in Pa) due to friction of fluid flowing through the section under consideration.

where

- p is the perimeter of flue (in m)
- z is the length of flue (in m) under consideration
- A is the cross-sectional area (in m^2) of part of flue under consideration
- f is the coefficient of friction (from *CIBS Guide, Section B13* (1970))
- v_p is the velocity pressure (in Pa)

For fittings, the pressure drop, H_f (in Pa), can be determined using the formula:

$$H_f = k_a v_p$$

where

- k_a is the velocity pressure factor (from *CIBS Guide, Section B13* (1970) and *Section C4* (1977))

NOTE. Velocity pressure factor is sometimes denoted by the symbol ξ .

The velocity pressure can be calculated using the formula:

$$v_p = \frac{175.8 v^2}{t_f + 273}$$

where

- t_f is the flue gas temperature (in $^{\circ}C$)

See also figure 7.

To determine the static depression created by the chimney draught, it is necessary to know the difference in level between the top of the flue and the point under consideration, and multiply this by the draught available per metre of chimney height. (See also figure 8.)

$$H_d = H_v \left[\frac{3440}{T_a} - \frac{3440}{T_f} \right]$$

where

- H_d is the theoretical draught available (in Pa) due to chimney effect
- H_v is the vertical length (in m) of the column of flue gases
- T_a is the ambient air temperature (absolute) (in K)
- T_f is the flue gas temperature (absolute) (in K)

It is suggested that T_a is assumed to be 273 K in winter and 293 K in summer for UK conditions.

Care should be taken when dealing with a fitting in which a velocity change takes place, since a decrease in velocity is

accompanied by a gain in static pressure. The change in static pressure, H_{fr} (in Pa), can be calculated using the formula:

$$H_{fr} = H_{fv} - H_f$$

where

- H_{fv} is the change in velocity pressure (in Pa) across the section under consideration

When the chimney fabric is of a non-permeable material it is not necessary to analyse the static pressure distribution. Calculate the total resistance, H_t (in Pa), of the system:

$$H_t = \Sigma (H_{f1} + H_{f2} + \dots) + H_b$$

where

- H_b is the draught required at boiler outlet (in Pa)

If the resulting value of $(H_t - H_d)$ is positive, it means that some form of mechanical draught is obligatory. Alternatively repeat the calculations using a lower flue gas velocity until the desired conditions are achieved.

7.5.7 The effects of pressure on the selection of materials.

When calculations show that any part of the flue system will operate under positive pressure, the materials and form of construction should be given careful consideration.

It is essential that seams and joints of steel or aluminium liners (other than joints between sections) are continuously welded to be gas-tight under test and operating conditions. Joints between sections shall similarly be gas-tight. At low pressure (e.g. below 1000 Pa) this can be achieved with conventional flanges and soft gaskets (e.g. woven asbestos) but at higher pressures machine faced flanges and suitable proprietary jointing gaskets are necessary. All expansion bellows and other expansion joints should be inherently gas-tight.

All relief doors, clean-out doors, etc. should be fitted with the requisite joints to withstand the anticipated range of pressures.

Some concrete or brick linings may leak if pressurized; such leakage can be minimized by using some of the forms of construction detailed in 6.1 and figures 3 and 4.

7.6 Temperature distribution through the flue system.

In 7.6.1 and 7.6.2 the flue wall is treated as a one-dimensional problem; this is sufficiently accurate for the majority of practical applications.

7.6.1 Temperature drop along flue. As flue gases pass along a flue, their temperature falls due to heat loss through the structure and in some instances due to infiltration of cold air.

It can be shown that the maximum acceptable thermal transmittance value, U (in $W/(m^2 K)$), for the flue structure is given by the formula:

$$U = \frac{m_r C_p}{A_s} \log_e \left[\frac{t_{fi} - t_{ai}}{t_{fo} - t_{ao}} \right]$$

where

- m_r is the mass flow rate (in kg/s) of flue gas
- C_p is the specific heat (in J/(kg K)) of flue gas at constant pressure
- A_s is the inner surface area of the flue lining (in m^2) through which thermal transmittance takes place
- t_{fi} is the flue gas temperature (in $^{\circ}C$) at flue entry
- t_{ai} is the air temperature (in $^{\circ}C$) at base of flue
- t_{fo} is the flue gas temperature (in $^{\circ}C$) at flue exit
- t_{ao} is the air temperature (in $^{\circ}C$) at top of flue

This formula assumes no air in-leakage, and it may be necessary to make an allowance for this when calculating the flue gas discharge temperature.

To maintain surface temperatures above a dew-point, it is essential that the gases flowing within a system are always at a temperature above that dew-point.

7.6.2 Temperature drop across flue structure. At this point, a decision has to be made about the permissible U value. A maximum U value, to prevent the outlet flue gas temperature falling below the dew-point, may be calculated as above, and this should have been done using the *minimum* flue gas flow rate. There are, however, other criteria to be met.

The heat losses through the lining should not result in overheating of adjacent spaces (e.g. offices, corridors, etc.). It is impossible to make a general statement of what is permissible, and each case should be treated on its own merits. One approach is to assume a probable air infiltration rate for the adjacent space and ensure that the heat from the flue gases will not increase the temperature of that adjacent space more than, say, 5°C^* .

The rate of heat transfer, Q (in W), from the flue to the occupied space can be calculated using the following formula for flat walls:

$$Q = UA_s (t_f - t_r)$$

For practical purposes, the formula for flat walls may be applied to most curved walls. Where the designer considers that a more accurate result is required for curved surfaces (e.g. for small diameter flues), reference should be made to a suitable textbook on heat transfer.

The heat that can be absorbed by the air changes in the adjacent space

$$= 5 n V_r C_p \rho \text{ for a } 5^\circ\text{C rise}^*$$

hence

$$U = \frac{5 n V_r C_p \rho}{A_s (t_f - t_r)}$$

where

- Q is the rate of heat transfer (in W)
- t_f is the temperature of flue gas (in $^\circ\text{C}$) at critical zone
- t_r is the temperature of air (in $^\circ\text{C}$) in adjacent space under consideration
- n is the number of air changes per second (in s^{-1})
- V_r is the volume (in m^3) of the adjacent air space
- C_p is the specific heat of air (in $\text{J}/(\text{kg K})$) at constant pressure
- ρ is the density of air (in kg/m^3) in adjacent space

The lower of the two U values derived (in this clause and in 7.6.1) should be used in the next stage of the calculation. The temperature gradient across the flue structure (see figure 9 and B.10 of appendix B) should be determined as follows:

$$\begin{aligned} \frac{Q}{A_s} &= U (t_f - t_r) = h_f (t_f - t_1) = \frac{k_1}{L_1} (t_1 - t_2) \\ &= \frac{k_2}{L_2} (t_2 - t_3) = \frac{k_3}{L_3} (t_3 - t_4) = h_r (t_4 - t_r) \end{aligned}$$

where

$$U = \frac{1}{\frac{1}{h_f} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} + R_a + \dots + \frac{L_n}{k_n} + \frac{1}{h_r}}$$

*In some instances a different temperature increase may be essential.

where

- h_f is the surface coefficient of heat transfer (in $\text{W}/(\text{m}^2 \text{K})$) to the inner surface of the flue lining (see figure 10(a))
- h_r is the surface coefficient of heat transfer (in $\text{W}/(\text{m}^2 \text{K})$) from the outer surface of the complete flue structure to the adjacent space (see figure 10(b))
- k_1, k_2 , etc. are the thermal conductivities of lining components (in $\text{W}/(\text{m K})$) (see table 2 of this code and Section A3 (1970) of the *CIBS Guide*).
- L_1, L_2 , etc. are the thickness of component parts of composite lining (in m)
- R_a is the lining air cavity resistance (in $\text{m}^2 \text{K}/\text{W}$) where applicable

These interface temperatures should be passed to the structural engineer to enable the effects of thermal stress to be checked.

7.7 Operation of a boiler installation to minimize condensation in a multi-flue system. Varying load on multi-boiler, multi-flue installations may require a boiler to cycle on and off. At restart, condensation occurs until the flue lining is above the acid dew-point temperature, and typically this may take 2 min for steel liners and 8 min for brick linings. The design and operation of the boiler sequence control system should aim to minimize on/off cycling of individual boilers in order to minimize flue gas condensation.

8. Structural design of linings

8.1 Information required. For the structural design of a flue lining, the following information is necessary:

- (a) type of lining, integral or free-standing;
- (b) lining material and thickness;
- (c) lining material properties;
- (d) lining geometry.

8.2 General structural recommendations

8.2.1 Design for repair and replacement. Even when every precaution is taken, it is not possible to guarantee that a flue lining will last the life of the building. Hence, linings should be designed giving consideration to methods of repair or replacement.

8.2.2 Free-standing or integral linings. It is preferable that the masonry linings should be integral, i.e. the lining is used as permanent shuttering, or is bonded to the brick casing, because the need for intermediate supports is reduced and, with it, the need for expansion joints requiring maintenance (see 6.3.3 and 10.11.5).

The construction of the lining should be as follows.

(a) Free-standing linings

- (1) *Brick linings.* Experience dictates a maximum of 10 m per lift, and this facilitates the repair of sections as opposed to that of the whole of the lining. The specific height between supports will be determined by calculation of stresses as stated in 8.5.
- (2) *Precast linings.* Intermediate supports are not usually needed to restrict longitudinal compressive stresses and, if used, they make it virtually impossible to replace sections below the top support.

However, if calculations in 8.5, particularly the effect of the slenderness ratio, indicate that intermediate supports are required, the maximum height of each lift will probably be influenced by thermal movements (see 8.9), suitable expansion joints and packing materials. As a guide, 20 m per lift is normally acceptable with conventional corbelling construction.

(b) *Integral linings*

(1) *Brick linings.* Intermediate supports are not recommended but, if used, regular bonding of the lining to the surrounding casing is essential.

(2) *Precast linings.* Intermediate supports should be avoided where possible.

8.2.3 Thickness and height of refractory lining. Initially the minimum thickness of the lining will be determined by the thermal requirements, according to 7.6. From practical considerations there is a minimum thickness, e.g. 114 mm for diatomaceous brickwork. The minimum practical thickness for diatomaceous concrete linings is 100 mm.

The structural design of the entire lining should then be carried out.

8.2.4 Internal dimensions of lining. The internal dimensions of the lining should be in accordance with 7.3 with consideration being given to the following:

- (a) for brick linings, to facilitate the laying of bricks and minimize cutting, there are preferred dimensions for flues (see 10.5.4 and 10.5.5);
- (b) where feasible, the internal dimensions should be large enough to allow inspection and repair by lowering a man inside the flue from the top (see 6.3.2.2).

8.2.5 Design of openings in flue linings. Openings are normally required for flue gas entry, inspection, removal of soot, or for measurement of flue gas characteristics. Where access doors are to be provided in the flue lining to allow access for a person and for the rigging of temporary support beams for hoists, bosun's chairs, etc., such doors should be gas-tight. They should preferably have sufficient insulation to make their thermal characteristics equivalent to the adjacent lining. The number of openings should be kept to a minimum and should be of such a size and shape as to minimize stress concentrations and also to ensure that such stresses are within acceptable limits.

Openings may be required for the insertion of probes and instruments. They should be constructed and insulated in such a manner as to preclude the infiltration of air, flue gas leakage and localized cooling of the system. Sample openings should normally be arranged at levels where access can readily be obtained for operation and maintenance of instrumentation.

8.3 Construction details

8.3.1 Flue lining details. Typical layouts of chimney entries, intermediate levels and chimney exits are shown in figures 11 to 14.

8.3.2 Walls between adjacent flues. To prevent flue gases passing from one flue to another through brickwork, it is necessary to use an impervious membrane (e.g. concrete or glass fibre reinforced high alumina cement board) (see figures 4(c), 4(d), 4(e) and 4(f)).

8.3.3 Intermediate supports. Intermediate supports are required in free-standing brickwork linings. Allowance should be made for expansion movement below the

supports, and the joints should be nominally gas-tight and maintainable, preferably from outside. These requirements are very difficult to achieve. One possible construction is shown in figure 12.

8.3.4 Top of lining. For a brickwork lining, the top of the lining should be constructed of engineering bricks for a height equal to three or four times the maximum horizontal dimension of the flue to give weather resistance (see figure 14(a)). For this brickwork, the mortar should be acid-resisting potassium silicate or similar. Forms of chimney capping for use with diatomaceous concrete linings are shown in figure 14(b) and for steel liners in figure 14(c).

8.3.5 Dead legs. Dead legs in the vertical flue below the point of entry of the gas flow should generally be avoided. However, from practical considerations, dead legs of up to 300 mm are acceptable (see 8.3.6).

8.3.6 Drainage. It is essential to provide adequate facilities to ensure that surface water on the roof cannot enter the chimney.

It is necessary to provide condensate drainage facilities at the base of flues. One method of achieving this is by means of a short dead leg forming a tundish and a final drain to a seal to prevent air ingress and waste gas egress.

8.3.7 Capping of flue. Where a considerable period of time may elapse between the completion of construction of a lining, and the flue being brought into use, the top of the flue should be capped off to prevent the ingress of rain and the entry of flue gases from an adjacent flue. The capped flue should be ventilated.

8.3.8 Access door. Flues should have an access door so that any deposits can be removed from the base of the flue, and the lining inspected.

8.4 Loads

8.4.1 General. The determination of dead load, wind load (if any), and other loads, should be in accordance with CP 3 : Chapter V. Some lining materials increase in density when wet, and recommended design densities are presented in table 2.

8.4.2 Lining temperatures. The temperatures across the thickness of the lining should be calculated according to 7.6.2. The hot face temperature of the lining should be used to calculate the vertical expansion of the lining, so that this movement can be accommodated.

8.5 Calculation of stresses in free-standing linings

8.5.1 General. This clause applies to linings that are constructed within a building where there is a space between the lining and the structure of the building.

Non-metal linings are usually constructed of materials of low modulus of rupture (e.g. 0.89 MPa for diatomaceous bricks) and cracking may occur where tensile stresses are present, owing to the thermal gradient across the lining. Conventional formulae for calculating stresses, which assume that the material remains elastic, cannot then be applied. The following procedure is proposed for determining stresses for circular or rectangular linings under combined axial, flexural and thermal loadings. The formulae are set out in appendix D, together with the design graphs (see figures 15 to 21).

8.5.2 Self-weight stresses and flexural stresses in lining

- (a) Calculate stress due to self-weight at the base of each lift or section of lining.

(b) Calculate, and add to the self-weight stress, the flexural stress (if any) in the lining. Generally, flexural stresses due to, say, wind movement of the external structure (building), are very small or insignificant. Conversely, if the flue structure projects beyond the external structure by more than approximately five times the external diameter, or the equivalent, it is necessary to consider the flexural stresses.

8.5.3 Effects of slenderness ratio of lining. The stress reduction factors for slenderness and eccentricity of applied loading (in table 4 of CP 111 : Part 2 : 1970) are essentially based on numerous tests on piers of brickwork, which were subjected to axial and eccentric loads. These reduction factors are not directly applicable to linings because the direct load in a lining is that derived from self-weight only. Therefore, the slenderness ratio is accounted for as follows.

The reduction factor, β , for permissible axial stresses should be calculated from:

$$\beta = 1 - \frac{0.654}{\gamma} \left[\frac{L_e}{100 r_y} \right]^2$$

where

0.654 is an empirical constant

L_e is the lining length (in m) between lateral supports

r_y is the radius of gyration (in m) of the flue

$\gamma = 1.9 - 0.9 \left(\frac{w}{100} \right)$ for both ends pinned

or

$\gamma = 0.794 - 0.544 \left(\frac{w}{100} \right)$ for one end free and the other end clamped,

where

w is the top load, expressed as a percentage, and $(100 - w) \%$ is the uniformly distributed load.

(w is the percentage load factor.)

To account for the slenderness of a lining, the inverse of the reduction factor should be calculated. This inverse, termed a 'load increase factor', should be multiplied by the algebraic addition of the self-weight stress plus flexural stress. This gives the factor, q , for the calculation of the maximum longitudinal compressive stress in the lining. The self-weight stress mentioned here is the stress due to self-weight at the base of the flue or at an intermediate support that is being considered.

Values of β are tabulated for $w = 0 \%$, 25% , 50% , 75% and 100% . This is done in table 8 for the situation when both ends are pinned, or when one end is free and the other end is clamped.

8.5.4 Maximum longitudinal compressive stress at base of each section of lining under self-weight, flexural and thermal conditions. Calculate the following four expressions:

θ , q/θ , f_t/θ and d_t/r with consistent units (see appendix D) in which

$$\theta = \frac{E\alpha\Delta t}{1 - \sigma}$$

where

q is the stress (in MPa) due to self-weight plus flexure (modified by slenderness ratio) in the absence of cracking, obtained from 8.5.3

f_t is the modulus of rupture of lining material (in MPa)

d_t is the thickness of lining (in mm)

r is the internal radius of flue (in mm)

E is Young's modulus of elasticity (in MPa) of the lining material (see table 2)

α is the coefficient of linear expansion of the lining material (in K^{-1}) (see table 2)

Δt is the temperature drop across lining (in $^{\circ}C$)

σ is the Poisson's ratio of the lining material (see table 2)

In figures 15 to 21, graphs are presented for various values of d_t/r . Each graph shows the relation between q/θ and c/θ for various values f_t/θ . For a rectangular lining $d_t/r = 0$, see figure 15.

Hence, to determine the longitudinal compressive stress, first choose the graph from figures 15 to 21 for the nearest d_t/r values. For calculated values of q/θ and f_t/θ , read off c/θ . As θ is known, then c , the compressive stress, is calculated. Linear interpolation between graphs is used for d_t/r values between the values provided. Linear interpolation is used on each graph for values of f_t/θ between the values plotted. On figures 15 to 21 it should be noted that the top graph line applies to values of $f_t/\theta \geq 0.4$.

8.5.5 Notes on the calculation in 8.5.4. The longitudinal compressive stress calculated is the maximum stress at the inside of the lining at the section considered. The circumferential stress at any section of the lining is calculated by the same procedure, but with $q = 0$. At the top of each section of lining the longitudinal stresses are the same as the circumferential stresses because the self-weight stresses and flexural stresses become zero.

8.5.6 Sample calculation. An example of the above calculation is given in appendix E.

8.6 Stresses in linings built as an integral part of the building

8.6.1 General. This applies to linings used as permanent shuttering for concrete, or where diatomaceous brick is bonded regularly with an outer skin of common brickwork. If, between the lining and the surrounding structure, there is additional insulation such as mineral wool, or if a membrane is placed between the lining and the external structure, the lining should be designed according to 8.5, i.e. this comes into the category of free-standing, but built within a space enclosed by a building.

8.6.2 Stresses due to self-weight. Due to adhesion between the lining and the external structure, the self-weight stresses may be very small. The height of the lining is governed by the recommendations in 8.2. Minimum recommended thicknesses of the lining are given in 8.2.3 and figures 3 and 4.

8.6.3 Thermal stresses. The structure surrounding the lining restrains the lining from expanding, so that, under thermal conditions, the whole of the lining is in compression, with the higher compressive stress at the inside of the lining. Due to the indeterminate nature of the adhesion between the lining and the surrounding structure, and the degree of restraint provided by the surrounding structure, stresses cannot be calculated with any degree of confidence.

8.6.4 Effect of combined stresses. Experience in service has shown that the deterioration of such integral linings due to thermal and self-weight stresses is usually insignificant, provided that acid attack is negligible.

8.7 Permissible stress for linings

8.7.1 Permissible compressive stress. The permissible crushing stress should follow the recommendations of CP 111 : Part 2 where two methods are available for obtaining the

allowable compressive stress of brickwork or blockwork. Blockwork includes precast insulating lining units of diatomaceous concrete or similar material.

8.7.1.1 The permissible compressive stress depends upon the crushing strength of the lining material and the grade of the mortar used. This is given in clause 315 and tables 3a and 3b of CP 111 : Part 2 : 1970, for brickwork members and blockwork members respectively. The crushing strength of the unit for use in tables 3a and 3b of CP 111 : Part 2 : 1970 when deriving the allowable compressive stress (termed 'basic' stress in CP 111 : Part 2) is the 'design value' as given in table 2 of this code.

8.7.1.2 Advantage may be taken of the results of full-scale tests performed on panels of lining material, where the test conditions are in accordance with clause 502 of CP 111 : Part 2 : 1970. The same section gives the relevant load factors to apply to tests on actual panels of brickwork, provided that the wet compressive strength of the bricks or blocks to be used in construction is not less than the compressive strength of sample bricks used in the panel. Table 10 of CP 111 : Part 2 : 1970 gives the load factors for various slenderness ratios and basic brick or block crushing strengths.

8.7.2 *Effects of slenderness ratio of lining.* There is no reduction of permissible stresses due to the slenderness ratio of the lining, since the effects of slenderness have already been incorporated by increasing the algebraic sum of the self-weight and wind stresses by the load increase factor according to 8.5.3.

8.7.3 *Allowances for the shape of the unit.* The figures from tables 3a and 3b of CP 111 : Part 2 : 1970 for the allowable basic stress are suitable when the unit of the lining is of common brick shape. This may be unnecessarily low for some units whose ratio of height to thickness is greater than that of common brick. Therefore, the basic allowable stress may be modified according to table 5 in CP 111 : Part 2 : 1970.

8.8 *Permissible stresses for wind and temperature effects.* The total compressive stress, including the flexural stresses arising from wind and thermal effects (acting separately or in combination), should not exceed the basic allowable compressive stress (derived from table 3a or table 3b of CP 111 : Part 2 : 1970 and modified, if appropriate, in accordance with 8.7.3) by more than 40 %.

8.9 *Movements in linings.* Movement occurs mainly due to temperature effects, i.e. initial shrinkage (especially with concretes) and thermal expansion or contraction, and provision should be made to accommodate this movement at all joints. Initial site shrinkage (during initial operation) of linings constructed in some materials may be significant and should be allowed for at the design stage. Factors or values for such shrinkage should be obtained from the suppliers.

For free-standing linings with intermediate supports, the joints at the supports should be designed to allow the necessary longitudinal temperature movement calculated from the coefficient of expansion and the height between intermediate supports. Attention should also be given to the design of lateral supports which are intended to provide lateral restraint whilst allowing longitudinal movement of the lining due to expansion.

In addition, the design of lateral restraints should ensure that differential movement between linings and external

structure can be accommodated without imposing local stress at the restraint position.

9. Steel liners

9.1 *General design information.* Steel liners should comply with the relevant requirements of BS 4076. They are normally built to parallel design and are generally made in angled flanged sections of welded construction. Where necessary, they can receive lateral support to prevent bending or failure under axial compression. These supports should be designed to permit both lateral and vertical expansion, but they should transmit only a minimum of heat from the liner, otherwise local corrosion spots may occur in the liner.

Steel liners should either be supported at the base level, if the inlets are at low level, or upon a sub-base if the inlets are at a higher level. It is essential that the liner be insulated from the floor or sub-base to minimize transference of heat from the liner to its support (see figure 11(b)).

The liner usually has to carry its own self-weight, and plate of 1.5 mm thick is normally sufficient for this load. If the liner is constructed from 6 mm * plate, it will have a corrosion allowance of 4.5 mm which gives a design life exceeding 20 years, provided the flue is operated normally and corrosion is minimal.

A carbon steel liner should not be subjected to a temperature above 480 °C. If the liner is subjected to a higher temperature, as with a flue serving an incinerator, it can be lined with a suitable refractory material (see table 1).

The vertical expansion of a carbon steel liner is approximately 1.25 mm per metre length per 100 °C temperature rise. Joints, particularly at the capping detail at the top of a flue, should be designed to accommodate this significant thermal expansion of the steel liner.

9.2 *Constructional details.* A truncated cone can be fitted at the top of a steel liner to increase the efflux velocity and so minimize cold air inversion. It is good practice to allow the top of the liner to be parallel for a length of one to three times the final diameter to help smooth the flow of flue gases and to simplify the weathering and expansion problems where the liner passes through the roof.

Attack by the weather at the top of a carbon steel liner can be minimized by manufacturing the top 1.5 m to 3 m from stainless steel, and grade 316S16 of BS 1449 : Part 2, or similar, is recommended. This stainless steel section may be designed to incorporate the truncated cone if this design feature is required.

It is not possible for a person to carry out effective repairs in a steel liner less than 750 mm in diameter. Therefore, when the internal diameter of the liner is less than this dimension, it should be designed so that it can be removed from the top of the building without a person having to descend into the lining.

As steel liners, except a portion which may project above a cap plate at the roof of the building, are protected from the weather, they do not require painting other than initially after fabrication. If the faces of the cap plate exposed to the weather are galvanized and treated with a suitable paint, such as one based on epoxy resin, they will require only a minimum of maintenance. The section of a steel liner that projects above the cap plate can be fitted with a galvanized

*Minimum to comply with the requirements of BS 4076.

steel shield similarly painted, or the shield can be made from stainless steel or aluminium cladding.

9.3 Insulation. Steel liners may be insulated with perlite, vermiculite, mineral wool, glass fibre or other suitable materials.

9.3.1 Loose fill insulation (see figure 3(c)). Perlite is an exfoliated aluminium silicate; vermiculite is exfoliated from a group of hydrated laminar materials which are aluminium-iron-magnesium silicates, resembling mica in appearance. Both perlite and vermiculite are non-hygroscopic, odourless and free-flowing and, for this type of application, may be considered as chemically inert.

Loose fill insulants are very effective and are normally used at a minimum thickness of 100 mm and are extremely free-flowing. They fill all crevices without leaving air pockets. The loose products are difficult to handle because of their low bulk density, and it is essential that there are no leaks into the building or in the liner jointing flanges, otherwise loss of fill will occur. These materials compact by up to 10 % within about 6 months to 9 months of being placed, and it is necessary to top up an insulated chimney 9 months to 12 months after installation. After this period no noticeable compaction occurs. Compaction does not significantly affect the insulation qualities.

Loose fill insulants are introduced into the space between the lining and the building by pouring in from the top of the chimney, and are removed from the base. It is necessary to incorporate suitable fittings for these operations at the design stage.

9.3.2 Mineral wool and glass fibre (see figure 3(b)). Mineral wool and glass fibre are formed into mattresses of various thicknesses, generally from 25 mm to 100 mm, the thickness of mattress being dependent upon the degree of insulation required and the density of the material used. For thicknesses over 50 mm they are usually applied in two layers to give the total required thickness of insulation.

During application, both the horizontal and vertical seams are staggered, and they are held in position with steel strapping. Such mattresses are not so effective an insulant as perlite or vermiculite, although they have a similar k value, as it is not possible to ensure that there are no small voids or air spaces in the mattress. Mineral wool and glass fibre are usually limited to a maximum thickness of 100 mm as opposed to an unlimited thickness of loose-fill insulants. This fact is of importance only when greater thicknesses of insulation are necessary to control the surface temperature of the wall of the casing.

9.3.3 Lightning protection. Lightning protection should follow the recommendations of CP 326. It is normal practice to bond each steel liner to the cap plate and the cap plate to the building's lightning conductor system.

10. Workmanship

10.1 General. The need to achieve a high standard of gas-tightness in flues imposes requirements on the standard of workmanship that are far higher than from those for other aspects of building, particularly when constructing brick linings.

10.2 Materials storage on site

10.2.1 General. Consignments of materials should be stored so that they will normally be used in order of delivery, and so that inspection and sampling is facilitated.

10.2.2 Diatomaceous bricks. Diatomaceous bricks are usually packed on wooden pallets and are protected by shrink film plastics sheeting. The palletized bricks may be rapidly off-loaded by crane or forklift truck, but may also be hand-stacked if no mechanical equipment is available. Care should be taken to ensure that bricks do not become wet, and on no account should bricks be exposed to frost if they have accidentally become wet. Bricks should not be stacked directly on the ground, clinker, or ashes, unless precautions are taken to prevent chemicals being drawn into them by rising moisture.

10.2.3 Mortars for bricks and precast units. Proprietary mortars are supplied in ready-mixed bags and should be stored off the ground on a timber floor in a dry structure. Any mortar affected by dampness should be discarded.

10.2.4 Cement for units to be cast on site. Cement should be stored off the ground on a timber floor in a dry structure. Cement affected by dampness should be discarded.

10.2.5 Refractory aggregates for units to be cast on site. Refractory aggregates are supplied in bags and delivered to site. The aggregate is inert and has unlimited shelf life if kept dry. Should it become wet in store, it should not be exposed to frost.

10.2.6 Precast diatomaceous concrete. Units are packed on lorries with card or timber separators. It is advisable to retain these buffers between units in order to protect against chipping. Although wetting will not harm the units, it is advisable to keep them sheeted where possible to avoid the amount of drying out that may be required when they are erected. Units should not be stored directly on the ground, or on clinker or ashes, unless precautions are taken to prevent chemicals being drawn into them by rising moisture.

10.2.7 Glass fibre reinforced plastics units. Glass fibre reinforced plastics units can be stored in the open, but care should be taken to avoid physical damage.

10.2.8 Metals. Metal components should be stored under cover where possible. Under damp conditions, ferrous and non-ferrous metals should be separated and care should be taken to prevent direct contact between copper-bearing materials and aluminium or zinc.

Rolls of aluminium or zinc should be stored in a dry atmosphere to prevent storage stain.

10.2.9 Materials for sealing joints. Materials used for packing in joints, such as lightly packed glass wool, lapped aluminized asbestos, woven glass fibre, etc., should always be stored in dry and uncompressed conditions.

10.2.10 Materials for thermal insulation. Mineral wool or glass fibre should always be stored in a dry condition. Perlite and vermiculite may be delivered in bulk or in bags.

10.3 Mortars

10.3.1 Types of mortar. Mortars for diatomaceous brickwork and precast units should be suitable, dry, ready-mixed material, pre-packed and requiring only the addition of water, as recommended by the manufacturers, for use with bricks or units.

Acid-resisting mortar for diatomaceous brickwork should be an approved potassium silicate mortar recommended by the manufacturers for use with their bricks.

10.3.2 Mortar mixing and preparation. Mortar for diatomaceous brickwork and precast units should be prepared and mixed strictly in accordance with the manufacturer's printed instructions. Only sufficient water should be added to

produce the desired consistency. The same applies to acid-resisting mortar.

10.4 Precast diatomaceous concrete units. Unless of very small size, all units are provided with two or more lifting eyes usually recessed flush with the top surface of the unit.

10.5 Laying bricks and precast units

10.5.1 Work in cold weather. Care should be taken to ensure that brickwork and concrete are in no way damaged by frost, and all work should be protected to prevent such damage.

Brickwork or concreting should not be carried out when the air temperature is below 2 °C when the temperature is falling, and work should not be resumed until an air temperature of at least 1 °C has been reached when the temperature is rising. No material containing frozen matter should be used.

10.5.2 Coursing. Brickwork built with standard 73 mm diatomaceous bricks will rise at the rate of four courses to 304 mm as will brickwork built with standard 65 mm engineering bricks. Unless the risk of extrusion of wet mortar can be precluded, not more than 20 courses of diatomaceous brickwork, nor 12 courses of engineering brickwork should be built in any one day.

Where the lining is to be bonded to the shell brickwork at specified centres, an occasional course of non-standard diatomaceous bricks (available as standard specials) may be introduced. Alternatively the diatomaceous bricks may be machined if required to rise four courses to 300 mm.

10.5.3 Toothing. Any brickwork rising above the general level shall be fully raked back. No toothing should be allowed.

10.5.4 Bonds for diatomaceous brickwork. Diatomaceous brickwork should be built in the following bonds:

- (a) 114 mm *walls*: stretcher bond, using 229 mm x 114 mm bricks;
- (b) 152 mm *walls*: one-third bond, using 229 mm x 152 mm bricks;
- (c) 229 mm *walls**: three courses in stretcher bond; one course of headers;
- (d) *circular flues*, 114 mm and 152 mm *walls*: stretcher bond, using standard special or spécial radial bricks;
- (e) *circular flues*, 229 mm *walls*: three courses, stretcher bond, and one course headers, using standard special or special radial bricks;
- (f) 229 mm *mid-feathers (between adjacent flues)*: stretcher bond using 229 mm x 114 mm in two skins (see 8.3.2).

10.5.5 Bonds for engineering brickwork. Engineering brickwork should be built as follows:

- (a) *half-brick walls*: stretcher bond using standard 215 mm x 102.5 mm x 65 mm bricks;
- (b) *one-brick walls*: three courses, stretcher bond, and one course, headers, using standard 215 mm x 102.5 mm x 65 mm bricks;
- (c) *one-brick walls in mid-feathers*: stretcher bond using standard 215 mm x 102.5 mm x 65 mm bricks in two skins;
- (d) *circular flues*, *half-brick walls*: stretcher bond using radial bricks;

(e) *circular flues*, *one-brick walls*: three courses stretcher bond, one course headers using radial bricks.

10.5.6 Wetting of bricks. Care should be taken to ensure that bricks are not wetted before laying, except for diatomaceous bricks, which should be laid dry or wet according to the type of mortar selected. The use of bricks that have become wet on storage should be avoided.

10.5.7 Jointing. Failure to ensure complete filling and closure of all brickwork joints will lead to leakages in the system and weaknesses in the structure. This may result in a loss of efficiency of the plant connected to the flues, as well as dangerous leakage of flue gases and instability of the flue structure. Therefore any method of bricklaying that does not ensure that all joints are completely filled should be avoided.

Laying of lining brickwork differs from conventional brickwork and requires the expertise associated with refractory brick setters. The following notes are given for guidance.

(a) *Insulating brickwork.* All joints of insulating brickwork should be 3 mm thick. All joints, including bed-joints, collar joints, and perpends, and also joints between flue lining brickwork and concrete casing should be completely filled with mortar. Bed-joints should be buttered with mortar to approximately 4 mm to 5 mm thickness, covering the entire bedding surface; vertical bedding surfaces, both perpendicular and collar joint faces, should be fully and evenly buttered, and the brick tapped firmly in position. If, for any reason, the brick is lifted for rebedding, all mortar adhering to the jointed surface should be removed and discarded, and fresh mortar applied.

(b) *Engineering brickwork.* Bed-joints of engineering brickwork should be 11 mm thick where brickwork is to rise four courses to 304 mm, and 10 mm thick where four courses are to rise to 300 mm. Perpends and collar joints should be 10 mm thick. All joints, including joints between flue-lining brickwork and concrete casings, should be completely filled with mortar. Bed-joints should be buttered with mortar to approximately 12 mm to 14 mm thickness, covering the entire bedding surface; vertical bedding faces, both perpendicular and collar joint faces, should be fully and evenly buttered with mortar, and the brick tapped firmly into place.

(c) *Joint finishing.* All brickwork joints to interior flue faces should be finished as the work proceeds and while the mortar is still green. The joints should be finished flush with the surface of the brickwork and trowelled or tooled to give a smooth even surface. Neither recessed nor projecting jointing should be allowed, and all surplus mortar should be removed from the face of the brickwork. The outside faces of the brick, where not immediately adjacent to supporting structures, should be jointed and finished to the same standard as the interior flue faces.

10.5.8 Preferred dimensions of diatomaceous brick linings. Depending on the internal dimensions and lining thickness, as determined by the building services engineer, the dimensions may be adjusted to minimize or completely eliminate the need for cutting any bricks.

(a) *Rectangular linings*

- (1) 114 mm and 229 mm *brick*: internal dimensions should be in units of 116 mm. No cutting required (see figures 22 and 23).

* Because of the physical dimensions of insulating bricks it is not possible to build a wall with this bond which is fairfaced on both sides. It is essential that the wall be built fairfaced on the flue gas carrying surface.