



BS 5970:1981

UDC 696:621.64.076:699.86:662.998

Code of practice for

**Thermal insulation of pipework and equipment
(in the temperature range -100°C to $+870^{\circ}\text{C}$)**

(Formerly CP 3005)

Code de bonne pratique pour le calorifugage des tuyauteries et de l'équipement
(gamme de température -100°C à $+870^{\circ}\text{C}$)

Tichtlinie für die Wärmedämmung an Rohren und Einrichtungen
(im Temperaturbereich von -100°C bis $+870^{\circ}\text{C}$)

British Standards Institution

AVA Documents
Document Sharing Hub

Contents

	Page		Page
Foreword	3	10. Selection of finishing materials, including ultimate treatment of finish	20
Cooperating organizations	Back cover	10.1 Finishing materials: general	20
Code		10.2 Reasons for use	21
Section one. General		10.3 Typical uses for finishing materials	21
1. Scope	4	10.4 Finishes for tropical conditions	22
2. References	4	10.5 Finishes for refrigeration work	22
3. Definitions	4	10.6 Finishes to improve fire-protective properties	22
4. Exchange of design data	5	10.7 Finishes for use over pipes in ducts and subways, or beneath buildings	22
4.1 Information to be supplied by the purchaser	5	10.8 Ultimate treatment of finish	22
4.2 Information to be supplied by the manufacturer or contractor	6	10.9 Identification	23
4.3 Drawings	6	11. Selection of thermal insulating systems	23
5. Factors affecting planning and programming	6	11.1 Optimum effectiveness	23
		11.2 Extent of system	23
		11.3 General	23
		11.4 Factors for consideration	23
Section two.		Section three.	
Selection of insulating materials and systems		Site considerations	
6. Typical characteristics	7	12. Basis and method of presenting schedule of work	25
6.1 Thermal conductivity	7	13. Packaging and transport to site	25
6.2 Physical forms	7	13.1 Suitable methods of packing	25
6.3 Bulk density	7	13.2 When to use cartons or crates	25
6.4 Suitability for service temperature	7	13.3 Need for weatherproof protection	25
6.5 Thermal expansions	7	13.4 Protection against crushing	25
6.6 Resistance to compaction	7	13.5 Packing of plastic compositions and finishing compositions or cements	25
6.7 Resistance to water vapour penetration and to water absorption	7	13.6 Methods of identification of packages	26
6.8 Mechanical strength and durability	8	14. Labour and supervision	26
6.9 Fire and explosion hazards	8	15. Provision of storage space: protection and safety during storage	26
6.10 Resistance to vermin and fungus	8	16. Provision of power, water, light, heat and accommodation for personnel	26
6.11 Health hazards	8	16.1 Power and water	26
6.12 Suitability for removal and replacement	9	16.2 Light and heat	26
6.13 Optimum life	9	16.3 Accommodation and storage	26
6.14 Optimum heat capacity	9	17. Provision of access equipment	27
6.15 Freedom from objectionable odour	9	18. Responsibility for studs, cleats, etc.	27
6.16 Corrosion	9	19. Observance of site safety and security regulations	27
6.17 Chemical resistance	9	20. Protection of adjacent plant and machinery	27
6.18 Maintenance requirements	9	21. Clearing waste material from site	27
7. Selection of thermal insulating materials	9	22. Health considerations	27
7.1 General	9		
7.2 Types available	10	Section four.	
7.3 Typical properties of thermal insulating materials	10	Methods of application	
7.4 Identification of asbestos-free thermal insulating materials	14	23. General	28
7.5 Dimensions	14	24. Surface preparation and accessories	28
7.6 Applicability of thermal insulating materials	14	24.1 Surface preparation	28
8. Selection of securing materials	16	24.2 Attachments	28
8.1 General	16	24.3 Insulation supports	29
8.2 Adhesives	16	24.4 Securement	30
8.3 Mechanical securements	19	24.5 Reinforcement	30
8.4 Combination	20	25. Cold insulation: application for systems operating in the temperature range -100°C to +5°C	31
9. Selection of vapour barriers	20		
9.1 Vapour barriers: general	20		
9.2 Vapour barriers for use over insulation on surfaces below dew point	20		
9.3 Vapour barriers for use over insulation on surfaces above dew point	20		

	Page		Page
25.1 General	31	33.9 Provision for differential thermal movement	59
25.2 Adhesives and fastenings	31	33.10 Provision for preventing settlement and cracking	59
25.3 Typical erection methods	31	33.11 Insulation of pipes in ducts and subways	59
25.4 Pipework and fittings	32	33.12 Insulation for air-conditioning ductwork	59
25.5 Vessels and large curved surfaces	32	33.13 Fire hazards	60
25.6 Air conditioning ductwork	33	33.14 Insulation against freezing	61
25.7 Flat and irregular surfaces (including machinery)	34	33.15 Protection against surface condensation	62
26. Hot insulation: application for systems operating in the temperature range +5°C to 870°C	34	33.16 Vapour barriers	62
26.1 General	34	33.17 Corrosion, stress-corrosion cracking and liquid metal attack	66
26.2 Pipework	34	34. Formulae and calculations	68
26.3 Vessels and large curved surfaces	36	34.1 List of symbols	68
26.4 Air ducts and gas flues	38	34.2 Heat flow through insulation	69
26.5 Flat and irregular surfaces (including machinery)	42	34.3 Surface temperature	70
		34.4 Interface temperature	70
		34.5 Surface coefficients	70
		34.6 Determination of design thickness	72
Section five.			
Finishes: methods of application		Tables	
27. Indoor finishes	43	1. Typical materials for higher temperature ranges	11
27.1 Hard-setting composition or self-setting cement	43	2. Typical materials for lower temperature ranges	13
27.2 Textile fabrics	43	3. Guide to colour change of asbestos-free insulating materials after service	14
27.3 Plastics sheet and elastomer sheet	43	4. Insulation bonding adhesives for preformed sections and slabs	17
27.4 Mastic and coating finishes	44	5. Thickness of metal cladding	45
27.5 Metal sheet	44	6. Recommendations for respiratory protective equipment	51
27.6 Board finishes	46	7. Thermal conductance of vertical closed air spaces	55
28. Weather resistant finishes	46	8. Typical values for water-vapour permeance	64
28.1 Metal sheet	46	9. Water-vapour permeance conversion factors	65
28.2 Weatherproofing compounds	47		
28.3 Self-setting cement	48	Figures	
28.4 Plastics sheet and elastomer sheet	48	1. Typical conductivity values for insulating materials	76
28.5 Roofing felt and wire netting	48	(a) Materials for use at relatively high temperatures	76
29. Ultimate treatment of finish: painting	48	(b) Materials for use at intermediate temperatures	77
		(c) Materials for 'cold' insulation	77
Section six.		2. Contraction joints: linear thermal movement of materials	78
Inspection, testing and maintenance		(a) Typical contraction joints in insulated piping (refrigeration)	78
30. Inspection and testing	49	(b) Linear thermal movement of various materials between +20 °C and -100 °C	79
31. Site maintenance recommendations	49	3. Detail of a typical compression/support joint (refrigeration)	80
31.1 General	49	4. Typical cladding and/or insulation support for vertical pipework	81
31.2 Inspection, maintenance and sealing of insulation containing asbestos	49	(a) Spacing of joints (hot insulation)	81
31.3 Stripping old asbestos-containing insulation	49	(b) Support arrangements (hot insulation)	82
		5. Typical method of insulating vertical vessel when welding is permissible on site	83
Section seven.		6. Typical method of insulating vertical vessel that has been stress relieved	83
Guarantees			
32. Guarantees: general	52		
Section eight.			
Design considerations			
33. Practical considerations	53		
33.1 General	53		
33.2 Economic thickness	53		
33.3 Effect of air spaces	54		
33.4 Thermal efficiency	56		
33.5 Specified conditions at the point of delivery	57		
33.6 Protection of boundary surfaces	58		
33.7 Protection of personnel	58		
33.8 Clearance between insulation and the surrounding surfaces	58		

	Page		Page
7. Typical insulation support for bottom of hot vessel	84	30. Details of inverted collars at manholes etc.	98
8. Hanger for horizontal insulated pipe (refrigeration)	85	31. Typical method for insulating vessels with conical bottoms	99
9. Two-piece strap, direct contact, insulation covering strap	85	32. Typical method for the insulation of dished ends of vessels	99
10. Two-piece strap using insulating ring	86	33. Typical method for insulating roof and sides of vessel with internally reinforced roof	100
11. Typical method of insulating flanges (for cold work)	87	34. Joints in sheet metal	101
12. Typical method of insulating branches of vessels (for cold work)	88	35. Insulated support plate for metal cleading: 150 mm square	102
13. Typical method of insulating manhole (cold work)	88	36. Typical expansion joint between hot vessel and self-setting cement covering	102
14. Typical method of insulating dished ends of cold vessels	89	37. Time to reach freezing point from 10 °C (static water in a pipe): air at -10 °C, thermal conductivity of insulation 0.04 W/(m K)	103
15. Typical methods of insulating pipe flanges	89	38. Additional time for complete ice formation (static water in a pipe at 0 °C): air at -10 °C, thermal conductivity of insulation 0.04 W/(m K)	103
16. A method of insulating pipe flanges (hot insulation)	90	39. Chart solution of the expression $\chi = 0.5 (d_o + 2L) \ln (1 + 2L/d_o)$	104
17. Method of insulating a valve (applicable to a plastic finish)	91	40. Vapour barriers: suggested values for water vapour permeance	105
18. Typical method of staggering insulation sections on a straight pipe	91	41. Modifying factor C for heat loss curves (streamline flow)	106
19. Two-piece strap, direct contact, insulation clear of strap	92	42. Surface coefficient against emissivity parameter (turbulent flow) for vertical planes, large cylinders and for average bodies of various shapes: based on constant of $B=1.45$	107
20. U-bolt cradle, direct contact	92	43. Total heat exchange to still atmosphere at 20 °C (turbulent flow): based on constant of $B=1.45$	108
21. Inverted U-bolt cradle, direct contact	93	44. Saturation vapour pressure against temperature over ice	109
22. U-bolt cradle using insulation ring	93	Index	110
23. Inverted U-bolt cradle using insulation ring	94		
24. Two-piece strap cradle using insulation ring	94		
25. Typical method of insulating flexible pipe	95		
26. Typical method of insulating expansion bellows	95		
27. Typical method for insulating steam traced pipe	96		
28. Metal box valve cover	97		
29. Removable flange box	98		

Foreword

This British Standard code of practice has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee and replaces CP 3005 : 1969, which is now withdrawn.

The code explains the basic principles that should be followed in selecting the most suitable insulating systems for specific requirements. It is not practicable to deal with every possible combination of insulating material and finish, so general principles only are indicated. For clarity, the subject has been dealt with in eight main sections covering: general considerations; selection of insulating materials and systems; site considerations; methods of application; finishes; inspection, testing and maintenance; guarantees; design considerations.

Owing to the complexity of the thermal insulation industry and to the wide variation in site conditions, it has been difficult to avoid referring to matters that may be considered to be the subject of contractual arrangement rather than of technical importance; brief mention only has

been made of such matters to ensure that they are given appropriate consideration.

The guiding principle in the preparation of this standard has been to give a guide to good current practice while indicating the basic principles by which new materials can be assessed and adapted for use under the widely differing conditions that so often challenge the skill of the insulation contractor.

Several British Standards for the use of thermal insulating materials are available, and these give recommended methods for selecting suitable thicknesses based on a knowledge of the manufacturer's declared value for thermal conductivity at the appropriate temperature of use. They do not attempt to indicate the methods by which appropriate materials may be selected, or by which they may be applied on site. Other standards available, or in course of preparation, deal with methods of test and with the characteristic properties of individual materials.

British Standard Code of practice for

Thermal insulation of pipework and equipment (in the temperature range -100°C to $+870^{\circ}\text{C}$)

Section one. General

1. Scope

This standard deals with thermal insulation for pipework and equipment in the temperature range -100°C to $+870^{\circ}\text{C}$ but excludes structural insulation of buildings and cold stores, fireproofing structures, refractory linings of plant, airborne installations and all external underground mains. The code may be found to be generally applicable to the insulation of road and rail transport vehicles and of some assistance in marine insulation.

Specifications corresponding to parts of this code are contained in BS 5422.

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 preformed insulating material. Thermal insulating material that is prefabricated in such a manner that at least one surface conforms to the shape of the surface to be covered and that, when handled, will maintain its shape without cracking, breaking, crumbling or permanent deformation.

3.2 plastic composition insulating material. Thermal insulating material in loose, dry form that is prepared for application as a paste or dough, usually on site, and that is dried, naturally or artificially, in situ to form a continuous insulating layer.

3.3 flexible insulating material. Thermal insulating material that, lacking rigidity, tends to drape or to conform to the shape of the surface against which it is laid.

3.4 mineral fibre. Inorganic fibrous material from rock, slag, glass or ceramic origin, but excluding asbestos.

3.5 loosefill insulating material. Thermal insulating material in the form of powder, granules or loose pelleted fibres that is used in the dry state as a filling in cavities, casings or jackets. Blown or poured insulating materials are also covered by this definition (see also 7.2.4).

3.6 reflective insulation. Foil or thin sheet material of low emissivity that has the ability to reflect incident radiant heat. See 7.2.9.

3.7 thermal conductivity. The quantity of heat that passes in unit time through unit area of a homogeneous flat slab of infinite extent and of unit thickness when unit difference of temperature is established between its

faces.

Unit: $\text{W m}/(\text{m}^2 \text{K})$, simplified to $\text{W}/(\text{m K})$.

3.8 bulk density. The mass per unit volume of dry thermal insulating material.

Unit: kg/m^3 .

3.9 finishing materials. All materials used for covering thermal insulation, whether applied in a factory or on site.

3.10 hard-setting composition. Clay-bound finishing material supplied in loose dry form that is prepared for application by mixing with water and is dried in situ by the application of heat.

3.11 metal cladding, cladding, sheathing. Sheet metal fitted as a protective finish over insulation.

NOTE. These terms have the same meaning but local usage may vary.

3.12 self-setting cement. Finishing material supplied in loose dry form that is prepared for application by mixing with water. It will dry in situ without the application of heat and normally will give a harder finish than hard-setting composition. Normally the material contains Portland cement.

3.13 gypsum plaster. Finishing material supplied in loose dry form that is prepared for application by mixing with water. It will dry in situ without the application of heat. Normally the material is based on calcined gypsum with fibre reinforcement.

3.14 plastics insulating and finishing materials. A wide group of compounds, substantially organic, usually based on synthetic polymers or on modified polymers of natural origin.

NOTE. The use of the letter 's' at the end of the word 'plastics' serves to distinguish these organic products from those plastic inorganic products that derive their name from admixtures with water to form a paste or dough before application.

3.15 mastic. A protective finish of relatively thick consistency and with some degree of permanent flexibility, suitable for application to thermal insulation or other surfaces, usually by spray or trowel, in heavy layers of thickness greater than 1 mm.

3.16 coating. An aqueous dispersion or solution in organic solvent of a polymeric plastics compound, of consistency suitable for application by brush or spray in thicknesses of about 1 mm or less. The coating usually 'dries' in situ by evaporation of the liquid carrier.

3.17 paint. A suitably filled dispersion of powders in an organic drying oil or similar vehicle that hardens to form a substantially continuous film on drying.

3.18 polymeric plastics compound. A compound formed by the reaction of simple organic molecules (monomers) having groups that will react to form compounds of higher molecular weight under suitable conditions.

3.19 water vapour barrier. Material used to restrict the transmission of water vapour. As a general rule the permeance for a given material layer will vary with the temperature difference between the warm and the cold faces. See figure 40 and **33.16.16**.

3.20 permeance. The rate of transmission of water vapour through the actual thickness of a material, as applied, expressed in relation to unit difference of vapour pressure between the two principal faces, and per unit area.

Unit: g/(s MN). See table 9 for conversions.

3.21 permeability. The rate of transmission of water vapour through unit thickness of a material when unit difference of vapour pressure is maintained between the two principal faces.

Unit: g m/(s MN).

4. Exchange of design data

4.1 Information to be supplied by the purchaser. The purchaser should state either:

- (a) precise details of the insulation requirements, or
- (b) the service conditions for which the insulating materials are required so that the insulating contractor can make recommendations.

In the case of (b) the purchaser should provide the relevant information detailed in **4.1.1** and **4.1.2**.

4.1.1 Details of plant to be insulated

- (a) Location. Whether indoors, outdoors but protected, outdoors exposed to weather, enclosed in ducts or trenches below ground level.
- (b) Difficult or unusual site conditions that will influence the selection or application of insulating materials, or both, e.g. in regard to transport, scaffolding, weather protection or excessive humidity.
- (c) Type of material to be insulated, with details of special or unusual materials.
- (d) Dimensions of surfaces. If these are adequately detailed on drawings, preferably coloured to indicate areas to be insulated, the provision of copies of the drawings may be sufficient; otherwise detailed information will be required, e.g.
 - surface dimensions of flat or large curved areas;
 - external diameters of pipes;
 - lengths of each size of pipe;
 - number and type of pipe fittings, e.g. flanged joints, valves, tees, expansion bends.
- (e) Details of any pipework sections that are to be trace heated, of the trace-heating method and of the arrangements of insulation required.
- (f) Details of any sections to be left uninsulated to facilitate testing, e.g. welded and flanged joints.
- (g) Confirmation, with details, that heat will be available in insulated pipework for drying out any plastic insulating material or finishing composition used by the contractor.

4.1.2 Temperature conditions

- (a) Normal working temperature for each portion of the plant to be insulated.
- (b) Maximum temperature for each hot surface, if higher than (a).
- (c) Ambient temperature. Where a specified temperature is required on the outer surface of the

insulation (see note 1) it may be necessary also to give the conditions of ambient air for which the surface temperature is to be calculated, e.g. velocity of air passing over the surface (see also note 2).

(d) Any requirement to prevent condensation on the warm face of an insulated pipe or vessel containing cold media.

NOTE 1. A specified temperature on the surface of the insulation may be required for the following reasons:

- (a) to protect personnel, e.g. local insulation of hot pipes;
- (b) to provide local 'comfort conditions', e.g. at control panels and in operating galleries;
- (c) to provide a means of indicating the effectiveness of the insulation. This is deprecated, as the surface temperature will depend upon the diameter over the insulation, on the ambient conditions, and on the nature of the outer surface. Pipes of small diameter will show relatively low surface temperatures, but high unit rates of heat loss; air flow over the outer surface will tend to reduce the surface temperature but will increase the unit rate of heat loss; a polished metal surface will show appreciable increase in surface temperature compared with a non-metallic finish although the unit rate of heat loss will be reduced.

NOTE 2. Normally, the theoretical heat loss will be based on the manufacturer's declared value of thermal conductivity and, unless otherwise stated, it will refer to conditions of ambient still air at 20 °C. When making use of these theoretical figures, therefore, allowance has to be made for the effect of the ambient conditions at site and for supplementary heat losses such as will occur through supports, hangers, valve control wheels and other fittings. It should be noted that 'thermal efficiency' (see **33.4**) is not included.

As it is extremely difficult to measure with accuracy either the surface temperature or the heat loss from the surface of the insulation under site conditions, some reservation should be made when interpreting site measurements.

4.1.3 Preparation of surfaces (see also clause **24**). Special requirements, e.g. for the removal of works-applied protective paint or lacquer, or for the application at site of paint or other protective coating to the surface to be insulated, should be clearly stated.

4.1.4 Types of fittings and supports. Types of fittings and supports and whether or not these are to be provided by the purchaser (see **8.3** and clause **24**).

4.1.5 Type of insulation required

- (a) Main insulation for each portion of plant, e.g. preformed, plastic composition, flexible, loosefill, insulating concrete.
- (b) Insulation for bends, flanges, valves, hangers and other fittings.

4.1.6 Type of finish required. For example, hard-setting composition or self-setting cement, weatherproofing compound, sheet metal.

4.1.7 Special service requirements. For example, resistance to compression, resistance to fire, resistance to abnormal vibration. If there is any special hazard from contact with chemicals or oils on the plant, attention should be drawn to this.

4.1.8 Basis on which the thickness of insulation is to be determined. For example:

- (a) specified temperature on outer surface of insulation (see note 1 to **4.1.2**);
- (b) specified heat loss per unit dimension, linear or superficial (see note 2 to **4.1.2**);
- (c) economic thickness (see note 1);
- (d) specified conditions of temperature of the surfaces to be insulated (see note 2).

BS 5970 : 1981

Section one

- (e) specified conditions of fluid at point of delivery;
- (f) special thickness requirements.

NOTE 1. If the 'economic thickness' is required to be calculated the following additional information will be necessary:

- (a) cost of heat to be used for calculation purposes, e.g. pence per useful megajoule;
- (b) evaluation period (working hours);
- (c) whether or not the cost of the finish is to be included in the calculation.

NOTE 2. Insulation to provide specified conditions at the boundary surfaces of the containment system may be required for reasons such as:

- (a) to avoid differential thermal expansion between the insulated surface and adjacent structures;
- (b) to prevent condensation of moisture on the internal surfaces of the containment system, e.g. in waste gas flues;
- (c) to prevent the condensation of moisture on the external surface of insulated plant containing cold media;
- (d) to ensure that the walls of the containment system are not subjected to excessive temperatures.

Each application should receive special consideration when such factors as these are operative as they may be of dominant importance in controlling permissible heat losses.

4.2 Information to be supplied by the manufacturer or contractor

- (a) Information pertaining to the relevant portions of 4.1.
- (b) The manufacturer's declared value of thermal conductivity (λ) appropriate to the temperature of use, plus the corresponding bulk density. The manufacturer's declared value should include any necessary commercial tolerances. When the thermal conductivity is liable to change on ageing, the aged value should be stated.
- (c) Limitations of use, physical and chemical.
- (d) The overall thickness, with details of the thickness of the individual layers.
- (e) Information regarding the surface preparation.
- (f) The appropriate section of the code (to be specified) with which the following are in accord:
 - (1) insulating material;
 - (2) reinforcement (if any);
 - (3) fixing devices and finishes.

4.3 Drawings. If requested, the insulation contractor should provide drawings showing details as follows:

- (a) type and spacing of required insulation attachments;
- (b) particular methods to be adopted when applying material;
- (c) any special design that the contractor may wish to be considered;
- (d) shape and sizes of temporary buildings required by the contractor at site, together with particulars of required water, light and power supplies.

5. Factors affecting planning and programming

5.1 Insulation contractors' operations on site are dependent upon progress of other contractors. It is therefore recommended that the insulation contractor be provided with details of anticipated programmes that will control his work.

5.2 The following are the chief points to which early consideration should be given:

- (a) programme of commencing and completion dates;
- (b) availability of materials and labour;
- (c) responsibility for the supply and application of securing attachments;
- (d) preparation of surfaces;
- (e) areas to be left free from insulation on a temporary basis;
- (f) precise information on extent of work covered by contract;
- (g) limitations of access to work;
- (h) arrangements for dealing with repair and modification work;
- (i) conditions of employment at site, including the working week; labour and supervision required;
- (j) transport facilities;
- (k) storage for materials;
- (l) availability of water, power, heat and light;
- (m) accommodation and canteen facilities (including lodgings);
- (n) provision of access equipment;
- (o) special safety and security regulations (including advice of health hazards);
- (p) restriction on mixing compositions;
- (q) protection of adjacent plant and machinery;
- (r) clearing waste material from site.

Section two. Selection of insulating materials and systems

6. Typical characteristics

6.1 Thermal conductivity. A low thermal conductivity is desirable to achieve a maximum resistance to heat transfer. Therefore, for any given heat loss, a material of low thermal conductivity will be thinner than an alternative material of high conductivity. This is of particular advantage for pipes because thinner layers of insulation reduce the surface area emitting heat, and also reduce the area of the outer surface that will require protection.

The thermal conductivities of most insulating materials vary with temperature and with bulk density, so that both these factors should be considered. It is the normal practice of manufacturers to provide tables or graphs showing thermal conductivities for each of their standard products at a range of hot-face temperatures together with the relevant cold-face temperatures used for the tests. The information should also include the bulk density for each material tested. Materials for use under 'hot' conditions will normally be tested with a cold-face temperature in the range 10 °C to 50 °C. Materials for use at temperatures below about 5 °C will be tested with one face at or near to the required low temperature, with the other face within the range 5 °C to 20 °C. The recommended test figures are given in BS 874.

Although, under service conditions for insulating materials at elevated temperatures, the outer exposed surface may reach a temperature above that quoted for the test, the figures for any calculation of heat flow can normally be based on those published by the manufacturer. Provided that the outer surface temperature does not exceed about 50 °C, the resultant error is likely to be less than 5%.

For very high cold-face temperatures, which could apply, for example, with the inner layer of composite insulation or with materials exposed to high ambient temperatures on the exposed surface, special calculations are required (see 34.4 and BS 5422). These may involve reference to 'mean' temperatures, i.e. the arithmetic mean between the hot-face and cold-face temperatures of test; to avoid confusion, either the corresponding hot-face or cold-face temperature should also be quoted.

6.2 Physical forms. Insulation is usually supplied in one of the following forms: preformed (slabs or sections), loosefill, flexible, plastic composition, sprayed or metallic, e.g. crimped foil.

Each of these will be made up of granular, fibrous, cellular or reflective material (or a combination of these) depending on the purpose for which it was developed.

For lists of typical materials see tables 1 and 2.

Some of these materials may be used in a vacuum-type insulation system.

6.3 Bulk density. The bulk density for most thermal insulating materials falls within the range 16 kg/m³ to 320 kg/m³ and their effectiveness depends essentially on the large numbers of minute air or gas cells that they contain and that restrict transfer of heat by convection and radiation; at the same time, the limitation in areas of solid thermal bridges forms a good barrier to the passage of conducted heat.

Low bulk density is normally associated with low thermal conductivity in the low and medium temperature ranges, but it may also result in low compressive strength, in which case the material will not be suitable for loadbearing purposes.

As a general rule, increase in bulk density is associated with reduction in the size of the contained air or gas cells and this tends to maintain effectiveness of insulation at the higher service temperatures.

NOTE. Some physical properties of thermal insulating materials, in particular thermal conductivity and strength, are dependent on the direction in which they are measured.

6.4 Suitability for service temperature. The temperature at which the material is used should be within the range for which it will provide satisfactory long-term service under conditions of normal usage. See tables 1 and 2 for a guide to approximate operating temperatures.

For materials to be used at temperatures below about 10 °C, attention should be paid to the relevant limiting minimum as well as to the limiting maximum temperatures, and to the effects of possible excessive shrinkage, embrittlement, and porosity, in addition to resistance under conditions of occasional heating for defrosting purposes.

For materials to be used at elevated temperatures it will be necessary to consider the many factors that may result in deterioration under conditions of service. These include linear shrinkage under heat, loss of compressive strength and of weight during heating, and the effects of vibration and possible self-heating phenomena. In establishing maximum operating temperatures for preformed high-temperature insulation, particularly that in the form of pipe sections, the ability of the insulation to withstand moderate loads and vibration whilst in service should be considered. Some knowledge of the compressive strength both before and after heating may be of value. Additionally, the effect of long-term heating should be studied.

Where the compressive strength in service undergoes significant reduction, as in the case of bonded mineral wool due to volatilization of the organic binders at temperatures above about 260 °C, it may be necessary to support and protect the insulating material. Metal cladding (see table 5) is convenient for this purpose; where additional strength is required, the metal should be supported from the pipe independently of the insulation, e.g. by insulated metal spiders or by suitable loadbearing insulation.

It is preferable that the appropriate tests should be carried out by the manufacturer and the results used to compile a report on suitability for particular applications; judgement is then needed in selecting material for specific conditions of use.

6.5 Thermal expansions. Most thermal insulating materials have a lower thermal expansion coefficient than metals. Differential thermal movement between the insulated surface, insulation and outer finish should be considered.

6.6 Resistance to compaction. Loosefill material and unbonded mattresses are liable to compact under the influence of vibration and thermal cycling.

6.7 Resistance to water vapour penetration and water absorption. Whilst closed-pore materials, e.g. cellular glass, may have appreciably low water-vapour

permeability characteristics, open-pore and fibrous insulating materials can absorb considerable quantities of water that will adversely affect the thermal conductivity and the effectiveness of the insulation.

Insulation applied to cold surfaces has to be protected from water-vapour penetration that gives increased conductivity. If water is allowed to penetrate and freeze, the cells of the insulation may rupture and the material be permanently damaged. It is an advantage if the material itself is of low water-vapour permeability.

6.8 Mechanical strength and durability

6.8.1 Mechanical strength. In general, insulating materials are mechanically weak and strength normally decreases after heating. The finish applied frequently affords some protection against mechanical damage, but the insulation itself should be strong enough to withstand reasonable handling. Strength and abrasion resistance should be related to the work and material in question, and have to be taken into consideration at the design stage.

6.8.2 Durability. The durability of an outdoor insulation system may be important. For instance, shrinkage in sunlight or breakdown by frost may have serious consequences.

6.9 Fire and explosion hazards. Whilst it is usually desirable that insulation should be non-combustible there may be areas where such materials are not necessary, in which case some relaxation could be considered; the relevant building and fire authorities should be consulted. The fire hazards, whether caused by quantity of combustible material, susceptibility to ignition, ease of surface spread of flame, or quantity of smoke or toxic gas produced in a fire may be influenced considerably by the protective coating and associated materials, e.g. adhesives, vapour barriers and sealants. Many insulating materials are free from risk, but if inadequately protected can absorb quantities of oil, etc. that may ignite spontaneously (see 10.6 and 33.13).

The production by the insulation and associated materials of large quantities of smoke and/or toxic gases is particularly hazardous within staircases and other shafts, corridors and enclosed escape routes in a building, or within ventilation ducts and ceiling voids used as ventilation ducts.

In certain areas of high fire (or explosion) risk, e.g. where powerful oxidizing agents are handled, the insulation should not contain any organic matter. See also 7.6.2.8.

6.10 Resistance to vermin and fungus. The resistance of insulation to vermin, insects and fungal growth can be important, particularly in cold stores or food factories. Insulation surfaces likely to become wet should not be finished with materials that may be attacked by these agencies. Finishing with non-absorptive materials is desirable for severe cases.

6.11 Health hazards

6.11.1 Attention is drawn to the First Report entitled: 'Asbestos: Work on Thermal and Acoustic Insulation and Sprayed Coatings', issued by the Advisory Committee on Asbestos (ACA) who recommended, inter alia, that:

- (a) It should be made an offence to apply asbestos or any product containing asbestos by means of a spray process (Recommendation 1), and
- (b) A ban should be put on the use of materials containing asbestos for any *new* thermal or acoustic insulation except in any limited applications for which

suitable substitutes are not yet available. This recommendation does not affect products which may have thermal or acoustic insulation properties incidental to their main functions, such as asbestos cement and fire protection board (Recommendation 2).

See also the Second Report of the Advisory Committee on Asbestos.

6.11.2 Reference should be made at all times to the requirements of the Health and Safety at Work Act 1974, to the appropriate instructions from manufacturers, and to other relevant publications that may be issued from time to time. See also HSE Discussion Document (1979) on the health aspects of 'Man-made Mineral Fibres' available from HMSO.

6.11.3 Certain finishing cements are strongly alkaline when wet and may cause skin irritation. Gloves should be worn when handling these materials.

6.11.4 Chemical fumes from the components of some insulating materials, e.g. foamed urea-formaldehyde, phenol-formaldehyde resins, isocyanates and polyurethanes can be toxic or cause bronchial irritation, sometimes with persistent sensitization effects. When materials of these types are sprayed, new hazards can arise because non-volatile components are formed into respirable aerosols. Suitable respiratory protective equipment should be provided and, particularly in confined spaces, air-fed hoods or respirators are required for many materials, especially isocyanates and epoxy-resin compounds.

6.11.5 Contact with certain resinous coatings, adhesives and epoxy-resin components can cause dermatitis, which may occur after brief contact, or long exposure leading to allergy. Associated solvents may cause damage to the eyes and skin irritation (see Health and Safety at Work Act 1974). Goggles and gloves should be worn when necessary. Barrier cream and the provision of adequate washing facilities will be of assistance. Special respiratory hazards can exist when these materials are sprayed.

6.11.6 Many fibrous insulating materials can cause skin irritation. Normally this is associated with the coarser fibres, so that the same materials of smaller fibre diameter may not cause this type of irritation, although they may then have other undesirable effects. (See 6.11.7 and also BS 4275.) The use of barrier creams and the provision of adequate washing facilities will help to reduce the incidence of skin irritation, but tight clothing, e.g. round the neck and at the wrists, may trap fibres and thus increase local irritation. (See HSE Technical Data Note No. 14; 'Health and Dust in Industry', and the Health and Safety at Work Act 1974.)

6.11.7 Respirable dust particles from insulating material containing asbestos, silica, etc., may enter the bronchial passages and cause persistent lung disease. Because of this risk to health where these materials are manipulated, e.g. mixed, handled or removed, adequate protective equipment should be provided and used. Insulating materials maintained in good order in quiescent use are likely to present only a low degree of risk.

6.11.8 The risks to health associated with the removal of thermal insulation containing asbestos are particularly well-known, especially when crocidolite (blue asbestos) is encountered (see 6.11.9 and clause 31). Diseases that have been related to asbestos are: asbestosis, lung cancer, and mesothelioma. Reference should be made to HSE Guidance Note EH10, 'Asbestos, Health and Safety'.

Standards and Measurement of Air-borne Dust Concentrations' and to HSE Certificate of Approval (Respiratory Protective Equipment) 1978, with Schedule (revised annually).

6.11.9 Before any stripping work is carried out it is necessary to determine what type of insulating material is involved (see clause 31). Although the presence of crocidolite is sometimes discernible by its rich lavender-blue colour, it is not correct to rely on this test alone. It is always necessary to obtain positive analysis by a responsible laboratory.

Where the Asbestos Regulations 1969 apply and where crocidolite is identified, written notice has to be given to the Inspector for the District at least 28 days prior to commencement of the work, or such shorter notice as the Inspector may agree to accept.

For the disposal of any waste asbestos, see 31.3.2.8.

6.12 Suitability for removal and replacement. When removal and replacement of insulation is to be undertaken, reference should be made to the recommendations of 6.11.1, 6.11.6, 6.11.7, 6.11.8, 6.11.9 and clause 31.

6.13 Optimum life. The required life of the insulation system should be considered because this affects the annual cost and hence the economic thickness. If the plant has only a short life, a cheap insulation system may be adequate; if the plant has a longer life, a more expensive insulation system with longer life may be the more economical.

When the technical requirements of the application have been met, the total cost (as distinct from the initial cost) during the life of the installation is the prime consideration. See 33.2 for economic thickness.

6.14 Optimum heat capacity. As the heat capacity (alternatively 'thermal capacity') of an insulating material varies according to its bulk density, it is preferred that this thermal property shall be expressed in terms of 'heat capacity per unit mass' (alternatively 'specific heat capacity'). In SI units this value is expressed in J/(kg K). It should be noted that the value will vary with 'mean temperature' even though it is given in terms of unit increment of one kelvin.

An insulating material of low thermal capacity will absorb relatively small quantities of heat with increase of temperature and consequently, under fluctuating temperature conditions, it will be associated with rapid heating and cooling. Conversely, a material of high heat capacity will tend to impart thermal stability to an insulated system.

For certain applications it may be convenient to refer to 'heat capacity' per unit volume, J/(m³ K), but this value will be typical only for a representative product, i.e. at a specific bulk density.

6.15 Freedom from objectionable odour. It is of particular importance that insulating materials for use in food factories, canteens or buildings in which food is processed or served, should be free from objectionable odour. See also 6.10.

6.16 Corrosion. An insulated metal surface may be affected by corrosive attack if the insulating material is applied in a wet state or if it is allowed to become wet for prolonged periods after application. The corrosion may be specific or general.

A typical example of specific corrosive attack is that of stress-corrosion cracking of austenitic steel due to the

action of water-soluble chlorides in the presence of moisture. Most thermal insulating materials contain traces of water-soluble chlorides. Additionally, some organic-foam insulating materials contain chlorinated organic compounds that may form soluble chlorides when heated in the presence of water. Both can give rise to stress corrosion cracking in susceptible austenitic alloys, even if only trace quantities are present. It is not practicable to indicate a safe upper limit for chloride content as water can leach out soluble chlorides from substantial volumes of wet insulating material and allow them to be concentrated at the junction layer with the metal surface. Additionally, ingress of water from external sources, e.g. rain water, plant spillages and water used for hosing-down equipment, may contain sufficient chloride to be potentially dangerous.

General corrosion may occur if wet insulation is allowed to remain in contact with carbon steel surfaces for prolonged periods, particularly if acidic products are present in the water or if they can be extracted from the insulating material itself. Due regard should also be paid to possible corrosive attack on a variety of metals, e.g. those used as finishes, that may be in contact with wet insulating materials.

See 33.17 for more detailed treatment of corrosion problems.

6.17 Chemical resistance. Thermal insulation used in process plants should not react with chemicals present.

6.18 Maintenance requirements. Maintenance costs can be significant in the total cost of an insulating system. These costs can be minimized by correct selection of materials and finishes and by attention to detail in the layout of the system. Particular attention should be given to the accessibility of removable sections, valves, etc., and the protective systems used in inaccessible locations such as ducts.

7. Selection of thermal insulating materials

7.1 General. Before deciding on the insulating material to be used for any specific purpose, the following factors should be considered.

<i>Heat insulation</i>	<i>Refrigeration</i>
(a) Cold-face temperature (min. and max.)	Cold-face temperature (min. and max.)
(b) Hot-face temperature (max. and min.)	Warm-face temperature (max. and min.)
(c) Ambient temperature	Ambient temperature and humidity
(d) Thermal conductivity	Thermal conductivity (aged)
(e) Thickness of insulation required.	Thickness of insulation required.
(f) Mechanical strength	Mechanical strength
(g) Health hazard (see 6.11)	Health hazard (see 6.11)
(h) Fire hazard	Fire hazard
(i) Thermal movement (expansion)	Thermal movement (contraction)
(j) Permeability of insulating material with need for protection	Vapour sealing of system
(k) Protective covering and finish	Protective covering and finish
(l) Cost (including that for application and finish)	Cost (including that for application and finish)

7.2 Types available

NOTE. The meaning of the terms used in this subclause is explained in BS 3533.

7.2.1 General. Although all thermal insulating materials, with the exception of reflective insulation, depend on entrained air or gas for their effectiveness, it is convenient to classify them according to their type of structure or method of application as set out in 7.2.2 to 7.2.13.

7.2.2 Preformed. Normally this term is applied to slabs, pipe sections and related shapes based on cellular granules or mineral fibres that are bonded to form a substantially rigid mass, but it will also include such products as rigid cellular plastics, cellular glass and bonded natural materials, e.g. cork and exfoliated minerals.

7.2.3 Flexible. In addition to such fibrous products as felts, blankets, mats and mattresses this type includes flexible foamed or expanded plastics materials, many of which differ from the true preformed materials only in the ease with which they can be bent or compressed to shape. Textile products, e.g. woven cloth, tapes, twisted yarns, and plaited packings are also of this type.

7.2.4 Loosefill. Included in this type are all granular, fibrous, and various discrete aggregates that can be poured or lightly packed into cavities, casings or jackets. Loose or lightly bonded fibrous materials, shredded plastics polymers, and loose expanded volcanic or micaceous products, e.g. perlite or vermiculite, as well as such insulating aggregates as foamed slag and granulated diatomaceous brick would also fall under this heading.

7.2.5 Plastic composition. Material of this type consists of insulating aggregate, with or without fibrous reinforcement, that is prepared for application as a paste or dough by mixing with water. Normally the wet materials require the use of heat for drying out after application, but some products harden by hydraulic setting. It is important to distinguish between plastic compositions and organic plastics materials; the latter are spelt with a letter 's' at the end of the word 'plastics' (see also note to 3.14 of this standard).

7.2.6 Spray-applied. Granular, foamed or fibrous material that adheres to the surface on application by means of a spray-gun. An adhesive may be included in the original mix or it may be applied through a separate nozzle during the application process. In no circumstances should insulating material containing asbestos be sprayed.

7.2.7 Foamed in situ. Normally cellular organic plastics agglomerates that are foamed in a cavity by physical or chemical means during or immediately after application.

7.2.8 Microporous insulation (silica aerogel). Opacified fine powder having microscopic pores that confer particularly low thermal conductivity properties, lower than those of still air at the same temperatures. It is available as block encapsulated in metal foil or woven fabric.

7.2.9 Reflective insulation. Foil or thin sheet material of low emissivity that has the ability to reflect incident radiant heat. Metals such as aluminium foil and thin polished stainless steel sheet are common examples, but reflective metal deposited on plastics film will also be included. These materials are normally used in association with one or more air spaces, which may be closed or open.

7.2.10 Insulating boards. Rigid or mainly rigid boards, often with fibrous reinforcement, bonded into a compact mass. The bonding material may be a hydraulic cement, a lime-silica reaction product, gypsum, or an organic plastics polymer.

7.2.11 Insulating bricks and allied products. Rigid insulating shapes, based on an inorganic lightweight aggregate and bonding clay, that are produced by firing at relatively high temperature in a kiln. These include products that contain kieselguhr or exfoliated vermiculite as the aggregate.

7.2.12 Insulating concretes. Typical products may consist of concrete made from a lightweight porous aggregate with hydraulic cement as the bonding agent, or they may be made into cellular form by aeration or by foaming prior to or during the initial stages of the hydraulic setting process.

7.2.13 Prefabricated shapes. For specialized types of application it may be advantageous to fabricate the insulation to predetermined shapes for ease of application and removal. Various types of insulating material can be used for this purpose, as also can various types of covering material. Typical products would be prefabricated valve covers, insulated metal valve boxes, prefabricated flexible mattresses and thin layers of fibrous or granular filling sealed inside prefabricated metal-foil envelopes.

7.3 Typical properties of thermal insulating materials. Table 1 indicates some typical characteristics for a number of thermal insulating materials available for use, mainly for temperatures higher than the ambient temperature.

Table 1. Typical materials for higher temperature ranges

Ref.	Material	Physical forms	Type	Approximate maximum operating temperature*	Normal bulk density	Compressive strength†
				°C	kg/m ³	
1	Aluminium foil	Plain/corrugated foil	Reflective	500		Negligible
2	Stainless steel	Dimpled foil	Reflective	760		Negligible
3	Mineral fibre (glass)	Loosefill‡	Fibrous	510		Negligible
4		Resin-bonded slabs	Fibrous	230 to 510§	16 to 96	Fair/good
5		Preformed pipe sections	Fibrous	230 to 510	80 to 160	Fair/good
6		Mattresses	Fibrous	510	48 to 144	Fair/good
7		Flexible strip, ropes, twisted yarn, woven cloth and tape	Fibrous	230 to 510	48 to 96	Negligible
8	Mineral fibre (rock)	Loosefill‡	Fibrous	760 to 950		Negligible
9		Resin-bonded slabs	Fibrous	260 to 760§	16 to 192	Fair/good
10		Preformed pipe sections	Fibrous	260 to 700§	80 to 144	Good
11		Flexible mattresses	Fibrous	570 to 760	88 to 128	Fair
12		Sprayed	Fibrous	760	224 to 240	Good
13	Mineral fibre (slag)	Loosefill‡	Fibrous	760		Negligible
14		Bonded slabs	Fibrous	760§	48 to 320	Negligible/good
15		Preformed pipe sections	Fibrous	260 to 700§	144 to 256	Fair/good
16		Mattresses	Fibrous	650 to 800	80 to 256	Fair
17		Flexible strip	Fibrous	230	80 to 160	Negligible
18						
19	Diatomite (kieselguhr)	Loosefill	Granular, natural	900	192	Negligible
20			Granular, calcined	1090	160	
21		Bricks and slabs	Granular	900	640	4.1 MN/m ²
22	Vermiculite	Loosefill	Granular	1090	48 to 144	Negligible
23	Vermiculite/concrete	Slabs and sprayed	Granular	430 to 1090	320	
24	Vermiculite/sodium silicate	Slabs and sprayed	Granular	890 to 980	432	Good
25	85% magnesia	Plastic composition	Granular	310	176 to 224	Fair
26		Preformed slabs	Granular	310	176 to 224	Good (345 kN/m ²)
27		Preformed pipe sections	Granular	310	176 to 224	Good
28	Calcium silicate	Plastic composition	Granular	650 to 1000	160 to 320	Fair
29		Slab/lags	Granular	650 to 1010	160 to 320	Good (345 kN/m ² minimum)

BS 5970:1981

Section two

Table 1. Typical materials for higher temperature ranges (*concluded*)

Ref.	Material	Physical forms	Type	Approximate maximum operating temperature*	Normal bulk density	Compressive strength†
				°C	kg/m ³	
30		Preformed pipe sections	Granular	650 to 760	160 to 320	Good
31	Foamed glass	Slabs and pipe sections	Cellular	400	112 to 144	(6.4 MN/m ² ultimate)
32	Alumino-silicate	Loosefill	Fibrous	1260	8 to 128	Negligible
33		Spray applied	Fibrous	1260	192	Fair
34		Blanket, felt, paper	Fibrous	1260	50 to 200	Fair
35		Ropes, tubes	Fibrous	1260	48 to 144	Negligible
36	Silica	Loosefill	Fibrous	980	8 to 128	Negligible
37		Cloth, felt tape	Fibrous	980	48 to 144	Fair
38		Opacified aerogel slatted blanket	Granular	980	192 to 384	Negligible
39	Perlite	Loosefill	Granular	870	32 to 64	Negligible
40	Polyurethane rigid foam	Slabs, pipe section, sprayed, formed in situ	Cellular	100	32 to 96	Good
41	Polyurethane flexible foam	Blanket, slab and pipe sections	Cellular	70	32 to 64	Negligible
42	Isocyanurate and phenolic rigid foam	Slabs, pipe sections, sprayed	Cellular	130 to 145	32 to 64	Good
43	Foamed slag	Loosefill	Granular	900	≤680kg/m ³	Good

* These are intended to apply only when one face is heated. When both faces are heated lower temperatures will apply.

† For fibrous materials, the compressive strength will vary with the bulk density and with the binder. See also 3.4.

‡ Loosefill materials should be packed to densities to suit the thermal conductivity required.

§ Above 260 °C compressive strength may be reduced significantly owing to volatilization of the bonding material.

|| Withdrawn.

NOTE 1. For typical thermal conductivity values see figure 1(a) and (b).

NOTE 2. Care is necessary in interpreting the maximum operating temperatures in this table. These are based on manufacturers' claimed figures and may require modification (possibly considerable) in practice.

Table 2 indicates the corresponding characteristics for typical materials particularly suitable for the lower temperature ranges, i.e. below ambient temperature, but it should be noted that the maximum service temperature for some of these materials is such that they can be used also for elevated temperatures. Additionally, this table indicates typical water-vapour permeabilities for those materials in normal use for refrigeration work, and it gives approximate maximum temperatures of use. The use of a sealed double-skin enclosure or sealed cavity may permit the use of materials of relatively high permeability to water vapour.

In figure 1:

(a) indicates typical thermal conductivity graphs for materials particularly suitable for use at relatively high temperatures;

(b) indicates typical conductivity graphs for materials normally used for 'intermediate' temperatures;

(c) indicates typical thermal conductivity graphs for 'cold' insulating materials.

Table 2. Typical materials for lower temperature ranges

Ref.	Material	Physical forms	Type	Approximate maximum operating temperature	Normal bulk density	Compressive strength*	Water vapour permeability
				°C	kg/m ³		10 ⁻³ g m/(s MN)
1	Phenolic foam expanded	Preformed slabs and pipe sections	Cellular	150	36 to 64	Fair/good	2.1 to 22.0
2	Polystyrene expanded	Preformed slabs, preformed pipe sections	Cellular	75 to 80	16 to 32	Fair/good	2.1 to 22.0
3	Baked cork	Preformed slabs, Preformed pipe sections	Cellular	60	112 to 192	Good	13 to 17
4	Granulated baked cork	Loosefill	Granular	60	104	Fair	High
5	PVC expanded	Preformed slabs	Cellular	65	64 to 112	Good	0.09 to 0.15
6		Flexible slabs				Fair	High
7	Polyurethane rigid foam foamed in situ	Slabs, pipe sections, sprayed	Cellular	100	32 to 96	Good	4.3 to 8.7
8	Polyurethane flexible foam	Slabs, pipe sections	Cellular	70	32 to 64	Negligible	High
9	Isocyanurate rigid foam	Slabs, pipe sections, sprayed	Cellular	145	32 to 64	Good	4.3 to 8.7
10	Foamed glass	Rigid slabs, rigid pipe sections	Cellular	400	128 to 160	Good	Very low
11	Mineral fibre (glass)†						High
12	Mineral fibre (rock)†						High
13	Mineral fibre (slag)†						High
14	Silica aerogel	Loosefill	Granular	980	8 to 128	Negligible	High
15		Opacified slatted blanket	Granular	982	192 to 384	Fair/good	High
16	Perlite	Loosefill	Granular	870	48	Good	High
17	Rubber	Flexible slabs, flexible pipe sections	Cellular	80 to 105	80 to 100	Good	Low

* For fibrous materials, the compressive strength will vary with bulk density and with the binder.

† For physical forms and properties see table 1.

NOTE 1. For typical thermal conductivity values see figure 1(c).

NOTE 2. Care is necessary in interpreting the maximum operating temperatures in this table. These are based on manufacturers' claimed figures and may require modification (possibly considerable) in practice.

BS 5970 : 1981

Section two

7.4 Identification of asbestos-free thermal insulating materials

7.4.1 Government regulations* for the control of asbestos dust require that special precautions are observed in order to safeguard the health of individuals who are handling materials that contain asbestos or who are working in the vicinity. In accordance with the Health and Safety at Work Act 1974, the employer, the organizer of the operation, and every person employed on the work, *all* have responsibility. See **6.11** and clause **31**.

7.4.2 Although it is the intention of the authorities that asbestos-free insulation is used for future work, there is still an important need for a reliable means of identifying asbestos-free products on site, particularly when old insulation is to be stripped after a period of service on the plant. For identification purposes, magnesia and calcium silicate insulating materials are given distinctive colouring during manufacture (see BS 3958 : Part 1 and Part 2). See also **6.11.7** and clause **31**.

7.4.3 The compounds used for colouring vary in their reaction to heat so that, for positive identification after a period of service, the 'cold' outer face should be examined. The degree of colour change and the thickness of the material affected will depend upon the temperature involved. See table 3.

Table 3. Guide to colour change of asbestos-free insulating materials after service

Material	Original colour (cold face)	Colour after heating (hot face)
<i>Magnesia</i>		
Containing asbestos (old material only)	White	White
Not containing asbestos (all new material)	Pink/red	Pink/red
<i>Calcium silicate</i>		
Containing asbestos	White	Some may turn pink
Not containing asbestos	Yellow	Varies: some may turn whitish; some may be pink/red

NOTE. For the colour changes in finishing compounds see **10.9.1**. See also **31.3.1.3** for colouring in some older products.

7.4.4 Mixed systems of asbestos-containing and asbestos-free materials are not likely to be encountered in recently completed work but, when asbestos-free materials are used for the repair of local areas from which old asbestos-containing insulation has been removed, positive means of identification of the boundaries between the old and the new materials should be provided.

7.4.5 Advice should be obtained by the purchaser from the manufacturer or contractor concerning all insulating materials to be used. The absence of a characteristic colour or other identification may result later in precautions being taken unnecessarily.

See **10.9.1** for the identification of asbestos-free finishing materials.

7.5 Dimensions

7.5.1 General. Preformed insulation and factory-made mattresses of the sizes shown in **7.5.2** and **7.5.3** are

readily available. Individual manufacturers can often supply a wider range and their sales catalogues should be consulted.

7.5.2 Preformed insulation

NOTE. The dimensions of the preformed materials shown in **7.5.2.1** to **7.5.2.3** are given in the metric sizes or metric equivalent sizes in which they are generally available at the time of publication of this standard.

7.5.2.1 Slabs

Length 0.6 m, 0.9 m, 1.2 m and in some cases 1.8 m
 Width 0.15 m, 0.3 m and in some cases 0.45 m, 0.6 m and 0.9 m
 Thickness 12 mm to 100 mm in approximately 12 mm increments; greater thicknesses are available in certain materials

7.5.2.2 Pipe sections

Length 0.6 m, 0.9 m and in some cases 1.2 m
 Diameter to fit pipe from 17.4 mm to 508.0 mm outside diameter (or larger from some manufacturers)
 Thickness 25 mm to 100 mm in 12 mm increments; certain materials are available in 12 mm thickness, and 6 mm increments up to certain sizes

7.5.2.3 Bevelled, or radiused and bevelled, lags

Length 0.6 m or 0.9 m
 Diameter shaped to fit pipe diameters from 220 mm to 1.8 m outside diameter
 Width usually prepared to fit particular cylinder sizes so that lags on one layer are interchangeable
 Thickness 25 mm to 100 mm in 12 mm increments

7.5.3 Mattress insulation

Scrim-covered stitched quilts up to 2.75 m x 1.0 m
 Wire-netting-covered mattresses up to 2.0 m x 1.0 m
 Expanded-metal-covered mattresses up to 2.4 m x 0.685 m
 Nominal thickness 12 mm to 100 mm

Where mattress insulation is for use on a pipe, it can be cut to suit the pipe and where thickness of insulation of a pipe exceeds 50 mm it can be supplied for fitting as two layers of different size.

7.6 Applicability of thermal insulating materials

7.6.1 General. For various reasons, many commercial thermal insulating materials are suitable only for use within a restricted range of temperatures, whereas others may be used satisfactorily over a wider range. To ensure the suitability of any particular type of material, the expected performance data for the specified conditions should always be obtained from the appropriate manufacturers.

As a general rule, it is convenient to distinguish between an insulation system that is particularly suitable for use at temperatures below about 5 °C and one that is applicable mainly for elevated temperatures. Principally, this is because it is essential to ensure that water vapour will not condense, and possibly freeze, inside the insulation under 'cold' conditions, either internal or external. Thus, the need to exclude water vapour from the insulation may well be the dominant factor for applications at temperatures below the 'dew point' of the ambient air.

* The Asbestos Regulations 1969.

7.6.2 Refrigeration and general cold work

7.6.2.1 The initial and operating costs for a cooling plant may be high, and the danger of spoiling valuable cooled products serious, so that only efficient insulating systems should be used. The insulating material should be of adequately low thermal conductivity, compatible with economic considerations, and it should be capable of remaining so under the anticipated conditions of service. On the basis of convenience in application, the normal preference would be either for preformed material, or for foamed-in-situ products, which are often based on an appropriate plastics polymer.

7.6.2.2 An alternative would be to use a sealed double-skin construction in which the annular space could be filled with a suitable expanded granular loosefill material preferably of low thermal conductivity; perlite is often used for large vessels. If the double-skin enclosure can be evacuated so that the insulating material is maintained under relatively low pressure, the overall rate of heat transfer may be reduced appreciably, thus increasing the effectiveness of the insulation system. Microporous insulating materials would be of value for small installations of this type, provided that the relatively high cost could be justified.

7.6.2.3 For refrigeration and general 'cold' work, where the plant is to operate continuously at temperatures below that of the ambient air, it is essential that the insulating material shall be protected by a vapour-sealing barrier. It is advantageous if the insulating material itself is resistant to the passage of water vapour, in order to supplement the protective effect of the external vapour seal.

7.6.2.4 Only dry insulating material should be used and it should be kept dry until after the vapour barrier has been applied and completed. It is important to remember that unsealed joints between sections and at branch connections, or badly fitting insulation, can provide easy passage for water vapour. Thus, the insulating material chosen should be one that can be secured in close contact with the insulated surface, by means of a suitable adhesive (but see 25.2.1). Additionally, all joints and cavities should be filled with suitable vapour-barrier/joint sealant. 'Heat bridges', e.g. at 'through' metal supports, should be avoided wherever possible.

7.6.2.5 The insulating material should be resistant to occasional defrosting of the plant, particularly if this is to be done by steam-purging that may raise the temperature of the plant locally to a level above the softening point of the insulation. Allowance should be made for expansion/contraction of insulation under hot/cold cycles. See 33.9.3 and figure 2 for contraction joints.

7.6.2.6 In locations where compression-resisting insulation is required, e.g. at pipe supports, sling points, or at support areas for the inner container in double-skin construction, it may be convenient to use foamed glass slabs or segments. If wood or other absorbent material is used it is important that this be kept dry during service.

7.6.2.7 As many low temperature insulating materials are flammable, careful attention is required to avoid potential fire hazard under service conditions.

7.6.2.8 Insulating materials that may be exposed to liquid oxygen, e.g. by direct spillage or by the partial condensation of air, should be of inorganic composition and should be entirely free from oil or other organic

contaminants. Resistance to other reactive oxidizing chemicals may require special consideration. In all cases the material of the vapour barrier should be selected with care and, where possible, it should be protected by an outer metallic cover adequately sealed. (See also 6.9).

7.6.2.9 When selecting insulating material for the protection of pipes of small diameter against frost conditions, the thermal capacity (specific heat capacity $\times$ bulk density) as well as the thermal conductivity should be considered. A high thermal capacity improves the thermal stability of the system and therefore increases the level of protection against transient frost conditions. The effect of the thermal capacity of the insulating material may not be of major significance for steel pipes of diameter exceeding about 60 mm. (See also 33.14.)

7.6.3 For normal ambient and elevated temperatures

7.6.3.1 When the surface to be insulated is of regular shape it is likely that preformed materials will be the most suitable; their physical properties, shapes and dimensions can be controlled during works manufacture. Also, they are easy to apply and they are likely to retain their physical characteristics under service conditions. Care should be taken to ensure that the material will be satisfactory in service, and this will include the need to preserve physical and mechanical integrity as well as to maintain thermal effectiveness; some types of preformed materials contain organic bonding agents that can migrate or even develop internal self-heating at elevated temperatures. (See 33.13 and also 18.1 of BS 2972 : 1975.)

7.6.3.2 Although flexible materials can be used for plant of both regular and irregular shape, they are easily deformed by superimposed loads, e.g. by the weight of finishing material. Thus, they may not be of reliable thermal effectiveness in service unless adequate support is provided from the plant surface for any substantial protective layer, independently of the insulating material itself. On the other hand, a flexible fabric-covered mattress may have specific advantage for locations where frequent removal of the insulation is required, e.g. for valves or access manhole covers.

7.6.3.3 Certain types of plant with double-skin construction, e.g. reaction or storage vessels, may require the annular space to be packed with a loosefill insulating material, which may be in the form of a loose mass of fibre or a porous granular aggregate. In such cases it is necessary to achieve reasonably uniform packing at an optimum bulk density, e.g. by the provision of internal spacer supports to prevent settlement under service conditions.

For some specific applications, notably the horizontal or near-horizontal tops of large outdoor ducts and flues with multiple external stiffeners, it may be convenient to build up an appreciable depth of granular aggregate to form a camber, either from the longitudinal centre line outwards or across the full width of the surface, before applying preformed slab insulation. A small proportion of bonding cement may be added to ensure stability, and it is good practice to use relatively fine aggregate for the upper surface layer in order to provide a uniform base for the slab insulation, which may be finished with a layer of self-setting cement. A final coat of weatherproofing compound may be added, as required.

7.6.3.4 For irregular shapes of plant it may be convenient to make use of plastic composition insulating materials but, in these cases, it will be necessary to preheat the plant and to maintain the heat until all the insulation is dry. As wet plastic composition has to be applied in successive layers, allowing each one to dry before the next is applied, the costs for labour and for the provision of heat for drying out may be substantial.

Plastic composition mixes are likely to contain soluble chloride salts, either as normal impurities or in the water used for forming the paste. For this reason they are not suitable for direct application to austenitic steel surfaces on account of the potential danger from stress-corrosion attack. Additionally, only clean water should be used for mixing in order to ensure freedom from attack on carbon steel surfaces by soluble nitrates. See **33.17.2.2**.

7.6.3.5 For large areas of plant or for large complicated shapes, particularly those for which close adherence of the insulation is essential, e.g. steam turbines, it may be advantageous to use spray-applied insulation. Special care will be required to achieve uniform bulk density and thickness. The problem of drying-out should also receive special attention.

7.6.3.6 Notably low thermal-conductivity values, together with light weight, are characteristic of many types of foamed-in-situ insulating materials, which normally involve the mixing of two reactive chemicals, e.g. for the production of polyurethane. They are of particular value for filling the annular spaces between the containment surfaces of a lightweight structure as, in many cases, they can increase the mechanical stability of the structure. It is possible to use a similar process for the production of preformed insulating shapes. Care should be taken to ensure that the foamed material is used only within the correct temperature range and that it does not add to the fire hazard in the insulated plant.

7.6.3.7 The advantage of microporous insulation relates to its low thermal conductivity, which persists to high temperatures. This characteristic permits the use of lower thicknesses than would be appropriate for more conventional materials and may justify a higher initial cost. It is important that microporous insulation should never become wet as this can result in an irreversible breakdown of the microporous structure.

7.6.3.8 Reflective insulation is more effective in reducing the absorption or emission of radiant heat than is a non-metallic surface. It may be used in conjunction with granular, fibrous, or powder-type insulating materials, and as intermediate barriers in air cavities required for insulation purposes. Where the use of non-metallic insulation is not acceptable for technical reasons, e.g. in certain types of plant heated by nuclear fuels, multilayer reflective metallic insulation may be particularly suitable.

7.6.3.9 Insulating boards may be substantially of organic composition, e.g. made from wood fibre, sugar cane, etc., or they may be wholly inorganic, e.g. mineral fibres bonded with a cement-type product. Included in this range are gypsum plasterboard and sheet products made from rigid organic polymer foam, both of which may have one or both surfaces covered with aluminium foil to reduce thermal transmission. When a choice is to be made from various types of board for a specific application, attention should be paid to fire hazard, moisture absorption, and the upper limiting temperature, as well as to the thermal conductivity under the required conditions of use.

7.6.3.10 Insulating fire brick and related prefired or formed rigid shapes are used in locations where the insulation has to be self-supporting or partially loadbearing or where it is to be exposed directly to hot gaseous products, e.g. for lining flues that contain hot low-abrasion gas. It is usual to distinguish between 'hot-face' insulating bricks and those that should only be used for 'backing' insulation, i.e. behind a protective surface, on account of their sensitivity to abrasive attack or because of limited resistance to the anticipated temperature conditions.

7.6.3.11 Significant advantages over fire brick can be gained in lower thicknesses and/or lower heat losses by the use of calcium silicate insulating blocks or slabs. The high crushing strength of calcium silicate blocks, combined with a low thermal conductivity, makes them suitable for use in partially loadbearing applications, and as a back-up to fire bricks where they have to resist crushing movement due to expansion at high temperature. See **7.6.3.14**.

7.6.3.12 Ceramic fibre may be used in applications where low thermal mass and high resistance to thermal shock are important, such as in annealing furnaces or those used intermittently. Greater resistance to abrasion and mechanical damage may be obtained by the use of inorganically bonded wet felt as a lining or by the use of a rigidizer directly on to the surface of the ceramic blanket.

7.6.3.13 Insulating concretes, which are normally based on a mixture of Portland cement or aluminous cement with a lightweight aggregate, require to be mixed with water immediately before application; they are then poured, spray-applied, or placed in position manually. Alternatively, the wet mass may be foamed or aerated so that large numbers of air cells are contained in the final dry product to give material of lower bulk density and improved insulating properties. Many of the lightweight insulating concretes can undergo appreciable changes in volume with variations of moisture content, and their mechanical strength may be reduced on heating.

7.6.3.14 It may be convenient to use two different types of insulating material for a portion of plant if the operating temperature is above the limiting temperature for the preferred main insulating material. In such cases the inner layer, of suitable resistance for the higher temperature, is used in sufficient thickness to reduce the temperature at the interface with the main insulating material to an acceptable level. (See also **6.4**.)

8. Selection of securing materials

8.1 General. Insulation systems may be secured by means of adhesives, by mechanical means, or by a combination of both. See also clauses **23** and **24**.

8.2 Adhesives. Adhesion depends on molecular forces and, because the surfaces in thermal insulation systems are often rough and irregular, adhesives used for these systems require special gap-filling properties. Compatibility with the surfaces involved is also important and particular insulating materials may require specific adhesives. Fluid primers may be required to assist penetration and wetting, particularly when it is necessary to bond or to consolidate friable surfaces.

In addition to gap-filling capability, correct viscosity is also important. Adhesives of nominally similar type may differ in their resistance to water, in their behaviour under

conditions of fire, and in their resistance to temperature variation.

8.2.1 Classification according to use. Adhesives for insulation may be classified as follows:

Insulation bonding adhesives. Used for securing preformed slabs and sections, or flexible insulating materials to themselves and to structures such as equipment and ducts. Generally the substances in this group are of relatively heavy consistency and have good gap-filling characteristics, i.e. are of high build and have high solids content.

So-called 'lagging' adhesives. Used for bonding, sizing and coating surface-finishing fabrics over insulated pipework and equipment. Usually these are water-based polyvinyl acetate (PVA) and PVA copolymer emulsions.

Facing and film-attachment adhesives. Used for attaching flexible laminates, foils and plastics films to thermal insulation, and for bonding the overlaps of these materials. This group includes a wide range of products, generally of consistency suitable for brush or spray application. They are chosen for economy and for ease of application. For plastics films in particular, the long-term compatibility with the chosen adhesive should be established at the design stage.

Obviously some overlapping occurs in the above groups, which are intended to illustrate the primary function, i.e. that of adhesive. Good design practice frequently permits economical brush or spray-type adhesives to be used for attachment of insulating materials when existing features of the design can be employed to provide back-up mechanical support, such as metal banding or a strong fabric-reinforced mastic finish.

8.2.2 Application characteristics. Important properties that affect use are:

- (a) build, i.e. ability to resist sagging, etc.;
- (b) consistency, i.e. suitability for brushing, spraying, etc.;
- (c) coverage;
- (d) solids content (influencing the ease with which solvents or water are lost);
- (e) degree of absorption with porous insulating materials.

Other properties that may require consideration are: flashpoint; toxicity; temperature and humidity range (for application); range of bonding times; curing time; stability in storage; possibility of corrosive attack; danger from attack by solvents. (Slow loss of water can give rise to corrosion; alkaline adhesives, e.g. sodium silicate, can attack aluminium and glass fibre; organic foams, especially polystyrene, are susceptible to attack by certain solvents.)

8.2.3 Service properties. Properties affecting the behaviour of the adhesive after installation are outlined in 8.2.3.1 and 8.2.3.2.

8.2.3.1 Temperature limits. There are limiting temperatures between which an adhesive will remain effective without significant loss of bond strength. Most adhesives for thermal insulation have service temperature limits within the range -50°C to $+120^{\circ}\text{C}$, although many special adhesive/insulation combinations can be used outside this range.

Below about -50°C most adhesives undergo dramatic loss of flexibility. When bond failure occurs it is most often manifested as shearing of a relatively brittle (though stronger) layer away from a comparatively weak insulating material; usually part of the insulating material remains attached to the adhesive, so that the mode of failure relates to the cohesion of the insulating material. With the exception of some very sophisticated and expensive adhesives, most products that have the required flexibility at low temperatures do not have sufficient bond strength at normal ambient temperatures.

Above service temperatures of about $+150^{\circ}\text{C}$, the most widely used adhesives are based on filled sodium silicate solutions, which are not resistant to water or high humidity. When assessing the required service temperatures, attention should be given to the possibility that there may be periodic departures from the assumed conditions, e.g. through steam-cleaning requirements or variations of boiler operation.

Table 4. Insulation bonding adhesives for preformed sections and slabs

Mineral fibre (glass, rock, slag)	Styrene-butadiene rubber (SBR) emulsions and solutions, neoprene-phenolics, bitumen/rubber emulsions and solutions, natural rubber solutions, alkyd solutions, latex rubber/hydraulic cement
Polystyrene foam	Some SBR solutions, SBR emulsions, bitumen/rubber emulsions, rubber/alcohol solutions, polyurethanes, latex rubber/hydraulic cement
Polyurethane foam	SBR solutions, neoprene-phenolics, filled alkyd solutions, polyurethanes, hot-melt bitumens
Polyisocyanurate foam	SBR solutions, neoprene-phenolics, filled alkyd solutions, polyurethanes, bitumen/rubber emulsions, hot-melt bitumens
Phenolic foam	SBR solutions, bitumen/rubber emulsions, filled alkyd solutions, latex rubber/hydraulic cement, polyurethanes, hot-melt bitumens
Baked cork	Natural rubber solutions or lattices, SBR emulsions or solutions, hot-melt bitumens
Expanded polyvinyl chloride (PVC)	Neoprene-phenolic, nitrile-phenolic, epoxies hot-melt bitumens, polyurethanes
Cellular glass	Latex rubber/hydraulic cement, polyurethanes, epoxies, bitumen/rubber solutions and emulsions, hot-melt bitumens

NOTE. The adhesive groups shown here are indicative only and in no way preclude selection of alternative materials recommended by the adhesive or insulant manufacturer. Final selection should be made only after full consideration of all the factors outlined in this section together with any special chemical resistance or other requirements.

8.2.3.2 Adhesive strength. Because of the low bulk density and loose bonding of many insulating materials, high strength of adhesive is not usually the most important requirement. However, the adhesive strength has to exceed the cohesive strength of the insulating material by a safe margin under all conditions of service. For materials of higher bulk density and strength, stronger adhesive will be required, and these have to be adequate to carry the required load with an ample margin of safety. The main components of adhesive strength are those relating to tensile, shear, and peeling forces; the latter usually are the most destructive and they are a frequent cause of failure. For example, if the layer of adhesive is too thin for bonding slightly distorted insulation boards to metal surfaces, e.g. metal ducts, the resulting insufficient area of adhesive contact may be inadequate to resist the severe peeling forces generated by thermal movement, especially at the edges of the areas of contact. Under typical conditions this type of failure is accentuated after an initial period as the stresses are propagated by cantilever and other effects.

Where permanent bond strength is important, the effect of 'ageing' due to heat should be taken into account; this may be of significance in reducing the acceptable maximum service temperature. However, long-term performance of adhesives cannot be assessed in isolation; the whole system has to be considered, especially the behaviour of the insulating material itself.

8.2.4 Mechanism of curing

8.2.4.1 Solvent-based adhesives. Appreciation of the curing or setting process is of fundamental importance in ensuring the successful use and performance of adhesives. Most insulation adhesives form a bond by the evaporation of organic or aqueous solvents or by the absorption of water into porous adherends with subsequent evaporation. Whilst many of these adhesives have an additional curing phase due to cross-linking, this follows solvent loss and cannot properly take place before solvent loss.

Failure to ensure that all solvent, aqueous or organic, can escape from the assembly is the most frequent cause of application difficulties and service failures.

Thickness of applied wet film and porosity of the adherends are major determinants in establishing an appropriate application technique. The wet film thickness, when related to the solids content of the adhesive, shows the proportion of solvent that has to be lost; increasing the thickness generally increases the drying time disproportionately, e.g. bonding two relatively impermeable materials and doubling the recommended thickness could extend the curing period from hours to days or even preclude any possibility of the adhesive ever curing.

In general, solvent-based or water-based adhesives are used where one of the adherends is porous; in this case the adhesive may be applied to one surface and the bond made immediately or after a short 'open-time' during which the adhesive develops 'grab'. This technique is referred to as 'one-way wet stick'.

With two non-porous adherends certain adhesives may be applied to both surfaces and the bulk of the solvent left to evaporate for a period up to the maximum specified by the bonding time range before closure is made. This procedure is often called 'two-way dry stick'. A degree of

operator skill and strict compliance with manufacturers' instructions are necessary to assure success.

Some water-based gap-filling adhesives with high solids content, or heavily filled solvent may be used to bond relatively impervious insulants provided the assembly is supported or shored for a prolonged period whilst cure is developed. This technique relies on solvent loss through edges and joints together with a slow loss through the insulant; again considerable skill and adherence to makers' instructions are required for trouble-free application.

8.2.4.2 Chemically curing adhesives. These, generally set by a chemically activated cross-linking process, are increasingly used for insulation work. Usually two-component materials based on epoxies or polyurethanes and modifications of these with other polymers, their use is generally indicated for heavy-duty bonding of impermeable materials. Some types may contain a small proportion of volatile solvent to facilitate application, but this has little effect on curing times. They are frequently available as a combined joint-sealant/adhesive; some polyurethane versions are especially useful for low-temperature work. Complete mixing of two-component adhesives according to instructions is essential; part mixing of components for small jobs will normally result in a failed bond. Most assemblies need to be supported until sufficient strength has developed.

8.2.4.3 Hot melt adhesives. These are applied as hot viscous liquids and form a bond by solidification on cooling to ambient temperatures. As no solvent loss is required they are useful for bonding non-porous adherends but most types are restricted to a comparatively narrow range of service temperature.

8.2.5 Health and safety. Adhesive users and specifiers are urged to consult all available safety information before individual products are used. Container labels, technical data series and manufacturers' health and safety data sheets give valuable information and should be obtained for study. Attention is also drawn to the British Adhesive Manufacturers' Association booklet 'Guide to the Safe Use and Handling of Industrial Adhesives'.

8.2.6 Types and typical properties. The materials referred to, with summaries of properties, in 8.2.6.1 to 8.2.6.11 are not intended to provide an exhaustive list; the particulars are given for guidance only, and more detailed information should be obtained from the manufacturers. All the adhesives listed are based on natural or synthetic resins, rubbers, or other polymers, which are formulated into suitable adhesives in a variety of ways. Other ingredients, such as fillers, plasticizers, anti-oxidants, tackifiers, etc., are added to achieve desirable properties and working characteristics. Thus, quality and properties can vary widely between adhesives of nominally similar type, so that it is essential to specify requisite application and service properties in terms of the criteria given in this section.

8.2.6.1 Bitumens. These are low-cost thermoplastic materials of mineral origin, generally of dark colour and with poor elasticity and strength. At operating temperature they may be brittle or soft, depending on the compound used. They will adhere to many types of surface, including concrete, glass, metal and felt and can be used in applications where low stresses are encountered. Reinforcement with mineral fibre or with

metal mesh will give improved strength. They have good resistance to water and to alkalis, but oils and many solvents may cause softening. The addition of rubber improves the flexibility and the bond strength.

They are flammable, of low acute toxicity, and may have an odour. Pitch and bitumens can be harmful to the skin as a result of their content of polycyclic aromatic hydrocarbons. The commercial products may be supplied as aqueous emulsions or as 'cut-backs' with organic solvents.

8.2.6.2 Epoxy resins. These are two-part adhesives that can be formulated to cure at ambient temperature. High bond strengths are obtainable but they have a limited 'pot life', low flexibility, and poor impact strength. The flexibility can be improved by modification with polyamides or polysulphides but even these modified compounds are brittle below temperatures of about -25°C . Bond strengths up to 100°C are satisfactory for all normal purposes.

Epoxy resins have excellent resistance to oils and mould growth, with good resistance to water, alkalis and solvents. Their main advantages are low volume shrinkage, no evolution of volatiles during cure, and the fact that only contact pressure is required. They have good electrical insulating properties and they can be useful in gap-filling applications. Epoxy resins themselves are non-toxic and non-flammable, but they can cause dermatitis. The solvents in the resin adhesive may be toxic, and inhalation of spray can be harmful. The manufacturer should be consulted.

8.2.6.3 Natural rubber. Cements based on natural rubber are available in a range of colours, depending on the rubber stock and the fillers used. They may have flammable or non-flammable solvents. Adhesives also are available on a basis of rubber latex and these are relatively non-toxic; they may be cured as a one-component cement at room temperature. Solvent-based cements can be vulcanized or cured with a second component. Unvulcanized bonds lose much of their strength at 50°C but vulcanized bonds normally are satisfactory up to 100°C ; the bonds of both types become brittle at about -35°C . Natural rubber has good resistance to water and to mould growth, but poor resistance to oils and organic solvents.

8.2.6.4 Neoprene-phenolic. These adhesives may be used as unvulcanized dispersions to give good bonds up to 100°C (or 140°C intermittently); two-part mixes may have higher resistance to heat. The bonds become brittle at about -55°C , but the resistance to water, to mould growth, and to some oils and solvents is excellent. The adhesives may contain either flammable or non-flammable solvent, with varying toxicity, and some grades will meet the class 1 spread of flame requirement as defined in BS 476 : Part 7.

8.2.6.5 Nitrile-phenolic. The properties of nitrile-phenolic adhesives are similar to those of neoprene-phenolic type, but the cured adhesives have higher resistance to heat. Bonds become brittle at about -50°C , but the resistance to water, oils, and to mould growth is excellent.

8.2.6.6 Polyvinyl acetate. Used as solvent-based solutions or water-based emulsions, mainly for adhesion to wood. These adhesives normally are brittle at room temperature but are softer at 50°C , and they can be plasticized to improve flexibility. The resistance to oils and to mould growth is good, but resistance to water is only moderate.

A comprehensive range of water-based emulsions is available, including copolymers and terpolymers containing ethylene vinylacetate (EVA), vinylchloride (VC) and acrylics; they comprise a useful range of adhesives.

8.2.6.7 Reclaimed rubbers. Low-cost adhesives available with flammable or non-flammable solvent. The maximum service temperature is 70°C , but they may be used intermittently up to 100°C if not required to be loadbearing. They become brittle at -15°C ; they have good resistance to water and to mould growth, but have only poor resistance to oils. They are flammable, and have the properties of the petroleum or other solvent.

8.2.6.8 Styrene-butadiene-based (SBR) cements. These are an important class of adhesives. They may contain either flammable or non-flammable solvent and normally are combustible when dry, although the resistance to spread of flame may be improved by suitable additions. The resistance to heat is similar to that of adhesives based on natural rubber. SBR emulsions in aqueous dispersion form an important group of adhesives.

8.2.6.9 Alkyd resins. Filled alkyd-resin solutions in organic solvent are useful as gap-filling adhesives and they can be used as joint sealants with some insulating materials. Although the solvent may be flammable, the dry adhesive will meet the requirement for class 1 spread of flame when tested in accordance with BS 476 : Part 7. The dry adhesives have good chemical resistance and have secondary vapour-barrier properties.

8.2.6.10 Rubber latex/hydraulic cement. A range of two-component adhesives that normally are best applied by means of a notched trowel or spatula. Some types are suitable for service temperatures ranging from -50°C to $+90^{\circ}\text{C}$. Usually they are of heavy consistency with a high solids content. They are useful as gap-filling adhesives with excellent tolerance to substrates of high moisture content.

8.2.6.11 Polyurethanes. These comprise a wide range of adhesives with differing characteristics. The types used most frequently for bonding insulating materials are the two-component adhesives that cure by chemical reaction; they have a high solids content (over 95 %) and show excellent blend of strength and flexibility, even at relatively low temperatures. Their main service range is from -50°C to $+100^{\circ}\text{C}$. Although, normally, they are flammable in the wet state, when dry they can be formulated to meet the requirements of class 1 surface spread of flame when tested in accordance with BS 476 : Part 7. These materials are often recommended for use as dual joint-sealant/adhesives, and they can be compounded to give vapour-barrier properties.

8.3 Mechanical securements. The securing materials under this heading generally can be classified as welded attachments, bolted fittings, or banding and wire securements. Care is required to avoid bimetallic contact between metals of appreciably different electrochemical properties (see 33.17.1.5).

8.3.1 Welded attachments are used mainly on the vertical faces of piping, or vertical and downward-facing vessels and equipment. They can be in the form of cleats, angles, pads, studs, bolts, nuts, etc. that will provide support for bolted fittings and permanent datum positions relative to each other. The spacing of these attachments may be varied locally to control thermal movement. (See 24.3.2, 33.9 and figures 2, 3 and 4(a) and (b).) Care

is required to avoid danger from attack by liquid metal (see **33.17.3**).

Site welding of securing and fixing devices should not be undertaken without prior consultation with the purchaser.

On large areas of equipment, e.g. oil storage tanks, the attachments provide a secure base for secondary angle rings, etc.; the spacing is determined by the maximum permitted span under wind loading conditions for the cleading used. (See CP 3 : Chapter V : Part 2.)

8.3.2 Bolted fittings are used mainly in conjunction with welded attachments and they can be in the form of angle rings, flat rings, etc; as such they provide the horizontal support for insulating and cleading materials. (See figure 5, 6 and 7.) Bolted fittings, whether plain or spring-loaded, if not used in conjunction with a welded attachment on a vertical surface, are likely to slip and become ineffective in their control of the insulation system.

8.3.3 Banding and wire securements are used mainly to hold materials firmly to the plant to be insulated; they may be of metal, fabric, plastics strip, etc. The size and spacing of these securements will depend on the materials chosen and on the design parameters of the insulation system (see **24.4.1**).

NOTE. When fixing attachments by welding, brazing, etc., it is important that metallurgical damage be avoided. It is essential that the conditions laid down in the appropriate application standards, e.g. BS 806, be followed rigidly.

8.4 Combination. In certain circumstances, mechanical fixing devices may be applied with the use of adhesives. In such cases mechanical strength is very important, especially for large tanks where the insulation may be subjected to substantial wind forces. See **24.2.5** and **24.2.6**.

9. Selection of vapour barriers

9.1 Vapour barriers: general. Condensation of water will occur on surfaces at temperatures below the atmospheric dew point, due to water vapour drawn towards the cold surface as a result of difference in partial vapour pressure between the air at ambient temperature and that at the temperature of the cold surface. Unless it is possible for this moisture to be re-evaporated, it can be absorbed into any permeable insulating material that may be applied to the cold surface, thus increasing the thermal conductivity of that material, with impairment of its effectiveness. See figure 44.

The purpose of the vapour barrier is to reduce, and if possible to prevent, the ingress of water vapour into the insulating material. Thus, the barrier should always be applied to the warmer surface of the material (see **33.15**). It may take the form of a coating or sheet material resistant to the passage of water vapour, i.e. of low permeability, and the sealing of joints and overlaps should be effective. See **33.16**.

9.2 Vapour barriers for use over insulation on surfaces below dew point. Since it is essential to prevent the deposition of moisture, with the consequent risk of ice formation within the insulating material in those zones that are below freezing point, the use of an effective vapour barrier is an important technical requirement. The deposition of moisture within the insulating material could lead to eventual saturation of the material, with possible resultant mechanical and physical deterioration within the

insulation system, and the risk of corrosive attack on the insulated metal surface. It is essential that the barrier should not be used as the exposed surface finish if it is likely to be damaged during service; it should be noted that even penetration by 'pin-holes' will impair the effectiveness of the vapour seal. See also **33.16.5**.

Although insulation for 'cold stores' is outside the scope of this code, it should be noted that where the inner 'cold' surface is permeable it may be possible for condensed moisture to re-evaporate through that permeable boundary, in which case the stringent permeance requirements may be relaxed compared with requirements for plant and equipment that form non-permeable barrier surfaces.

9.3 Vapour barriers for use over insulation on surfaces above dew point. If the cold surface is at temperatures below the atmospheric dew point for short periods only, any deposited moisture may evaporate later, in which case the use of a vapour barrier may not be essential, or a surface 'breather coat' may be adequate. See also **33.16**.

It should be noted that the atmospheric dew point is likely to vary from day to day in accordance with the relative humidity, so that account should be taken of this likely variation when the requirements of vapour protection are under consideration.

10. Selection of finishing materials, including ultimate treatment of finish

The choice of the protective covering for thermal insulating materials can influence the choice of the insulating material itself; for example a composition or cement applied in wet paste form requires a firm base to which it can be applied effectively. Conversely, if a self-supporting metal cover is adopted, fibrous materials may be suitable.

For the insulation of plant at sub-ambient temperatures, where it is important to avoid condensation within the insulation system, a vapour seal may be needed and both the insulating material and the finish has to be of a type that does not require heat for drying out. Also, since it is necessary to exclude all moisture from the system, care has to be taken to ensure that only dry materials are used and that they are maintained dry before the vapour barrier layer is applied. For a similar reason, the joints of sheet finishing materials, especially those used for outdoor work, should be sealed. Overlaps should be arranged to shed water or other liquid spillage, and it may be necessary to protect the inner surface of metal covering in order to avoid corrosive or galvanic action from condensed moisture.

10.1 Finishing materials: general. It is convenient to classify finishing materials under four broad types:

- (a) Dry mixtures brought to paste consistency with water, e.g. hard-setting composition, self-setting cement, and gypsum plaster.
- (b) Sheet materials, e.g. metal, plastics sheet, roofing felt, insulation board, metal foils and woven mesh. Metal sheet may be profiled or flat sheet of aluminium or steel (black, galvanized or stainless).
- (c) Liquid solutions and dispersions, e.g. weatherproofing and decorative coatings (organic solvent or water-based) that may be applied manually or by spray gun.

(d) Woven or knitted fabrics, or fibrous sheet materials that may be based on cotton, jute, organic polymer, or glass fibre. All these may be further treated with a decorative solution or dispersion for identification or surface protection.

10.2 Reasons for use. The contribution of the finishing material to the thermal effectiveness of the insulation system is, in general, negligible but usually a finish is desirable for one of the following reasons:

- (a) To give appropriate protection against mechanical damage.
- (b) To assist in identifying the pipe or vessel. This may be achieved by painting, either with a characteristic colour or by means of coloured bands at intervals. This identification also may be used to indicate the direction of flow for the fluid contents.
- (c) To give protection against excessive moisture, corrosive vapour, etc. in the atmosphere.
- (d) To give protection against spillage of oils and other flammable liquids.
- (e) To improve appearance or to provide a surface that can be cleaned easily.
- (f) To retard, or if possible to prevent, the spread of flame.
- (g) To protect against chemical attack, vermin, and mould growth.

10.3 Typical uses for finishing materials. The four main types of finishing materials indicated in 10.1 in general have characteristic properties that can influence the choice of the insulation system for particular applications.

10.3.1 With the exception of gypsum plaster, which substantially is self-drying and therefore useful for work at sub-ambient temperatures, the finishing materials of group 10.1 (a) are used mainly over preformed insulation on pipework and plant that can be heated for drying-out. For spray-applied insulation, e.g. over turbines in power stations, the finish invariably is self-setting cement; hard-setting composition is used largely for the heating and ventilating applications. In all cases some form of metal mesh reinforcement should be used and the final dry thickness should be sufficient to resist accidental mechanical danger. Sometimes it is possible to toughen the surface of a relatively friable hard-setting composition by embedding open-mesh woven textile fabric into the exposed surface.

All the typical finishes of this group will absorb water, but, with the exception of hard-setting composition, they do not disintegrate when wet. As the application of these 'wet' finishes is relatively slow, requiring considerable skill on the part of the insulation operative, the process can be labour-intensive and, for this reason, there is a current trend towards dry finishes.

10.3.2 Sheet materials of the types indicated in 10.1 (b) are mainly of value for large uniform areas of plant or for long lengths of pipework. Metal sheet is now very widely used over both preformed and flexible insulating materials, for its resistance to mechanical damage and for its attractive appearance when correctly applied. Corrosion is often a problem and, for this reason aluminium may be preferred for some applications, provided that isolation from dissimilar metals can be ensured.

Profiled metal sheet gives increased rigidity, while permitting lateral expansion movement. If there is a danger of condensation on the inner surface of the metal that is in direct contact with the insulating material, it may be advisable to protect the contact surface with bitumen, suitable paint or a polymeric plastics compound before site application.

Metal foils can be applied over insulation on pipework, particularly in locations where they are not vulnerable to mechanical damage, but where an attractive appearance is desirable. Organic polymer films may be used for similar purposes, and these may be combined with metal foil, e.g. polyethylene-backed aluminium foil, to give improved durability. Frequently they may be secured to the surface of the insulating material by means of a suitable adhesive.

Insulation boards generally are rigid and therefore are used mainly over insulation on flat surfaces; the method of fitting has to include provision for differential thermal movement between the insulated surface and the board finish. Plastics sheet reinforced with glass fibre (GRP) can be used to give a tough board-like finish, of limited flexibility in thin sheet form.

10.3.3 Solutions or dispersion coatings of the types indicated in 10.1 (c) may be of bituminous or polymeric plastics compounds, which may vary in consistency from a heavily-filled viscous mastic, designed essentially for trowel application, to a mobile liquid suitable for application by brush or spray gun. The products may be used for mechanical protection or for weatherproofing, or they may be self-coloured for decorative purposes over the finishes indicated in 10.1 (a). Alternatively, they may be applied over the sheet materials of the type described in 10.1 (d).

Aqueous dispersions, on drying, tend to give films that are porous to water vapour (the so-called 'breather coats'), whereas solutions in organic solvents tend to give dry films of low porosity. Application normally is by brush or spray gun. Thickness may vary according to the degree of protection required, but the final dry films for most normal coatings are likely to be about 1 mm or less. Mastics, which are heavy dough-like products of asphalt, bitumen, or polymeric plastics compounds, are used mainly as 'high-build' coatings, usually thicker than 1 mm. All of them may be reinforced with short mineral fibres to give increased durability. For heavy-duty weatherproofing the material preferably should be applied in two layers, with suitable open-mesh reinforcement, to give a final dry thickness of about 3 mm to 5 mm.

10.3.4 There is an extensive range of flexible protective sheet finishes based on some form of textile product, e.g. woven glass fabric or cotton fabric. Alternatively, flexible sheet materials of organic polymeric compound, e.g. flexible polyvinyl chloride or polypropylene, are of value when used as integral dry finishes over preformed pipe sections, in which case they may be secured to the outer surface of the insulating material by means of a suitable adhesive. Otherwise they may be applied as an outer covering to improve the finished appearance of the insulating material.

Frequently the woven or knitted textile fabric, after application to the surface of the insulating material, may be treated with a polymeric plastics coating by brushing or by spraying, and this coating may act both as an adhesive and as a self-coloured decorative finish.

10.4 Finishes for tropical conditions

10.4.1 General. Under hot and damp conditions, the surface temperature of insulation systems will be higher than for similar material and thicknesses in temperate climates, and due allowance should be made for this, particularly where the insulation is associated directly with the protection of personnel. Special attention may be required for the ambient humidity conditions and the possibility of mould growth, of termite attack on organic bonding and finishing materials and, in certain cases, of the absorption of moisture by the insulating material itself. Frequently, in conditions of high humidity, it will not be possible to avoid surface condensation.

10.4.2 Interior plant in tropical climates. In humid climates it is advisable to avoid the use of exposed cotton fabric finishes and care should be exercised even in the choice of sheet metal if corrosion is to be avoided. Galvanized steel sheet may be used without additional treatment if the plant is operating under reasonably dry conditions, but electrogalvanized sheet should be painted on both surfaces and the edges if the ambient air is of high humidity. Hot-dipped galvanized sheet may not require painting except at cut edges.

Aluminium sheet is likely to be satisfactory without surface protection if the correct alloy is used, unless the plant is liable to contamination with brine, seawater spray, or alkalis. Special attention has to be paid to avoidance of bimetallic contact in humid atmospheres.

10.4.3 Outdoor plant in tropical climates. Usually, it is essential that the weatherproof finish should be resistant to heavy rain storms and, particularly on high ground, to hail stones of appreciable size. In areas where severe hail storms are probable the softer metals such as aluminium should be avoided, and even mild steel can sustain mechanical damage unless an adequate thickness is used.

Weather-resisting emulsion finishes, being somewhat resilient, may offer reasonable resistance to mechanical impact and have the additional advantage of possessing lower coefficients of thermal movement than do metals. Heavily filled cut-back weatherproofing mastics may possibly soften under high sun temperatures, and they should not be used over damp or wet insulation as they will prevent the escape of moisture when the plant is heated under operating conditions.

Water-based emulsions will allow the escape of enclosed moisture and, if adequately filled, will not flow under normal tropical ambient conditions. Non-bituminous finishes are obtainable in suitable colours to reflect some of the incident solar heat.

10.5 Finishes for refrigeration work. Where the preferred finish is, in itself, inadequate as a vapour seal, an additional sealing layer should be applied, but it is important to remember that internal heat may not be available for drying-out. For dry sheet finishes all joints and overlaps should be adequately sealed. All cement and plaster finishes have to be suitably reinforced.

Advice should be obtained from the manufacturers concerned regarding the choice and method of application of vapour sealing materials. See **33.16**.

10.6 Finishes to improve fire protective properties

10.6.1 Many finishes in common use are non-combustible, e.g. glass fabric, metal cladding and foil-faced mineral fabric. These provide a good degree of protection against fire, but they may not prevent an

involvement of combustible materials in a developed fire nor the production of smoke in the earlier stages of a fire, thus obstructing a means of escape and creating a fire-fighting hazard. Oil-resisting compounds are often used to protect insulating material against the spillage of flammable liquids, which could be absorbed in porous materials and so create a fire hazard.

10.6.2 Other finishes, such as bituminous compounds, roofing felt, cloth and canvas, and some insulating boards and impregnated tapes are flammable and they should not be used in locations where they may be exposed to fire hazard, including within certain areas that may be deemed to be somewhat remote from fire danger, such as escape routes and ceiling voids. They may be used safely in other locations, however, provided that there is no danger from spillage of flammable liquids. Surface-spread-of-flame characteristics may be improved by the application of flame-retardant coatings, but these may have the disadvantage of causing the production of greater quantities of smoke in a fire. Several such compounds are available and the manufacturers should be consulted with regard to choice, permanence of effectiveness, and method of application. See also **6.9, 33.12** and **33.13**.

10.6.3 Aluminium should not be used where there is a serious risk of the development of large fires, and all banding should be with stainless steel bands.

10.7 Finishes for use over pipes in ducts and subways, or beneath buildings. The appropriate choice can be made from the finishes recommended in **10.3**. See also BS 4508 and CP 3009. Regard should be paid to the fire and smoke hazard presented by some finishes, particularly when the ducts are used for the passage of air or when subways are used as means of escape for personnel.

10.8 Ultimate treatment of finish. Additional treatments may be desirable for the finishes described in **10.3**, e.g. for identification purposes, for colour blending with the environment or to provide additional corrosion and chemical resistance.

10.8.1 Painting as a final finish. The distinction between paints, polymeric plastics coatings and mastics is primarily one of application consistency and dry film thickness. Paints generally are more fluid and of lower 'build' than polymeric plastics coatings and mastics, but they are used widely to confer extra protection, to provide a smooth outer surface, and to improve the final appearance. Care should be taken to ensure that the application of a paint or coating does not diminish the resistance to fire.

Aluminium paints based on nitrocellulose should not be used where a flammable atmosphere may exist, and no aluminium paint, whatever its base, should be used in flammable atmospheres if the painted surface is likely to be heated to a temperature of 150 °C or above. Below this temperature aluminium paints, except those based on nitrocellulose, may be used on ferrous metals, even when the surrounding atmosphere may be flammable.

10.8.1.1 Indoor applications. Paint normally is used over indoor finishes to provide a smooth surface and it can serve the dual purpose of identifying the contents of pipes by colour (see BS 1710). Tinted so-called 'lagging adhesives' also are available. Hard-setting composition, self-setting cement, gypsum plaster, and all woven fabrics applied directly to the insulating material, may receive a

initial coat of size or copolymer emulsion coating that should be allowed to dry before the paint is applied, in a minimum of two coats.

10.8.1.2 Outdoor applications. Paint or polymer plastics coatings may be applied for decorative and protective purposes. Bituminous-based paints should be used over bituminous weatherproofing finishes, preferably using an intermediate coat of aluminium sealer containing flake aluminium. Polymeric plastics primers are preferred for self-setting cement finishes on account of possible alkaline reaction. (See 28.3.2.) Paints based on chlorinated rubber, epoxy resin or polyurethane will provide good protection over many insulation finishes, particularly in corrosive atmospheres.

It should be noted that galvanized steel requires a primer of mordant solution or of calcium plumbate before the application of ordinary undercoats and gloss paints. Aluminium, if to be painted, should be primed with zinc chromate unless the surface has previously received a chemical conversion treatment. Bituminous paints should be used over roofing felt.

10.9 Identification

10.9.1 Identification of asbestos-free finishes. (See 7.4.) The precautions to be observed when handling insulating materials apply equally to finishing materials, and thus it is necessary to be able to identify those that do not contain asbestos. BS 3958 : Part 6, requires that hard-setting composition, self-setting cement, and gypsum plaster shall have a distinctive red-brown colour when they do *not* contain asbestos, whereas any such materials that contain asbestos shall be natural grey or buff in colour. Finishes are not normally subject to significantly elevated temperatures, but certain types of asbestos fibre can change to red-brown on heating, so that freedom from asbestos should not be assumed from colour alone if there is a possibility that the finish has been subjected to relatively high temperature.

10.9.2 Identification of the contents of a system. See BS 1710 which recommends methods for identifying hazards; it gives examples of colour identification and suggests methods of incorporating ground colour, bands, and indications of direction of flow, hazards, etc.

11. Selection of thermal insulating systems

11.1 Optimum effectiveness. The use of thermal insulation should be so arranged that the optimum effectiveness is derived from all components of the complete system, bearing in mind always any economic limitations that may be imposed by the purchaser. Where optimum effectiveness cannot be obtained, as a result of economic or other limitations, it is the duty of the insulation contractor to advise the purchaser to this effect, giving the reasons for his opinion. A requirement that an insulation system should be depreciated in efficiency for the purpose of meeting a low price is not good practice and, ultimately, it can bring discredit on those responsible for the final choice.

11.2 Extent of system. A thermal insulating system should be understood to include the following.

- (a) The required attachments to the surface to be insulated.
- (b) Means of securing the insulation system to those attachments, where appropriate, or to the surface directly.

(c) The types and thicknesses of the insulating materials to be used.

(d) Means of protecting the insulating material, other than the outer finish, e.g. vapour barrier. This could also be extended to include initial protection of the surface to be insulated, e.g. from corrosive attack and to joint sealants.

(e) Reinforcing materials.

(f) Finishing materials.

11.3 General. Consideration should be given individually to systems for pipework, to flat surfaces (e.g. air ducts, gas flues, walls of drying ovens, walls of large boilers, etc.), and to vessels, tanks, and large curved surfaces.

The components of the system should be appropriate to the specific requirements of use. Generally, materials to be exposed to outdoor weather will differ from those used indoors, if only in the type of finish employed. Different types of system are likely to be required for the following ranges of application:

- (a) refrigeration (– 100 °C up to +5 °C);
- (b) chilled and cold water supplies, industrial use;
- (c) central heating, air conditioning, and domestic hot and cold water supplies (10 °C up to 200 °C);
- (d) process pipework and equipment (from ambient temperature up to 870 °C);
- (e) dual temperature systems, e.g. refrigeration with occasional use at higher temperatures.

11.4 Factors for consideration. The main controlling factors that should be considered at an early design stage are outlined in 11.4.1 to 11.4.10.

11.4.1 Temperature. Thermal insulation on plant operating at temperatures below the dew point of the surrounding air has to be kept dry, both before and after application. This means that some form of vapour barrier is essential. For elevated temperatures the insulating material has to be adequately resistant to the highest temperature involved under eventual service conditions.

11.4.2 Mechanical stability. The system, including the insulating material, the method of fixing, and the finishing material, has to be capable of giving effective service during the required life period of the installation. This is of special importance for certain nuclear-energy plant in which access for repair work may be difficult. At all times the system should have good resistance to vibration, mechanical damage and thermal movement, and it should retain its physical effectiveness and stability in service.

11.4.3 Resistance to degradation. This requirement can have wide implications, from resistance to vermin and fungoid attack, to freedom from fire hazard. Also it will include resistance to the required environmental conditions, e.g. adequate weather resistance for outdoor service as well as resistance to accidental spillage of oils or other chemicals. The insulating material itself should not tend to dissociate nor to disintegrate.

11.4.4 Thermal effectiveness. A low thermal conductivity figure for one test sample may not be a reliable guide to the thermal effectiveness of a complete insulation system during prolonged periods of service. There should be adequate quality control at all stages of the manufacture of materials and at all stages of their application at site.

BS 5970 : 1981

Section two

11.4.5 Type and dimensions of the plant to be insulated.

The size and configuration of the plant will have an important bearing on the suitability of a particular insulating material, as well as on the reinforcement, means of securing, and type of finishing material to be used. Particular care will be required with large flat areas, especially when elevated temperatures may cause extensive thermal movements.

11.4.6 Compatibility of the components of the system. Care should be exercised to avoid the use of solvent-based adhesives or polymeric finishing compounds where these may attack the main insulating material, e.g. polystyrene. Also it is important to avoid corrosion problems, e.g. those caused by electrochemical action between dissimilar metals under possible humid conditions.

11.4.7 Total weight of the system. Although substantial thicknesses of insulating material may be desirable for energy saving, consideration should be given to the resultant need to provide additional supports, especially if a heavy metal finish is to be used for mechanical protection. On the other hand, a fibrous or exfoliated loosefill insulating material of low bulk density, with a lightweight finish, may tend to disintegrate or to settle under service conditions where there is substantial vibration, caused for example by road vehicles.

11.4.8 Potential hazard to health. It is now realized that certain types of fibrous insulating materials, notably asbestos, and certain finely divided aggregates such as crystalline silica, can be a hazard to health when inhaled into the lungs. While only asbestos-free insulation should now be used, appropriate care should be exercised to ensure that the selected insulation system is a safe one, bearing in mind the probable need for subsequent removal of the insulation.

11.4.9 Corrosion hazards. As no insulating materials, with the possible exception of multiple-foil stainless steel, are substantially free from soluble chlorides, adequate protective measures should be adopted as an essential part of the insulation system when the surface to be insulated is sensitive to chloride attack, e.g. austenitic steels. In such cases these precautions may include covering the surface with aluminium foil, or treatment with suitable protective compound.

11.4.10 Fire hazard. It is possible to provide some form of protection for insulation that would otherwise be flammable by careful choice of a finishing material or outer sheet cover, but this may only obscure a dangerous condition within the system. Conversely, some forms of covering materials may themselves introduce a fire hazard that would not otherwise have existed, e.g. certain types of weatherproofing materials. See BS 476 : Part 5, Part 6 and Part 7.

Section three. Site considerations**12. Basis and method of presenting schedule of work**

12.1 Well in advance of commencement of work at site, the purchaser should provide the contractor with a clear programme indicating when the site will be made available to him and the completion date for each section of the work. The contractor should then submit to the purchaser a corresponding document giving an assurance that agreed programme dates will be met and that adequate materials and labour are available.

If initial programme dates are later amended by the purchaser the contractor should immediately be informed in order that execution of work may be adjusted to comply with the required sequence. Similarly, if the contractor finds himself unable to comply with the programme he should inform the purchaser at the earliest possible date.

12.2 The purchaser and contractor should clearly understand their responsibilities regarding supply or application of insulation securing attachments and any necessary preparation of surfaces, e.g. removal of grease, rustproofing, painting, etc.

12.3 Where areas of plant to be insulated are to be left bare for a period, e.g. to make provision for inspection or tests to be carried out later, this should be indicated to the contractor at the tender stage. Before work at site is commenced, precise details of such omissions should be provided by the purchaser to the contractor.

12.4 Where the satisfactory application of insulating and finishing materials is likely to be dependent on weather conditions, including frost, rain, ambient air temperature and humidity, the protective arrangements and, where applicable, the method to be used for recording the weather and ambient air conditions, have to be approved by the purchaser.

12.5 In order that the contractor may operate on an efficient and economical basis, it is desirable that complete sections of plant should be released for insulation and any limitations of access should be notified.

12.6 The contractor's tender and purchaser's subsequent requisition should contain a clear description of the extent of work covered by the contract. If the contractor is requested at site to carry out work outside the scope of the contract, immediate discussion regarding responsibility should be arranged with the purchaser. The additional work should not be undertaken until written instructions have been issued to the insulation contractor.

12.7 For various reasons a contractor may be called upon to repair or modify previously completed work. Should such a situation arise, the purchaser and contractor should immediately agree to a procedure for carrying out the additional work. It is customary for extra work of this nature to be executed on a 'time and material' basis; if such procedure is adopted, the contractor should submit weekly sheets to be certified by the purchaser. The 'time and material' sheets should contain a description of the work carried out, together with precise details of materials used and hours worked.

12.8 Before work at site is commenced, the purchaser and contractor should be in complete agreement regarding the extent of a contract working week, working conditions for personnel and all other items that affect the maintenance of previously approved programming.

13. Packaging and transport to site**13.1 Suitable methods of packing**

13.1.1 When packing preformed sections and slabs, it is desirable that three forms of packing be available: cartons, crates and shrink-wrapped systems.

13.1.2 Flexible forms of insulation can generally be packed in paper or polyethylene bags, or in hessian bales, and plastic compositions in plastics or multi-ply paper bags.

13.2 When to use cartons or crates. In general cardboard cartons are a sufficiently good form of packing for preformed insulation. Cartons are lighter in weight than crates and, because of their smaller overall size, they are easier to handle in confined spaces.

Although cardboard cartons meet most conditions for both home delivery and overseas shipment, care should be taken to ensure that overseas consignments are packed in double-corrugated cartons because of the greater handling involved and the possibility of exposure to wet conditions.

There are occasions when the size of sections exceeds the practical size for cartons and therefore wooden or strong mesh crates should be used.

Crates should be used where a robust form of packing is essential.

For overseas shipment, transport costs favour cartons rather than crates, but each contract should be dealt with on merit.

Preformed insulating material should not be despatched without some form of packing.

Preferably, insulating materials should not be unpacked at site until required for immediate use.

13.3 Need for weatherproof protection

13.3.1 All forms of insulation should be kept dry, and packing used for the transport of insulating material should provide a reasonable protection against inclement weather conditions.

13.3.2 Cartons should be of a corrugated construction, incorporating weatherproof paper.

13.3.3 If wooden or wire-mesh crates are employed they should be lined with a weatherproof material. For delivery within the United Kingdom it is usually sufficient for the weatherproof lining used in crates to cover the six faces only, but for overseas delivery additional lining should be employed at all corners.

13.4 Protection against crushing. Stacking of packed insulation should be limited in accordance with the nature of the material (see 15.3, 15.4, 15.6 and 15.7).

Wooden crates are normally sufficiently robust to permit continued stacking consistent with convenience.

13.5 Packing of plastic compositions and finishing compositions or cements

13.5.1 Packing of compositions should take into account the bulk of the material, to ensure that the size of bags is convenient for handling.

For home markets, plastic compositions may be suitably packed in three-ply paper or polyethylene bags. For export markets, it is recommended that they be packed in waterproof-lined hessian bags or in polyethylene bags.

BS 5970 : 1981

Section three

13.5.2 Finishing compositions and cements for overseas shipment should always be packed in waterproof-lined hessian bags or in polyethylene bags. Press packing and palletizing may be used for economy in shipping space.

13.6 Methods of identification of packages. All forms of packaging of insulating materials should be carefully marked. The marking should indicate the type of material and, where appropriate, the size, thickness, quality, and quantity contained in each package.

Where possible, it is recommended that the packages should be marked to show the particular section of plant on which the contents are to be applied, and it is desirable that all packages should clearly show the purchaser's contract number and supplier's identification number. Where possible, each consignment should be readily identifiable against the names of the consignee and the consignor.

14. Labour and supervision

The contractor should provide labour adequately trained for the duties they are to perform. The purchaser should indicate at the enquiry stage any special labour conditions he knows to exist. If new types of materials are to be used, with which the operatives are not likely to be familiar, special instructions should be provided.

It is desirable that, when issuing the enquiry, the purchaser should indicate to the contractor the level and method of supervision he expects.

15. Provision of storage space: protection and safety during storage

15.1 Space should be provided for the contractor to store insulation and ancillary materials.

15.2 All materials should be stored in a dry atmosphere under cover and inspected at periods not exceeding three months.

15.3 Cartons containing rigid sections or segments need to be stored end-up and be stacked no more than three high.

15.4 Bales containing slab insulation should be stored flat, stacked not more than six high and preferably only four high if storage is likely to exceed a year.

15.5 Bales containing mattress insulation should be stacked flat and not more than four high.

15.6 Metal sheets, e.g. aluminium or galvanized mild steel, may be delivered as single sheets or in bundles, dependent on the type of handling facilities in the stores.

15.7 Sheets or bundles should be stored under cover in a dry atmosphere at ambient temperature.

The first layer of sheets not exceeding 0.5 tonne or first bundle should be stacked on a pallet board. The second and subsequent layers or bundles should be supported on timbers spaced at not more than 600 mm centre between each layer or bundle.

15.8 Sheet edges should be examined at least monthly to see if any discoloration has taken place. If discoloration occurs the faces of the sheets should be examined and, if necessary, dried and restacked.

15.9 When storage for longer than three months is contemplated the supplier should be consulted for recommendations on packaging the sheets prior to storage.

15.10 Ancillary fixing materials, bandings, screws, mastics, etc., need to be stored under cover in a dry atmosphere not below 5 °C. It is important, particularly with two-part adhesives, mastics or foam systems, to verify the shelf life.

16. Provision of power, water, light, heat and accommodation for personnel

NOTE. The provisions of this clause may be varied by local agreement.

16.1 Power and water. Power and water will normally be supplied free of charge by the purchaser or main contractor. Connection to the supply and the provision of transformers and cables should be, subject to prior agreement, the responsibility of, and at the expense of, the contractor.

16.2 Light and heat*. General lighting and heating should be provided by the purchaser or the main contractor. The provision of local lighting and heating should be subject to prior agreement. Heat for drying out plastic composition should be provided free of charge by the purchaser or the main contractor.

16.3 Accommodation and storage*. Site offices and storage facilities should be provided by the contractor on a site made available to him by the main contractor or the purchaser. Toilets and washing facilities should be provided by the main contractor or the purchaser. These arrangements may vary in accordance with site agreements, and canteen facilities should be the subject of prior arrangement. If insulation that contains asbestos is to be removed, see clause 31.

*See also the following statutory instruments:

- (a) Construction (General Provisions) Regulations 1961 (e.g. Regulations 44 and 47).
- (b) Construction (Health and Welfare) Regulations 1966 (e.g. Regulations 11 and 12).
- (c) Construction (Working Places) Regulations 1966.

17. Provision of access equipment

All access equipment has to conform to national and local safety regulations. The contractor will normally provide his own access equipment to work up to heights of approximately 4.5 m. It should be clearly stated at the initial stage whether the contractor is, or is not, to provide access equipment for greater heights*.

18. Responsibility for studs, cleats, etc.

Responsibility for the supplying and/or fixing of these attachments should be the subject of agreement at the tendering stage between the contractor and the main contractor or purchaser.

19. Observance of site safety and security regulations

19.1 Local site and security regulations should be notified to the contractor at the tendering stage and the contractor has to allow for strict observance of these safety and security regulations.

19.2 If other work is proceeding on site, a safe working area has to be defined and agreed, from time to time, between the main contractor or purchaser and the contractor.

19.3 Serious fires have occurred during site-work involving cellular plastics insulating materials. Precautions should be taken as indicated in HSE Guidance Note GS3, 'Fire risk in the storage and industrial use of Cellular Plastics' (available from HMSO). See also **33.13***.

20. Protection of adjacent plant and machinery

The protection of equipment adjacent to insulation work should be the responsibility of the contractor.

21. Clearing waste material from site

Removal of waste material arising from the insulating work should be the responsibility of the contractor. The installation should be kept clean and tidy at all times during the course of the contract, and left so on completion.

NOTE. See **31.3.2.8** for disposal of asbestos.

22. Health considerations

The contractor should take all necessary safety precautions pertaining to the materials in use and should advise the main contractor or purchaser when any hazards exist. (See **6.11.**)

*See also the following statutory instruments:

- (a) Construction (General Provisions) Regulations 1961 (e.g. Regulations 44 and 47).
- (b) Construction (Health and Welfare) Regulations 1966 (e.g. Regulations 11 and 12).
- (c) Construction (Working Places) Regulations 1966.

Section four. Methods of application

23. General

23.1 Insulating materials should be kept dry in store and during erection, since wet insulation cannot always be dried out on site.

23.2 Apart from certain loadbearing materials, most types of insulating materials require support or reinforcement when applied; they also require to be secured to the surface to be insulated. For these reasons, it may be necessary to attach fixing accessories to the piping or equipment before application of the insulating materials is commenced.

23.3 All insulating materials, however fixed, should be in close contact with the surfaces to which they are applied, unless an air space is specially required.

23.4 Where the main insulation consists of preformed, or flexible material, all edges or ends should be closely butted; for multilayer work all joints should be staggered.

23.5 As a general rule insulation should be carried out at ambient temperature (but see **26.2.3.1**). In certain cases it may be advisable to apply finishing material at operating temperatures.

23.6 Before any section of the insulation work on piping, vessels or ductwork is commenced, all hangers, brackets, pipe clips, etc. should be in position and the necessary acceptance tests for pressure/vacuum, etc., have been carried out.

23.7 Attention is drawn to the possible danger of skin irritation when using plastic compositions. Materials with a high free-lime content require particular care.

23.8 The junction between removable and permanent insulation is to be so arranged as to be readily discerned, e.g. by painting the end of the permanent insulation or by laying a suitable textile fabric over it.

24. Surface preparation and accessories

(attachments, insulation supports, securing devices, and reinforcement)

24.1 Surface preparation

24.1.1 Piping and equipment should be clean, dry and free from grease, dirt, loose rust and scale. In special cases, e.g. to prevent corrosive attack, it may be required that the surface be painted (see **33.17**). The paint film has to be removed locally, down to the bare metal, before attachments are welded to the surface. Ideally, this paint would be applied after all welded attachments have been fixed in position.

24.1.2 Other forms of surface preparation may be needed for certain protective requirements, e.g. wrapping with aluminium foil over austenitic steel to prevent chloride attack. (See **33.17.2.1**.)

24.2 Attachments

24.2.1 For the purpose of this code it is convenient to use the term 'attachment' for any anchor fitting fixed permanently to the surface to be insulated, usually by welding. Some types of plastics fittings, e.g. nylon clips, may be fixed to the surface by means of a suitable adhesive, subject to temperature limitations. Attachments for welding may be flat or angle cleats, pipe bosses, threaded pillar nuts, washers or nuts welded 'on edge', studs of various kinds, e.g. round, flat, split pins, fork studs, etc. Their purpose is to serve either for the direct support

of insulating materials or as fixtures to which insulation supports can be secured, e.g. by bolting. Carbon steel fittings should not be welded directly to alloy steels. (See clause **18**.)

24.2.2 Attachments for application by welding gun may conveniently have flux in the contact end or edge, but pins of about 3 mm diameter can usually be gun welded without flux. The contact area of stud-welded attachments should be related to the thickness of metal to which each one is to be applied so as to avoid lack of fusion, undercutting or over-penetration. If the metal of the surface to be insulated is of such thickness that it may not be adequately heated during welding, local supplementary heating may be helpful.

24.2.3 Angles, flat cleats, and similar large attachments may be secured by electric arc welding or gas welding, using a procedure appropriate to the materials, the thickness of the surface, and that of the attachment.

24.2.4 For those surfaces on which site-welding of attachments is not permissible, e.g. for certain types of alloy steel, or where subsequent internal temperature and pressure could be a hazard, it may be satisfactory to weld suitable metal pads in the appropriate locations. These should be applied during manufacture of the equipment at the works, which would permit subsequent stress relieving; the attachments would then be joined to the pads at site. (See figure 6.)

24.2.5 When the service conditions, (including any abnormal conditions that may occur as a result of incorrect operation or accident) make it necessary for a pipe or portion of plant equipment to have post-weld heat treatment to avoid any risk of brittle fracture at sub-zero temperatures, of stress-corrosion cracking, or of other type of failure, either

(a) weld the attachments in place before final post-weld heat treatment, or

(b) attach the insulating material by means that do not involve welding.

24.2.6 For the choice and methods of attachment of plastics or metal clips by means of adhesive, the manufacturer's literature should be consulted. Frequently these clips are formed with an integral perforated flat base that permits penetration of the adhesive through to the upper surface. Self-adhesive insulation pins may also be used on flat smooth surfaces, such as galvanized metal or plastics ducting, provided that the surface is free from dust, and the manufacturer's weight and temperature limitations are not exceeded.

24.2.7 Typical attachments for gun welding would be plain pins of 3 mm diameter, end-fluxed studs of 10 mm diameter (plain or threaded), flat cleats 12 mm wide and 3 mm thick (or similar angle welded on edge), threaded pillar nuts up to 12 mm diameter, etc. Split pins, fork studs, and similar fastenings follow the general rule for studs, as above, with a preference that the contact area should not exceed about 78 mm²

24.2.8 The use of hand-welding technique may permit the application of attachments with larger contact areas than those indicated in **24.2.7** and, with relatively long angles or cleats, it may be sufficient to use intermittent (stitch) welding. If the difference in thermal expansion between the welded contact edge and the free edge is likely to be significant, distortion of the attachment may often be avoided by the introduction of saw cuts at

intervals along the free edge; these cuts should penetrate to a distance of about half the width of the attachment. Alternatively, the cuts may be made in the edge that is welded to the hot face, thus allowing the slots to open on expansion with no movement at the cold end.

24.2.9 It is sometimes preferred to weld a thick threaded nut or pillar nut on to the surface to be insulated, thus providing a fixture into which a threaded stud may be screwed at a later stage. This can be useful for avoiding mechanical damage to the stud during transit or during erection of the plant. Also it can permit the use of an alloy stud on a surface of carbon steel, thus avoiding welding problems.

24.2.10 The locations of studs or cleats will depend on the weight of insulation to be attached, as well as on the location of the surface, and on the degree of vibration to which the plant may be subjected under service conditions; for large flat surfaces, reasonable average spacings would be:

vertical surfaces	450 mm square spacing,
upward-facing surfaces	600 mm or 750 mm square spacing,
over-hanging and downward-facing surfaces	300 mm (maximum) square spacing.

Alternate rows may be offset by 50 % of the spacing, depending on the dimensions of the material used. Usually there should be a row of attachments parallel to each edge and to each stiffener or flange, and at a distance of 75 mm to 150 mm away from the edge.

24.2.11 For large-radius curved surfaces, if welding is permitted, 450 mm to 600 mm uniform spacing is considered suitable, but this may be modified for vertical large cylindrical surfaces when the cleats are required to prevent downward movement of the insulating material. Cleats may not be required for horizontal cylindrical surfaces if it is possible to provide circumferential straps that can be tensioned over the insulation.

24.2.12 Welded attachments should preferably penetrate into the insulating material only to the minimum extent necessary to achieve effective support and, except in special circumstances, such penetration should not be greater than about half the thickness of the insulating material. The cross-sectional area of the attachments should be the minimum consistent with the required mechanical strength in order to avoid excessive transfer of heat (or cold) by metallic conduction.

24.2.13 It is important to remember that a welded attachment will be subjected to the same extent of thermal movement as will the insulated surface, with the resultant possibility of tearing the insulation or finish, unless care is taken to allow for this e.g. by expansion or slip joints.

24.3 Insulation supports

24.3.1 Distinction should be made between the main supports for the plant or equipment and those required only to support the thermal insulation, together with any associated finish. Supports for the plant and equipment, e.g. pipe supports and hangers, have to be capable of bearing the distributed load of the equipment itself while permitting the appropriate extent of thermal movement. They may be isolated from direct metallic contact with the surface of the plant, e.g. by compression-resisting

insulating material, or they may be in direct contact with the plant surface while being enclosed inside the thermal insulating material. (See figures 8, 9 and 10.)

24.3.2 Supports for insulation and any associated cleading are required only to bear relatively light loading; they may consist of metallic flat bars, rings, part rings, varying lengths of angle, or studs. The flat bars, rings and angles normally will rest on stud or cleat attachments welded in the appropriate locations to the surface to be insulated. (See figures 5 and 6.) Angle supports, where used, may be bolted to the welded attachments on the plant, or they may rest loosely on top of floating flat rings; in the latter arrangement short angle pieces may be used to secure external metal cleading to which they are fastened, either by bolts or by rivets. (See figures 3 and 6, also 8.3.1.)

24.3.3 Stud-type supports are used mainly for preformed or for spray-applied insulation, although they may serve as suspension points for the metal-mesh covering of flexible insulating mattresses (see 24.2.10). The studs may be in the form of attachments welded directly to the plant, e.g. split pins, fork studs, or plain studs, or as threaded studs screwed into nuts that themselves are welded to the surface to be insulated. Alternatively, especially for vertical alloy-steel pipework, the studs may be welded radially to a ring that can be clamped around the pipe at the required vertical intervals. As these rings tend to slip downwards under service conditions, suitable support lugs or pads for the rings should be welded on to the pipe at the manufacturer's works, to be followed by any necessary stress-relieving process.

24.3.4 As a general rule, studs should not be greater than 10 mm in diameter, or of equivalent contact area, for gun welding. Angle cleats and flat bar normally will be about 5 mm to 10 mm thick, depending on the weight of insulation (and finish) to be supported; widths conveniently may be about 75 mm, varying according to the total thickness of insulation to be supported. For anchorage of spray-applied mineral fibres and insulating concretes it is usual to provide Y-shaped studs of approximately 5 mm to 10 mm diameter for the main leg; these may be welded directly to the surface of the plant or may be threaded for screwing into corresponding nuts, which themselves are welded to the surface to be insulated.

24.3.5 Preferably, the supports should not penetrate the insulation to a distance greater than about half its thickness unless through-metallic connection between cold and hot surfaces of the insulation can be avoided, or reduced to an appropriate minimum. This is of particular importance with insulation over refrigerated plant, or when the external finish over hot insulation is of sheet metal. Sometimes it is possible to interpose a pad of insulating material between the inner welded attachments and the supports for the main insulation system.

24.3.6 The cross-sectional area of each insulation support should be not greater than that necessary to achieve the required mechanical stability, so that thermal conduction can be reduced to an acceptable minimum. In appropriate cases the support may be non-metallic, e.g. plastics or wood, and it is possible to take advantage of the fact that many alloy steels have lower thermal conductivity than has carbon steel, at corresponding temperatures.

24.3.7 As a general rule, supports for finishing materials, apart from those for the insulation proper, are not required except when a cleading of metal sheet is to be used over flexible fibrous material. Where such supports have to be used, they may consist of pads or short lengths of compression-resisting insulation, applied directly to the surface to be insulated or mounted over the ends of studs or angle cleats that themselves are attached to the surface. Alternatively, if the insulating material is not of sufficient resistance to compression, particularly over horizontal surfaces, the supports may be in the form of metal rings or 'stools' spaced away from the surface on 'prongs' to restrict the total area of contact with the insulated surface, so reducing the rate of thermal transmission to an acceptable minimum.

24.4 Securement (tie wires, lacing wire, bands, clips, washers, nuts, etc.).

24.4.1 Unless the insulating material can be secured directly to the surface to be insulated, e.g. by means of adhesive (see **8.2**, **25.2** and **25.3**), it is usually necessary to provide some form of mechanical accessory to secure it to the permanent attachments. Tie wires, lacing wire, washers, clips, or nuts, are the most common when associated with the types of attachment and supports described in **24.2** and **24.3**. For cylindrical surfaces it may be satisfactory to secure the complete insulation system by means of circumferential bands that can be tensioned over the outer surface. Sometimes wire netting over the insulating material will serve the same purpose provided that the edges can be laced tightly together. Separate securing accessories may not be required if an integral sheet finish is arranged so that an edge overlap can be secured by means of adhesive.

24.4.2 For large flat surfaces it is usual to secure the insulating material by impaling it over the studs or cleat attachments, using lacing wire to hold it in position. Preferably the lacing wire should be wrapped round the main attachments and crossed for tensioning. With flexible fibrous mattresses enclosed in wire mesh it may be sufficient to tie the outer mesh to the individual attachments.

24.4.3 Lacing wire and tie wire normally will be of galvanized soft iron but one of the soft alloy steels may be required for special chemical resistance or for use at elevated temperatures. (See **33.17.1** for temperature limitations.) Typical sizes of wire are 1 mm diameter for general use, or 1.5 mm for heavier use. For refrigeration work use plastics tapes instead of metal wires. Over flat surfaces or large cylindrical vessels it may be desirable to use multistrand wire that can be tensioned between attachments; wire with seven strands each of 0.7 mm diameter, twisted in rope form, is suitable for heavy work. Other soft wires may be useful for special applications.

24.4.4 Securing wires should be fastened either by simple wrapping round each attachment or by means of nuts, clips or washers, as appropriate, at each fixed point. Rapid-fixing clips, which depend on spring-point devices for securement, may become loose in service as a result of corrosion of the points.

24.4.5 Insulation on cylindrical surfaces, with an outer finish of fabric or sheet, may be secured by means of outer circumferential bands of metal or plastics strip. Metal bands may be about 20 mm wide and 0.5 mm thick; they should be corrosion resistant, either by virtue of the nature of the metal or by a surface treatment. Plastics bands

preferably will be between 35 mm and 50 mm wide and should be sufficiently robust to withstand prolonged conditions of service. Special forms of rapid-fastening 'bristle-type' securing strip can be useful for special duties. When outer bands are used they may conveniently be applied also for identification purposes, by colouring or marking as appropriate. For outer covering of aluminium sheet only aluminium or stainless steel bands should be used. Metal bands for large vessels should be of adequate width and thickness to provide stability to the insulation system under the required conditions of service. For overall economy on large vessels, stainless steel banding should be used.

24.4.6 Flexible insulating mattresses that have wire-mesh covering integral in their construction and are stabbed through with inter-surface ties, should be impaled over the main attachments and further secured by tightly fastening together adjacent edges of the outer covering mesh. The tie wires for this purpose should be approximately 1.5 mm in diameter and of similar metal to that used for the wire-mesh. If a final covering of aluminium sheet is to be applied, care should be taken to avoid direct contact between dissimilar metals. (See **33.17.1.5**.)

24.4.7 If split-pin or fork-stud attachments have been used, the insulation should be secured by bending the prongs of the fork arrangement, either through and over reinforcing mesh or through washers of suitable size. Conveniently these washers may be 50 mm square, cut from expanded metal of suitable type; approximately 10 mm mesh and 0.6 mm metal thickness are commonly used. Typically, the prongs of the pins or studs should be about 3 mm in diameter or 3 mm square and the lengths should be such that the prongs can be depressed, if required, below the outer surface of the insulating material.

24.4.8 Lacing wire or other securing device that is likely to be in direct metallic contact with a final cleading of aluminium sheet, should be coated with a suitable plastics material in order to avoid bimetallic corrosion in the locations of contact. Alternatively, it may be convenient to use aluminium or stainless steel securing materials.

24.5 Reinforcement

24.5.1 The most commonly used reinforcing materials are galvanized wire netting or one of the various types of expanded metal, but open-mesh woven glass fabric may be suitable for certain applications, e.g. the reinforcement of weatherproofing compounds applied in paste form. The main uses for the metallic reinforcement are with plastic compositions, spray-applied fibrous insulation, wet applied finishing compositions, and wet finishing cements, but they also are of value for retaining dry fibrous insulation and various types of preformed materials.

The size of mesh for wire netting is normally either 25 mm or 40 mm, with wire of 1 mm diameter, but the mesh may be reduced to 12 mm or 20 mm for use over flexible fibrous materials. Expanded metal will normally vary from 12 mm to 50 mm across the short dimension of the mesh, with thickness of metal varying between 0.5 mm and 1.6 mm, but heavier material may be used, e.g. for reinforcement of insulating concretes.

24.5.2 Galvanized steel reinforcing mesh and securing devices should not be subjected to temperatures in excess of 65 °C under conditions of possible high humidity. Suitable heat-resisting alloy should be employed for all

service temperatures in excess of 400 °C. For intermediate temperatures, carbon steel may be used, but this should be coated with bitumen or paint for protection against corrosion during storage and prior to application on site. (See 33.17.1.1.)

24.5.3 Where substantial mechanical strength is required, e.g. for resistance to compression, it may be desirable to use square-pattern reinforcing mesh, which may vary according to the requirements from strands of 2 mm diameter at 40 mm spacing to strands of 6 mm diameter at 100 mm or 150 mm spacing. Sometimes the component wires may be welded together at the crossing points. It should be noted that material of square mesh pattern is likely to distort on expansion at elevated temperatures if it is secured rigidly to attachments on the insulated surface.

24.5.4 If metal reinforcement is to be located over the outer layer of insulating or finishing material and is likely to be in direct contact with cleading of a dissimilar metal, precautions should be taken to avoid electrolytic corrosion action, e.g. by the use of a suitable coating on the inner face of the cleading, or on the reinforcing metal.

24.5.5 A special type of reinforcing lath is used for spray-applied bitumen with admixture of glass fibres (see 26.4.4.3). It is woven to a rectangular mesh of size 50 mm x 40 mm, with the wire of 1.6 mm diameter, and the whole is galvanized for rustproofing. Strong waterproof bitumenized paper covers either one or both faces of the mesh, and this serves to prevent absorption of the spray-applied weatherproof finish while giving reinforcement over the outer surface of the insulating material.

24.5.6 Where mechanical strength is required, e.g. for puncture resistance, it is desirable to embed open-weave glass cloth or cotton scrim between layers of weatherproof or vapourproof mastics.

25. Cold insulation: application for systems operating in the temperature range -100 °C to +5 °C

25.1 General

25.1.1 Metal surfaces operating below the dew point should be given a brush coat of priming paint, which has to be thoroughly dry before the insulation is applied (alternatively, the treatment may consist of coating with bitumen or waterproof polymer solution, or wrapping with self-adhesive PVC, polypropylene pipe-wrap tape or wax-impregnated cotton tape). The initial protective layer has to be compatible with any adhesive joint sealant and vapour seal used. It should also be resistant to steam purging temperatures, where applicable.

25.1.2 Cold insulation should be carried out at ambient temperature. It is sometimes possible to use a liquid with low freezing point to defrost very small items of operating plant. (The appropriate safety precautions have to be observed when using a solvent.) If this is done the insulation and vapour seal has to be applied immediately. In general, this practice is not recommended and insulation applied after defrosting should be regarded as temporary.

25.1.3 The manufacturer's recommendations should be followed, particularly in respect of

- (a) the compatibility of the insulation material with adhesives, joint sealant and vapour sealants;

- (b) the maximum temperature of hot-dip adhesives;
- (c) the resistance to 'cheese knife' cutting if wire ties are used.

25.1.4 Where mechanical support of the insulation is required, wood, or plastics skewers, etc., are preferred. Such supports should be wholly within the insulation.

25.1.5 It is important that the insulation be cut and fitted accurately. It is preferable that moulded preformed bends of insulating material should be used, as appropriate, to ensure accurate fit without open joints. The practice of filling gaps in joints with plastic composition or rough slivers of insulation is deprecated.

25.1.6 Contraction joints may be required because of the differing rates of thermal movement between the equipment and various types of insulating materials. See figure 2(b) for some values relating to typical materials in the temperature range +20 °C to -100 °C.

Where two or more layers of insulating material are required (see 25.3.1) the inner layer should not be bonded to the vessel or pipework with adhesive, although subsequent layers may be bonded to the appropriate previous layer.

Where the service temperature is very low (see 25.2.1) or where there are appreciably large fluctuations of temperature, and depending on the type of insulating material and the configuration of the system, contraction/expansion joints of the type shown in figure 2(a) may be adopted.

Joint-sealer mastic of suitable elasticity should be applied to the edges of all portions of preformed insulating material, including those of the inner layer.

See also 33.9.3.

25.1.7 It is essential that the vapour seal be designed as an integral part of the insulation system and applied as soon as possible so as to keep the insulation dry. (See figures 11 and 12.)

25.2 Adhesives and fastenings

25.2.1 To maintain the integrity of the insulation system, preformed insulation should be applied using adhesives or bedding compounds. (See 8.2.) For temperatures below -40 °C adhesives are not generally used. The use of a bore coating may help to reduce abrasive attack, for example on a pipe from cellular glass or on the inner surface of the insulant with organic foams.

25.2.2 Most adhesives form a bond by evaporation of solvents which may be flammable and toxic; water based adhesives are slow drying. Adequate 'open time' should be allowed for evaporation of the solvent before making a bond between materials of low permeance.

25.2.3 Many adhesives will not continue to operate effectively at very low temperatures. They may still be used as an aid to erection, however, if mechanical support is also provided. The manufacturer's advice on the effective temperature range of the adhesive should be sought.

25.2.4 Additional mechanical support may be obtained from metal or plastics bands or adhesive tapes of plastics or textile fabrics.

25.3 Typical erection methods

25.3.1 *Using preformed insulating materials.* When preformed insulating materials are used, two-layer construction is preferred for surfaces operating below -18 °C; all joints have to be staggered.

25.3.2 Using hot-dip adhesives. Hot-dip adhesives are bitumens of a suitable specification or a mixture of bitumens and waxes. The adhesive should be made molten in a bath of appropriate size by gas burner, steam or electric heater. A thermometer should be used to ensure that the correct temperature is maintained. The bath should be close to the work. The insulating material should be dipped on one inner face, one long and one short edge and then held firmly against the vessel until adhesion is effected. Subsequent pieces of insulation should be similarly treated and closely pressed against the ones already erected so that all joints are completely bonded.

Rigid sectional materials may have the molten adhesive mopped onto the appropriate surfaces.

The adhesion of hot-dip bitumen adhesives is improved if the work piece is given a priming coat of bituminous paint.

25.3.3 Using 'cold' adhesives. These may be based on bitumens, resins or rubbers. The adhesive should be applied by brush or trowel to one or both faces or to the insulating material and work piece. Where necessary appropriate time should elapse before the bond is made. Precise positioning of the piece of insulating material will be needed where an impact type of adhesive is used. Some adhesives permit the piece of insulating material to slide before final adhesion is effected.

25.3.4 Using bedding compounds. These non-hardening substances are generally based on fully saturated petroleum hydrocarbons containing inert siliceous fillers, or resins or bitumens in suitable vehicles. The use of such compounds permits insulating materials to be stripped without damage and re-used. The compounds should be used for bedding and insulating material against the work piece and can be palmed on by a glove-protected hand or applied by trowel so that all joints are fully sealed. When using this method of erection the insulating material has to be securely held by mechanical means. (See 25.2.)

25.3.5 Dry erection. This method is used principally for small-diameter pipelines operating between ambient temperature and 0 °C or where easy replacement and high recovery of the insulation is required on short-term projects.

The half-sections should be applied around the pipe and held in place by adhesive tape, galvanized wire or metal bands at 150 mm intervals. It is important that the joining faces be pressed tightly together.

25.3.6 Pipe supports. Pipe supports for cold lines should not be attached to the pipe, as it is difficult to seal the insulation surface at the point where the support projects through, and condensation or frosting tends to occur at that point.

Where external supports are used, the load of the pipeline should be carried by the insulation. Very light loads may be supported by the insulating material, but for heavier loads inserts of wood or other materials of high compressive strength may be used, or, alternatively, metal cradles may be used to reduce unit loading on the insulation.

When wood is used, all surfaces should be coated with a sealant before assembly. Recommended methods of construction are shown in figure 8, and tables 1 and 2 list the compressive strength of typical insulating materials.

25.3.7 Vessel supports. Similar considerations apply as for pipes.

25.4 Pipework and fittings

25.4.1 Pipework. For general considerations see 25.1. It is generally good practice to insulate piping with preformed material, although in-situ foam or sprayed foam may be used, especially on larger sizes. It is essential that cellular glass sections not secured to the pipe by adhesives should have a bore coating of a non-setting compound to act as an anti-abrasive lining; this bore coating has to be allowed to dry before the section is fitted.

Preformed sections should be erected as detailed in 25.3.

Bends should be insulated with the same type of material cut lobster-back fashion and secured as for straight piping, with one tie per segment; although, alternatively, fully moulded or prefabricated bends may be used if these are available.

25.4.2 Flanges, valves and other fittings. Provision should be made to permit removal of bolts. Fittings should be insulated with 'oversize' sections, if necessary in conjunction with slabs of the same material. The individual pieces should be jointed with adhesive and may be reinforced, e.g. by temporary fixing bands. Space around the fittings should be filled with a mineral-fibre or non-setting sealing compound with pieces of insulating material. Covers that are to be removable should not be fixed permanently to the main insulation but should be separately secured. Two vapour barriers will be required, one to enclose the main insulation totally and the other to cover the removable insulation. (See figures 11, 12 and 13.)

25.5 Vessels and large curved surfaces. For general considerations see 25.1. All physical forms of insulating materials can be used for curved surfaces, but preformed materials are the most commonly used (see figures 11, 12, 13 and 14). Other materials are foamed-in-situ, spray-applied and loosefill insulation.

Radiused and bevelled lags, plain lags and slabs with saw cuts on the inner face are normally supplied.

In addition to the use of adhesive, each layer should be banded on. Large slabs will need at least two ties per slab. Wooden skewers or thin clips may be used to hold second and subsequent layers to the first.

Where banding is impracticable slabs may be impaled on studs that partially penetrate the thickness of insulation.

The necessity for weight-carrying supports is generally restricted to larger vessels or downward-facing surfaces; supports of timber or heavy-density plastics secured to cleats are then used. The vapour seal has to be continuous over all such supports.

Where differential movement between vessel and insulating material makes necessary the use of expansion/contraction joints, the positions of these should be marked off before erection of the insulation begins. Suitable flexible vapourtight cover strips have then to be provided.

Before the erection of the main body of insulation all protruding pipe stubs, fittings, manhole necks, etc., should be insulated.

The insulation should extend down any vessel skirt or legs or cradle for a distance not less than four times the thickness of the insulation on the vessel, measured from the surface of the insulation.

25.6 Air conditioning ductwork (temperature range up to 5 °C)

25.6.1 Whilst this section refers specifically to ducts carrying air below the temperature of the surrounding air, ventilation or air-conditioning ducts may carry air for both heating and cooling. The recommendations given in **26.4**, where appropriate, apply. See also CP 413 and **33.13** for fire hazards.

25.6.2 Ventilation and air conditioning ducts are usually constructed of galvanized sheet steel, glass-reinforced plastics sheet (GRP), or they may be made from preformed insulating material or insulating boards. They are frequently located behind false ceilings, or in voids, subways, rooms, or workshops. Sometimes they are located outdoors on the roof of a building, in which case they are exposed to weather conditions.

25.6.3 Where a special coating is provided to protect the fabric of the duct from deterioration, care should be taken to maintain this coating intact; if it is damaged accidentally, the coating should be made good before insulating material is applied.

25.6.4 Where the insulation is located inside the air-conditioning duct (usually where a particularly quiet installation is required), there may not be any further requirement for external insulation. The internal insulation should be covered with glass fabric (with or without neoprene coating), plastics film, or scrim cloth. For conditions of high air velocity, perforated metal sheet backed by appropriate film should be used as the surface covering. The leading edge should be adequately sealed to prevent pick-up of the fibres by the air flow.

Insulation and its appropriate covering should have an adequate resistance to the spread of flame, and it should be of a type that is not capable of producing substantial quantities of smoke or other toxic gases in a fire when it is within an air stream. See CP 413 and **33.13**.

25.6.5 Fresh-air ducts and exhaust ducts carrying cold air should be insulated in order to prevent condensation. The insulation should be continuous over the whole length of the duct, including fans, heat exchangers, and filter casings carrying cold air. Flanges and stiffeners should be covered either by means of insulated box-type fittings or by increasing the general thickness of insulation to give at least 6 mm cover. See BS 5422 for thicknesses. Insulation over 50 mm thick should be applied in two layers, with staggered joints.

25.6.6 Suitable insulating materials for ductwork in this temperature range will usually be the foamed or expanded organic polymers (see table 2), but bonded non-asbestos mineral-fibre insulation, cellular glass, or cork can also be used, although cork and foamed or expanded polymers may be a fire hazard.

25.6.7 The insulating material may be secured to the surface of the duct by means of a suitable adhesive (see **25.2**), supplemented where necessary by the use of plastics or welded-metal pins or studs on a base plate that can be attached firmly to the duct, e.g. by an adhesive, or by welding, as appropriate. The insulation and finish should terminate clear of instruments, detectors, and damper operating gear and accessories to permit free opening and closing of the dampers. The insulation and finish should also terminate clear of access openings and hinged or removable doors.

Where there are fire dampers within ducts, combustible insulation should stop approximately 1 m clear of the

damper (which could become very hot in a fire) to prevent excessive radiation of heat to the insulation on the side remote from the fire, so preventing the damper from performing its fire-separating function.

25.6.8 Where the contained air is at a temperature below the maximum design dew-point temperature for the surrounding air (usually the case in this temperature range), the outer surface of the insulation should be protected by a continuous water-vapour barrier of permeance not exceeding approximately 0.05 g/(s MN). The vapour barrier and insulation should not be pierced or fouled by supports. At discontinuities and at the ends of sections of the duct system, the vapour barrier should be returned to the ductwork to prevent entry of moisture at the edges of the insulation. See also **33.16**.

25.6.9 With organic polymer slabs or sections, and with bonded mineral-fibre slabs, the vapour barrier may take the form of aluminium foil, adhered to the insulation surface, with laps sealed with aluminium foil tape. If the insulation is supplied with a facing having a protruding overlap edge, this may be bonded with adhesive or secured with staples, and the joint covered with foil tape. Alternatively, the insulation may be covered with woven cotton or glass fabric of 300g/m² to 400g/m², which is secured by means of adhesive and then coated with two coats of appropriate vapour-sealing compound. Alternatively the securing and protection may be by means of two coats of polymer emulsion adhesive/vapour barrier coating. Cellular glass insulation should be treated with a polymeric mastic which is reinforced by scrim fabric. If plain unfaced insulation slabs are used and the foil facing is applied on site, the overlaps should not be directly above the joints of the slabs.

25.6.10 Typical alternative insulation schemes, using organic polymer slabs or bonded mineral fibre of suitable bulk density, would be:

- | | |
|---|--|
| (a) Concealed from view | As described in 25.6.8 |
| (b) Exposed to view, but not readily accessible | As described in 25.6.8 and painted in a colour to match decoration of surroundings |
| (c) Exposed to possible mechanical damage | As described in 25.6.8 but enclosed in metal sheet (1 mm thick aluminium or 0.8 mm thick galvanized steel) secured with bands |
| (d) Exposed to weather: | <p>(1) Aluminium foil adhered to the surface, all joints sealed, covered with 0.6 mm thick aluminium sheet with all laps sealed</p> <p>(2) As (1) but finished with roofing felt and wire netting, or with polyisobutylene sheet</p> <p>(3) As (1) but with a vapour-barrier coating of polymeric mastic or bitumen, applied by hand or by spray gun; an additional weather coating with scrim reinforcement if required</p> |

BS 5970 : 1981

Section four

25.6.11 It is important that the problem of fire hazard for air-conditioning ductwork should receive careful attention. A fire stop should be provided at each wall penetration. Recommendations are given in CP 413 and BS 5422. See also **33.13**.

25.7 Flat and irregular surfaces (including machinery). For general considerations see **25.1**. For erection against flat surfaces the basic recommendations given in **25.5** apply.

If intricate shapes are to be boxed in with board or slab insulation materials these should be jointed preferably with hot-dip adhesives and further reinforced with skewers or clips.

In the erection of cold boxes a supporting structure is normally necessary. The insulation manufacturer's advice should be sought if free-standing panels are to be used.

Alternatively, most preformed slabs can be laminated to a variety of facing materials to form large panels that may be used to clad a structure.

26. Hot insulation: application for systems operating in the temperature range +5 °C to 870 °C

26.1 General. Apart from certain loadbearing materials, most types of insulating materials require support or reinforcement when applied; also, they require to be secured to the surface to be insulated. For these reasons, it may be necessary to attach fixing accessories to the plant before application of the insulating materials is commenced. (See **8.3**.) Where the surface to be insulated is at a temperature below the dew point of the surrounding air, a vapour barrier should be provided on the exposed (warm) surface. See **7.6.1** and **33.16**.

26.2 Pipework

26.2.1 General considerations. It is preferable that the insulation of pipework should be carried out with preformed materials where the temperature limitations permit. Where the pipe diameter is too large for moulded pipe sections to be used the pipe should be covered as far as practicable by building up with radiused and bevelled lags.

The need to dismantle pipework with a minimum disturbance of insulation should be borne in mind, and permanent insulation should end sufficiently far from flanges and fittings to enable bolts to be withdrawn. Flanges should be insulated as far as practicable by premoulded material or insulated boxes that can be removed for maintenance. Figures 16 and 28 show a possible method of arranging this.

The junction between removable and permanent insulation should be made readily discernible, e.g. by painting the end or by laying a suitable textile fabric over the end of the permanent insulation.

Valves and fittings should be insulated with preformed sections as far as is practicable. See figures 17 and 28. It is appreciated that irregular surfaces are difficult to so insulate, but the maximum use of moulded sections entails the minimum wastage of material should it be necessary to remove and replace the insulation for inspection purposes. The insulation should be finished in such a manner that there is free access to instruments. All thermometer pockets, including the boss and welded pad, should be insulated. For some superheated steam installations it may be desirable to insulate

pressure-gauge pipework for a reasonable distance from the tapping point to avoid pressure loss due to cooling.

It is desirable that all insulation over 65 mm thick should be applied in multilayers with a maximum of 65 mm per layer.

All joints should be staggered (see figure 18).

Hangers and supports should be insulated from the pipe surface in a suitable manner, and where applicable should comply with the requirements of BS 3974. Recognized methods for hot pipes using direct-contact support or insulation rings are shown in figures 9, 10, 19, 20, 21, 22, 23 and 24.

Flexible piping, other than corrugated piping for steam services, should be insulated as shown in figure 25.

Corrugated piping should be insulated as plain piping. Expansion bellows pieces are frequently left uninsulated for metallurgical considerations but where required they can be insulated as shown in figure 26, with suitable external protection as necessary.

Pipe systems will usually have to be tested for leak tightness and the insulation should not be finally secured over joints until the system has proved to be leak-free under operating conditions. To facilitate regular inspection of welds and bolted joints, removable portions of insulating and finishing materials should be provided in the appropriate locations.

26.2.2 Preformed materials. Preformed pipe sections should conform with the requirements of the relevant Part of BS 3958. They should be fitted closely to the pipe, and any unavoidable gaps in circumferential or longitudinal joints should be filled with compatible insulating material. Where there is more than one layer of insulating material, all joints should be staggered (see figure 18).

Each section should be held in place by circumferential bands or wires (see **24.4.3** and **24.4.5**) at not greater than 450 mm spacing and not nearer than 50 mm to the end of the section. After tightening, the ends should be pressed on to the insulating material. The choice of material for the bands or wire and its corrosion protection should be based on the environmental conditions. See **23.6** for leak testing.

When sections are held in position and covered by a fabric, this should be secured by stitching or by the use of an adhesive. The edges of the fabric, if stitched, should overlap by at least 25 mm; if adhesive tape is used to cover the joints it should preferably be wound with an overlap of at least 25 %. Alternatively, with a fabric or sheet outer finish, the whole may be secured by circumferential bands (see **24.4.5**).

Sections that are split down one side only should be sprung on to the piping, and secured. Certain types of pipe sections can be secured by corrosion-resisting staples at the joints; these staples should be not further apart than 100 mm.

For vertical and near vertical piping, it is important to prevent downward displacement of the insulating material by the use of appropriate supports, which may be in the form of metal rings, part rings, or studs (see **24.3.2**). These supports should be located at intervals of not more than 5.0 m and, in any case, there should be a support immediately above each expansion break in the insulation (see **33.9.1**). See **24.3.5** for extent of penetration of the supports; see also **24.2.12** for the extent of penetration of