

Code of practice for

Thermal insulation of pipework and equipment (in the temperature range – 100 °C to + 870 °C)

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Refrigeration, Heating and Air Conditioning Standards Policy Committee (RHE/-) to Technical Committee RHE/9, upon which the following bodies were represented:

- Autoclaved Aerated Concrete Products Association
- Chartered Institution of Building Services Engineers
- Combustion Engineering Association
- Cork Industry Federation
- Cranfield Institute of Technology
- Department of Health
- Department of the Environment (Building Research Establishment)
- Department of Trade and Industry (National Physical Laboratory)
- Electricity Supply Industry in UK
- Eurisol (UK Mineral Wool Association)
- Gypsum Products Development Association
- Phenolic Foam Manufacturers' Association
- Power Generation Contractors Association (BEAMA Ltd.)
- Royal Institute of British Architects
- Thermal Insulation Manufacturers' and Suppliers' Association (TIMSA)
- Thermal Insulations Contractors' Association

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- British Chemical Engineering Contractors' Association
- Chemical Industries' Association
- Combined Heat and Power Association
- Engineering Equipment and Materials Users' Association
- Heating and Ventilating Contractors' Association
- Institution of Plant Engineers
- Polyethylene Foam Insulation Association

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Foreword

This Code of practice has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee. It supersedes BS 5970:1981, which is withdrawn.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.

As this is not a specification it takes the form of recommendations. This code does not, however, take precedence over a specification for a particular contract.

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 necessary to consider briefly matters that are the subject of contractual arrangement rather than of technical importance.

This standard is intended 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 deal with methods of test and with the characteristic properties of individual materials.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 138, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This standard describes aspects of thermal insulation for pipework and equipment in the temperature range – 100 °C to + 870 °C. 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.

NOTE 1 Structural insulation of buildings and cold stores, fire protection of structures, refractory linings of plant, airborne installations and all external underground mains are not covered by this standard.

NOTE 2 Specifications corresponding to parts of this code are contained in BS 5422.

NOTE 3 The titles of the publications referred to in this standard are listed on page an inside back cover.

2 Definitions

For the purposes of this British Standard, the definitions given in BS 874-1 and BS 3533 apply, together with the following.

2.1

finishing materials

all materials used for covering thermal insulation, whether applied in a factory or on site

2.2

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

2.3

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

2.4

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 Exchange of design data

3.1 Information to be supplied by the purchaser

3.1.1 *General*

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), if required by the contractor, the purchaser should submit information on **3.1.2** to **3.1.9**.

In all cases it is important that all aspects of clause 3 should be agreed between purchaser and manufacturer or contractor before a contract is drawn.

3.1.2 *Details of plant to be insulated*

The details of the plant to be insulated should be stated as follows:

- a) Whether the plant is located indoors, outdoors but protected, outdoors exposed to weather, or enclosed in ducts or trenches below ground level;
- b) any difficult or unusual site conditions that may 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 either adequately detailed on drawings, preferably coloured to indicate areas to be insulated, or otherwise detailed, giving:
 - 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, bends with radius and angle;
- 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 temporarily or permanently 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.

3.1.3 Temperature conditions

The temperature conditions should be stated as follows:

- 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 and, where a specified temperature is required on the outer surface of the insulation 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), and as it is difficult to measure with accuracy either the surface temperature or the heat loss from the surface of the insulation under site conditions, site measurements should be interpreted with reservation;
- d) any requirement to prevent condensation on the outer surface of an insulated pipe or vessel containing cold media.

NOTE Normally, the theoretical heat loss is based on the manufacturer's declared value of thermal conductivity and, unless otherwise stated, refers to conditions of ambient still air at a temperature of 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 occur through supports, hangers, valve control wheels and other fittings. It is important to note that "thermal efficiency" (see 32.4) is not included.

3.1.4 Preparation of surfaces

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. (See also clause 23).

3.1.5 Types of fittings and supports

Types of fittings and supports and whether or not these are to be provided by the purchaser should be stated (see 7.3 and clause 23).

3.1.6 Type of insulation required

The type of insulation required should be stated as follows:

- 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;
- c) type of material.

3.1.7 Type of finish required

The type of finish required, for example, whether hard-setting composition or self-setting cement, weatherproofing compound, or sheet metal, should be stated.

3.1.8 Special service requirements

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

3.1.9 Basis on which the thickness of insulation is to be determined

The first consideration should be to decide whether or not insulation is required at all.

NOTE 1 Either a hot or a cold surface in surroundings at a similar temperature may not require any insulation and, even if there is a temperature differential between the surface and the surroundings, it may be desirable to encourage heat transfer, e.g. bare hot pipes and radiators for drying or space heating, or cold surfaces for air cooling.

Considerations should be, for example:

- a) specified temperature on outer surface of insulation system;
- b) specified heat loss per unit dimension, linear or superficial (see note to 3.1.3);
- c) economic thickness (see BS 5422);
- d) specified conditions of temperature for the surfaces to be insulated (see note 2);
- e) specified conditions of fluid at the point of delivery;
- f) special thickness requirements.

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

- 1) to avoid differential thermal expansion between the insulated surface and adjacent structures;
- 2) to prevent condensation of moisture on the internal surfaces of the containment system, e.g. in gas flues;
- 3) to prevent the condensation of moisture on the external surface of insulated plant containing cold media;
- 4) 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.

3.2 Information to be supplied by the manufacturer or contractor

The following information should be supplied by the manufacturer or contractor:

- a) information pertaining to the relevant parts of 3.1;
- b) the manufacturer's declared value of thermal conductivity (λ) appropriate to the temperature of use; 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 and bulk density of the individual layers;
- e) information regarding the surface preparation;
- f) the appropriate section of the code (to be stated) with which the following are in accord
 - 1) insulating material;
 - 2) reinforcement (if any);
 - 3) fixing devices and finishes.

3.3 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.

4 Factors affecting planning and programming

4.1 Since insulation contractors' operations on site are dependent upon the progress of other contractors, the insulation contractor should be provided with details of expected programmes that will control his work.

4.2 Early consideration should be given to the following:

- a) programme of commencement 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 on health hazards);
- p) restriction on mixing compositions;
- q) protection of adjacent plant and machinery;
- r) clearing waste material from site;
- s) provision of weather protection during installation.

Section 2. Selection of insulating materials and systems

5 Typical characteristics

5.1 Thermal conductivity

The thermal conductivity should be considered when selecting a suitable material. For determination of design thickness see **33.6**. 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 higher conductivity. This is of particular advantage for pipes because thinner layers of insulation reduce the surface area that will require protection.

The thermal conductivity of most insulating materials varies with temperature and bulk density. Manufacturers usually produce a range of products, each one designed for a different application and/or temperature range. An insulant's effectiveness depends essentially on a mass of material which contains a large number of minute air (or gas) cells. This structure restricts the transfer of heat by convection and radiation. The limitation in area of solid thermal bridges forms a barrier to the passage of conducted heat.

The thermal conductivity of certain plastics foams increases with age and it is usual to specify this in terms of initial value and aged value. In the cases of polyurethane (PUR) and polyisocyanurate (PIR) foams the values used in BS 5608 are 3 days for initial value and 30 days for aged value.

In the case of material for use at temperatures above ambient, it is the normal practice of manufacturers to provide tables or graphs showing how the thermal conductivity of each product varies with temperature. This temperature is usually, but not always, quoted as the mean temperature, i.e. the arithmetic average of hot- and cold-face temperatures used during the testing of the product. It is necessary that the corresponding cold-face temperature is also quoted. In the case of materials for use at temperatures below ambient, it is usual for the manufacturer to quote both hot- and cold-face temperatures relevant to the declared thermal conductivity value.

Recommended test conditions are given in BS 874-2 and methods of calculating required thicknesses of insulation are given in BS 5422.

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

5.2 Physical forms

Insulation is usually supplied in one of the following forms:

- preformed (slabs or sections)
- loosefill
- flexible
- plastic composition
- sprayed and blown
- metallic, e.g. crimped foil.

Each of these are 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 Table 1 and Table 2.

5.3 Bulk density

The bulk density, which for most thermal insulating materials falls within the range 10 kg/m^3 to 320 kg/m^3 , should be considered when selecting a suitable material.

If necessary for the purpose of design, the applied load due to the insulation should be known and should be calculated either from the density and dimensions, or from the weight of the particular products to be used.

5.4 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 Table 1 and Table 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 cleaning and defrosting purposes.

For materials to be used at elevated temperatures the many factors that may result in deterioration under conditions of service should be considered, including linear shrinkage under heat, loss of compressive strength 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. It should be noted that 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.

Table 1 — Typical insulating materials for use at temperatures higher than ambient

Ref.	Material	Physical forms	Type	Approximate maximum operating temperature ^a	Normal bulk density
				°C	kg/m ³
1	Stainless steel	Dimpled foil	Reflective	760	—
2	Mineral wool (glass)	Resin-bonded slabs/lags	Fibrous	230	15 to 100
		Preformed pipe sects	Fibrous	540	60 to 100
		Flexible mats	Fibrous	230	15 to 35
		Lamella mat	Fibrous	230	20 to 40
3	Mineral wool (rock)	Loose wool	Fibrous	850	50 to 150
		Resin-bonded slabs/lags	Fibrous	850	20 to 200
		Preformed pipe sects	Fibrous	750	80 to 150
		Flexible mats	Fibrous	230	Up to 45
		Wired mattresses	Fibrous	850	90 to 130
		Lamella mat	Fibrous	230	30 to 48
		Pipe section mat	Fibrous	650	140
		Inorganically bonded slabs/lags	Fibrous	1 100	240 to 250
4	Mineral wool/cement/binder	Sprayed	Fibrous	650	100 to 300
5	Insulating compositions	Plastic composition	Granular	1 000	250 to 1 100
6	Vermiculite	Loosefill ^b	Granular	1 100	50 to 150
7	Vermiculite/cement	Sprayed	Granular	1 100	320
8	Vermiculite/sodium silicate	Slabs	Granular	1 000	450
9	Magnesia	Plastic composition	Granular	310	180 to 220
		Preformed slabs	Granular	310	180 to 220
		Preformed pipe sections	Granular	310	180 to 220
10	Calcium silicate	Plastic composition	Granular	1 000	160 to 320
		Slabs/lags	Granular	1 010	160 to 320
		Preformed pipe sections	Granular	800	190 to 260
11	Cellular glass	Slabs and pipe sections	Cellular	400	130 to 160
12	Alumino silicate	Loosefill ^b	Fibrous	1 260	80 to 100
		Spray applied	Fibrous	1 260	150 to 250
		Blanket, felt	Fibrous	1 260	50 to 150
		Paper	Fibrous	1 260	200
		Ropes	Fibrous	1 260	100 to 150
13	Silica	Loosefill ^b	Fibrous	1 000	50
		Blanket, felt	Fibrous	1 000	50 to 150
		Cloth, tapes	Fibrous	1 000	500 to 800
		Opacified aerogel slatted blanket	Granular	950	200 to 300

Table 1 — Typical insulating materials for use at temperatures higher than ambient

Ref.	Material	Physical forms	Type	Approximate maximum operating temperature ^a	Normal bulk density
				°C	kg/m ³
14	Perlite	Loosefill ^b	Granular	870	40 to 150
15	Polyurethane rigid foam	Preformed slabs and pipe sections, sprayed, and foamed in situ	Cellular	110	30 to 160
16	Polyurethane flexible foam	Blanket, slab and pipe sections	Cellular	70	30 to 65
17	Polyisocyanurate rigid foam	Preformed slabs and pipe sections and foamed in situ	Cellular	140	30 to 60
18	Phenolic rigid foam	Preformed slabs and pipe sections and foamed in situ	Cellular	120	35 to 200
19	Polyethylene	Preformed pipe sections	Cellular	80	30 to 40
20	Synthetic rubber	Flexible preformed pipe sections, flexible slabs	Cellular	105	60 to 100

NOTE 1 Above 230 °C, compressive strength of organically bonded materials may be reduced.

NOTE 2 For typical thermal conductivity values see Figure 1(a). Some values may alter if chlorinated fluorocarbons (CFCs) are replaced by alternative blowing agents.

NOTE 3 Materials are without facings.

^a Temperatures shown are maximum continuous operating temperatures depending on product type. Reference should always be made to manufacturers' literature before specifying. The limiting temperatures of any facing material should also be checked.

^b Loosefill materials should be packed to densities to suit the application and thermal conductivity required.

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 230 °C, the insulating material should, if necessary, be supported and protected.

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 should then be applied in selecting material for specific conditions of use.

5.5 Thermal expansions

Most thermal insulating materials have a different thermal expansion coefficient from metals; differential thermal movement between the insulated surface, insulation and outer finish should be considered.

5.6 Resistance to compaction

It should be noted that loosefill material and unbonded mattresses are liable to compact under the influence of vibration and thermal cycling.

5.7 Resistance to water vapour penetration and to water absorption

Whilst closed-pore materials, e.g. cellular glass, may have low water vapour permeability characteristics, open-pore and fibrous insulating materials can absorb considerable quantities of water which whilst present adversely affect the thermal conductivity and the effectiveness of the insulation.

Insulation applied to cold surfaces should be protected from water vapour penetration that gives increased conductivity, since if water is allowed to penetrate and freeze, the cells of the insulation may rupture and the material be permanently damaged. The material itself should be preferably of low water vapour permeability.

Table 2 — Typical insulating materials for use at temperatures below ambient

Ref.	Material	Physical forms	Type	Approximate maximum continuous operating temperature ^a	Normal bulk density
				°C	kg/m ³
1	Phenolic foam (types A, B and C)	Preformed slabs and pipe sections	Cellular	120	35 to 200
2	Polystyrene foam extruded	Preformed slabs, preformed pipe sections	Cellular	80	15 to 35
3	Baked cork	Preformed slabs, preformed pipe sections	Cellular	60	100 to 200
4	Granulated baked cork	Loosefill	Granular	60	80 to 150
5	PVC expanded	Preformed slabs	Cellular	65	60 to 120
6		Flexible slabs			
7	Polyurethane rigid foam	Slabs, pipe sections, sprayed	Cellular	110	30 to 160
8	Polyurethane flexible foam	Slabs, pipe sections	Cellular	70	30 to 65
9	Polyisocyanurate rigid foam	Slabs, pipe sections, sprayed	Cellular	140	30 to 60
10	Cellular glass	Rigid slabs, rigid pipe sections	Cellular	400	120 to 160
11	Mineral wool (glass)				
12	Mineral wool (rock)				
13	Silica aerogel	Loosefill	Granular	980	50 to 150
14	Perlite	Loosefill	Granular	870	40 to 150
15	Synthetic rubber	Flexible slabs, flexible pipe sections	Cellular	105	60 to 100
16	Polyethylene	Preformed pipe sections	Cellular	80	30 to 40

NOTE 1 For typical thermal conductivity values see Figure 1(b). Some values may alter if CFCs are replaced by alternative blowing agents.

NOTE 2 Care is necessary in interpreting the maximum continuous operating temperatures in this table. These are based on manufacturers' claimed figures and may require verification in practice.

NOTE 3 Materials are without facings.

^a The lower limiting temperature of insulating materials is dependent on several factors and the manufacturers should be consulted.

5.8 Mechanical strength and durability

5.8.1 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 should be taken into consideration at the design stage.

5.8.2 Durability

Regarding the durability of an outdoor insulation system the effect of sunlight and exposure to the elements should be considered.

5.9 Fire and explosion hazards

Whilst it is usual that insulation should be of limited combustibility there may be situations where such is unnecessary, in which case the relevant building and fire prevention authorities should be consulted. It should be noted that the fire hazard associated with the use of a particular thermal insulant, for example, combustibility, ignition susceptibility, surface spread of flame, emission of smoke or toxic gas, may be influenced considerably by the presence of adhesives, vapour barriers and sealants, which complete the overall insulation system; also many insulating materials do not constitute a fire hazard, but can absorb quantities of oil or other flammable liquids that may ignite spontaneously. (See 9.6 and 32.12.)

In certain areas where there is a high risk of fire or explosion and strong oxidizing agents are being handled, the insulation should not contain any organic matter.

5.10 Resistance to vermin and fungus

Insulation, particularly in cold stores or food factories, should be resistant to vermin, insects and fungal growth. Insulation surfaces likely to become wet should not be finished with materials that may be attacked by these agencies. Finishing with non-absorptive materials should be considered.

5.11 Health hazards

5.11.1 Reference should be made at all times to the current requirements of health and safety legislation, and to relevant publications that may be issued from time to time, and to the appropriate instructions from manufacturers.

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

5.11.3 It should be noted that chemical fumes arising from the in-situ foaming or spraying of organic insulating materials, e.g. 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 should be used for many materials, especially isocyanates and epoxy-resin compounds.

5.11.4 It should be noted that contact with certain resinous coatings, adhesives and epoxy-resin components can cause dermatitis and other skin complaints, which may occur after brief contact, or long exposure leading to allergy. Associated solvents may cause damage to the eyes and skin irritation and goggles and gloves should be used when necessary. Barrier cream and adequate washing facilities should be provided. The problem of special respiratory hazards when these materials are sprayed should be noted.

5.11.5 Simple hygienic precautions should be taken when using fibrous insulants that cause skin irritation. For detailed advice on the subject, the following publications of the Health and Safety Executive (HSE) should be consulted.

EH 44 "Dust in the workplace. General principles of protection"

EH 46 (Guidance note) "Exposure to mineral wools"¹⁾

5.11.6 When insulating materials are mixed, handled or removed, adequate precautions should be taken to minimize the risk of respirable dust particles entering the bronchial passages.

Reference should be made to HSE documents:

EH 40 "Occupational exposure limits"

EH 44 "Dust in the work place. General principles of protection".

5.11.7 Before any stripping work is carried out it should be determined what type of insulating material is involved and relevant precautions should be taken (see clause 30).

5.12 Removal and replacement

When removal and replacement or abutment to insulation containing asbestos is to be undertaken, any health hazards associated with removal should be considered and suitable precautions taken. (See also 30.3.)

NOTE Guidance notes issued by manufacturers together with legislation, codes of practice and guidance notes issued by HSE provide recommendations for good practice in removal of some types of insulation.

5.13 Optimum heat capacity

As the heat capacity (alternatively thermal capacity) of an insulating material varies according to its bulk density, this thermal property should preferably be expressed in terms of heat capacity per unit mass (alternatively specific heat capacity). In SI units this value is expressed in joules per kilogram kelvin [$J/(kg \cdot K)$] and it should be noted that the value will vary with mean temperature even though it is given in terms of unit increment of 1K.

NOTE An insulating material of low thermal capacity absorbs 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 tends to impart thermal stability to an insulated system.

For certain applications it may be convenient to refer to heat capacity per unit volume, [$J/(m^3 \cdot K)$], but this value will be typical only for a representative product, i.e. at a specific bulk density.

5.14 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 5.10.)

¹⁾ Available from HMSO, PO Box 276, London SW8 5ET.

5.15 Corrosion

It should be noted that 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.

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.

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. Austenitic stainless steels are susceptible to this type of attack when subjected to stress and when the temperature exceeds 50 °C. 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.

See 32.16 for more detailed treatment of corrosion problems and preventative measures.

5.16 Chemical resistance

Thermal insulation used in process plant should not present a hazard if inadvertently contaminated with chemical spillages. The risk of contamination should be minimized by optimum choice and design of finishing system.

5.17 Maintenance requirements

Maintenance costs can be significant in the total cost of an insulating system and should be minimized by correct selection of materials and finishes and by attention to detail in the layout of the system. The design of the system should pay particular attention to the incorporation of removable insulation modules to allow maintenance or inspection of the underlying components. Regular inspection and repair of damage should be carried out to minimize risk of large-scale deterioration of the insulation system and any subsequent corrosion of the plant.

6 Selection of thermal insulating materials

6.1 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 5.11)	Health hazard (see 5.11)
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)
m) Compatibility with atmosphere and possible spillages	Compatibility with atmosphere and possible spillages
n) Plant life	Plant life

6.2 Types available

NOTE The terms used are explained in BS 3533.

6.2.1 General

It should be noted that although all thermal insulating materials, with the exception of reflective insulation, depend partly 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 6.2.2 to 6.2.13.

6.2.2 Preformed

Normally this term is applied to slabs, pipe sections and related shapes based on cellular, granular or fibrous structures that are formed into a substantially rigid mass, but it also includes such products as rigid cellular plastics, cellular glass and bonded natural materials, e.g. cork and exfoliated minerals.

6.2.3 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.

6.2.4 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 be in this category.

6.2.5 Plastic composition

Material of this type consists of dry powder, 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.

6.2.6 Spray-applied

This type consists of 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.

6.2.7 Foamed in situ

This type is normally cellular organic plastics agglomerates that are foamed in a cavity by physical or chemical means during or immediately after application.

6.2.8 Microporous insulation (silica aerogel)

This type consists of 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 a preformed material or encapsulated in glass or silica fibre fabric.

6.2.9 Reflective insulation

This is 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 is also included. These materials are normally used in association with one or more air spaces, which may be closed or open.

6.2.10 Insulating boards

These are 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.

6.2.11 Insulating bricks and allied products

These are 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.

6.2.12 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.

6.2.13 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 moulded or prefabricated valve and flange covers, prefabricated flexible mattresses, lined metal valve and flange boxes.

6.3 Typical properties of thermal insulating materials

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

Table 2 gives 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 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.

Figure 1 shows the following:

- a) typical thermal conductivity values for materials particularly suitable for use at relatively high temperatures and intermediate temperatures;
- b) typical thermal conductivity values for cold insulating materials.

6.4 Typical dimensions

6.4.1 General

Preformed insulation and factory-made mattresses of the sizes shown in 6.4.2 and 6.4.3 are readily available but individual manufacturers can often supply a wider range and should be consulted.

6.4.2 Preformed insulation

The dimensions of preformed materials shown in the following list should be regarded as being indicative of the range of sizes commercially available but are not intended to be a comprehensive list for all materials; not all materials are available in the full range of sizes shown.

a) Slabs

Length	0.6 m to 2.0 m
Width	0.6 m to 1.0 m
Thickness	10 mm to 100 mm in increments of 10 mm or 12.5 mm

b) Pipe sections

Length	0.5 m to 2.0 m
Diameter	To fit pipe ODs from 17 mm to 950 mm
Thickness	10 mm to 100 mm in increments of 10 mm to 12.5 mm

c) Bevelled, or radiused and bevelled, lags

Length	0.5 m to 1.2 m
Diameter	To fit pipe diameters of 220 mm and above
Width	75 mm to 300 mm
Thickness	10 mm to 100 mm in increments of 10 mm to 12.5 mm

6.4.3 Mattress insulation

The dimensions for mattress insulation should typically be as follows:

a) wire-netting-covered mattresses	up to 7.0 m × 1.2 m;
b) expanded-metal-covered mattresses	up to 2.4 m × 1.2 m;
c) nominal thickness	25 mm to 100 mm

6.5 Applicability of thermal insulating materials

6.5.1 General

It should be noted that, 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 ambient (see Table 2) and one that is applicable mainly for elevated temperatures (see Table 1). 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.

6.5.2 Refrigeration and general cold work

6.5.2.1 The insulating material should be of adequately low thermal conductivity, compatible with economic considerations, and it should be capable of remaining so under the expected conditions of service and plant life. On the basis of convenience in application, the normal preference should be either for preformed material, or for foamed-in-situ products.

6.5.2.2 An alternative that should, if wished, be considered is 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.

NOTE 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.

6.5.2.3 Where the plant is to operate continuously at temperatures below that of the ambient air, it is essential that the insulating material should be protected by a vapour-sealing barrier. For full advantage the insulating material should itself be resistant to the passage of water vapour, in order to supplement the protective effect of the external vapour seal.

6.5.2.4 Only dry insulating material should be used and it should be kept dry until after the vapour barrier has been applied and completed. It should be remembered 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 24.2.1). 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.

6.5.2.5 If necessary, 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 plant under hot/cold cycles and the insulation system, i.e. insulation and vapour barrier, should be designed to accommodate thermal movement of plant. (See 32.8.3 and Figure 2 for contraction joints.)

6.5.2.6 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, the use of a compression-resistant loadbearing thermal insulation, e.g. cellular glass, high-density cork or expanded plastics, should be considered. If wood or other absorbent material is used it is important that this should be kept dry during service.

6.5.2.7 As many low-temperature insulating materials are combustible, careful attention should be paid to avoiding potential fire hazard under service conditions. (See 32.12.)

6.5.2.8 Insulating materials, joints sealers and vapour barriers 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 should, if necessary, be given 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 5.9.)

6.5.2.9 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.

NOTE 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 decreases with increase in pipe diameter. (See also 32.13.)

6.5.3 For normal ambient and elevated temperatures

6.5.3.1 When the surface to be insulated is of regular shape preformed materials should be considered as being probably the most suitable; their physical properties, shapes and dimensions can be controlled during works manufacture, 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.

6.5.3.2 Although flexible materials can be used for plant of both regular and irregular shape, it should be noted that they are easily deformed by superimposed loads, e.g. by the weight of finishing material. Thus, to ensure reliable thermal effectiveness in service, adequate support should be provided from the plant surface for any substantial protective layer, independently of the insulating material itself.

NOTE However, 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.

6.5.3.3 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 reasonably uniform packing at an optimum bulk density should be achieved, e.g. by the provision of internal spacer supports to prevent settlement under service conditions.

6.5.3.4 For irregular shapes of plant it may be convenient to make use of plastic composition insulating materials but, in these cases, the plant should be preheated and the heat maintained until all the insulation is dry. As wet plastic composition should 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.

Since plastic composition mixes are likely to contain soluble chloride salts, either as normal impurities or in the water used for forming the paste, they should not be used for direct application to austenitic steel surfaces on account of the potential danger from stress-corrosion attack. Additionally only potable water should be used for mixing in order to minimize the risk of corrosion from soluble salts in contaminated water. (See 32.16.3.2.)

6.5.3.5 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, spray-applied insulation should be considered. Special care should be taken to achieve uniform bulk density and thickness. The problem of drying out should also receive special attention.

6.5.3.6 It should be noted that 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 reactive chemicals, e.g. for the production of polyurethane, isocyanurate and phenolic foam. Such materials should be considered as being 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 should be 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.

6.5.3.7 It should be noted that the advantage of microporous insulation relates to its low thermal conductivity, which persists to high temperatures; this characteristic permits the use of lesser thicknesses than would be appropriate for more conventional materials. It is important that microporous silica insulation should never become wet as this can result in an irreversible breakdown of the microporous structure and loss of insulating properties.

6.5.3.8 It should be noted that reflective metallic surfaces are more effective than non-metallic surfaces in reducing absorption or emission of radiant heat.

NOTE Reflective metal foils may be used in conjunction with granular, cellular, fibrous or powder-type insulating materials and as intermediate layers in air cavities where required for thermal insulating purposes.

Multilayer all-metallic reflective thermal insulation should be considered as being particularly suitable for certain applications in the nuclear industry.

6.5.3.9 Insulating boards may be substantially of organic composition, e.g. made from wood fibre or sugar cane, 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.

6.5.3.10 Insulating fire brick and related prefired or formed rigid shapes should be 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 expected temperature conditions.

6.5.3.11 The significant advantages over insulating fire brick that can be gained in lesser thicknesses and/or lower heat losses by the use of calcium silicate insulating blocks or slabs should be considered. The high crushing strength of calcium silicate blocks, combined with a low thermal conductivity, makes them suitable for use in partially loadbearing applications, and they should also be considered as a back-up to fire bricks where they have to resist crushing movement due to expansion at high temperature. (See **6.5.3.14**.)

6.5.3.12 Ceramic fibre should be considered 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 should, if required, be obtained by the use of board or inorganically bonded wet felt as a lining or by the use of a rigidizer directly on to the surface of the ceramic blanket.

6.5.3.13 Insulating concretes, which are normally based on a mixture of Portland cement or aluminous cement with a lightweight aggregate, should be mixed with water immediately before application; they should then be poured, spray-applied, or placed in position manually. Alternatively, the wet mass should 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. It should be noted that 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.

6.5.3.14 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, should be used in sufficient thickness to reduce the temperature at the interface with the main insulating material to an acceptable level. (See also **5.4**.)

7 Selection of securing materials

7.1 General

It should be noted that the insulation systems may be permanently secured directly to the plant by means of adhesives, by mechanical means, or by a combination of both. Alternatively the insulation may be installed as a removable module. (See also clauses **22** and **23**.)

7.2 Adhesives

7.2.1 General

Adhesive users and specifiers should 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 Adhesives and Sealants Association booklet “Guide to the Safe Use and Handling of Industrial Adhesives”²⁾, and to HSE Guidance Note EH 40 “Occupational exposure limits”³⁾.

²⁾ Available from BASA, 33 Fellowes Ways, Stevenage, Herts SG2 8BW.

³⁾ Available from HMSO, PO Box 276, London SW8 5ET.

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

In addition to gap-filling capability, viscosity should also be correct. It should be noted that 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.

7.2.2 Classification according to use

Adhesives for insulation may be classified as follows:

Insulation bonding adhesives (see Table 3). 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 and tack characteristics.

So-called "lagging" adhesives. Used for bonding, sizing and coating surface-finishing fabrics over insulated pipework and equipment. Usually these are waterborne compounded products based on single or combination polymers using ethylene, vinyl acetate, vinyl chloride or acrylic monomers.

Facing and film-attachment adhesives. Used for attaching flexible laminates, foils and plastics films to thermal insulation, and for bonding and 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.

It should be noted that 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.

7.2.3 Application characteristics

Important properties that affect use and that should be considered are:

- a) build, i.e. ability to resist sagging, etc.;
- b) consistency, i.e. suitability for brushing, spraying, etc.;
- c) coverage;
- d) development of "grab";
- e) degree of absorption with porous insulating materials.

Other properties that should, if required, be considered 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. It should be noted that slow loss of water can give rise to corrosion; alkaline adhesives, e.g. sodium silicate, can attack aluminium, man-made-mineral fibres and cellular glass; organic foams, especially polystyrene, are susceptible to attack by certain solvents.

7.2.4 Service properties

7.2.4.1 General

Properties affecting the behaviour of the adhesive after installation, as outlined in 7.2.4.2 and 7.2.4.3, should be considered.

7.2.4.2 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 -40°C to $+120^{\circ}\text{C}$, although many special adhesive/insulation combinations can be used outside this range.

Below a temperature of about -40°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.

Table 3 — Insulation bonding adhesives for preformed sections and slabs

Insulant	Adhesive system
Mineral fibre (glass, rock)	Styrene-butadiene rubber (SBR), neoprene, natural rubber (NR) solutions, bitumen/rubber emulsion and solutions, latex hydraulic cements, alkyd resin compositions, copolymer emulsions
Polystyrene foam	SBR, neoprene, NR solutions, bitumen/rubber emulsions, moisture curing polyurethane, latex hydraulic cements
Polyurethane Polyisocyanurate Phenolic foams	SBR, neoprene, NR solutions, bitumen/rubber emulsions and solutions, latex hydraulic cement, alkyd resin compositions, polyurethane, epoxides, hot-melt bitumens
Baked cork	SBR, neoprene, NR solutions, copolymer emulsions, hot-melt bitumens
Expanded plastics and rubbers	SBR, nitrile, neoprene solutions, polyurethanes
Cellular glass	Latex hydraulic cements, bitumen/rubber solutions and emulsions, bitumen modified polyurethanes, epoxides
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.	

For service temperatures of above + 150 °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.

7.2.4.3 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 should 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 adhesives should be used, and these should 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; peeling forces 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.

Consideration should be given to the cross section of the ducting and to the fact that virtually all ducts move due to mechanical vibration.

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 should be considered, especially the behaviour of the insulating material itself.

7.2.5 Mechanism of curing

7.2.5.1 Solvent-based adhesives

It should be appreciated that 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 contact surfaces with subsequent evaporation. Whilst many of these adhesives have an additional curing phase due to cross-linking, this cannot properly take place before solvent loss.

It should be ensured that all solvent, aqueous or organic, can escape from the assembly; failure to do so is the most frequent cause of application difficulties and service failures.

It should be noted that this is especially important if foil-faced slab insulation has been bonded to the duct work and insufficient time has been left to allow the adhesive-carrying solvent to dry completely before the vapour barrier is completed with, for instance, self-adhesive foil tape. Thickness of applied wet film and porosity of the contact surfaces 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 applying double 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 should be used where one of the contact surfaces 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 contact surfaces 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”. Good operator skill and strict compliance with manufacturers’ instructions should be ensured to achieve success. Some water-based gap-filling adhesives with high solids content, or heavily filled solvent may be used to bond relatively impervious insulants but the assembly should be 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 should be used, with strict attention to makers’ instructions, to ensure trouble-free application.

7.2.5.2 Chemically curing adhesives

These are generally set by a chemically activated cross-linking process and are increasingly used for insulation work. They are 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. Two-component adhesives should be mixed completely according to instructions; part mixing of components for small jobs will normally result in a failed bond. Most assemblies should be supported until sufficient strength has developed.

7.2.5.3 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 contact surfaces but most types are restricted to a comparatively narrow range of service temperature.

7.2.6 Types and typical properties

7.2.6.1 General

The materials referred to, with summaries of properties, in 7.2.6.2 to 7.2.6.12 should not be regarded as an exhaustive list; the particulars should be taken as 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.

7.2.6.2 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 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 gives 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.

7.2.6.3 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 temperatures of 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.

7.2.6.4 Natural rubber

Cements based on natural rubber are available in a range of colours, depending on the rubber stock and the filler 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 a temperature of 50 °C but vulcanized bonds normally are satisfactory up to a temperature of 100 °C; the bonds of both types become brittle at a temperature of about – 35 °C. Natural rubber has good resistance to water and to mould growth, but poor resistance to oils and organic solvents.

7.2.6.5 Neoprene-phenolic

These adhesives may be used as unvulcanized dispersions to give good bonds up to a temperature of 100 °C (or 140 °C intermittently); two-part mixes may have higher resistance to heat. The bonds become brittle at a temperature of 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 476-7.

7.2.6.6 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 a temperature of about – 40 °C, but the resistance to water, oils, and to mould growth is excellent.

7.2.6.7 Polyvinyl acetate

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.

7.2.6.8 Reclaimed rubbers

These are 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 a temperature of – 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.

7.2.6.9 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.

7.2.6.10 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 meets the requirement for class 1 spread of flame when tested in accordance with BS 476-7. The dry adhesives have good chemical resistance and have secondary vapour barrier properties.

7.2.6.11 Rubber latex/hydraulic cement

A range of two-component adhesives that is suitable for service temperatures ranging from -40°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.

7.2.6.12 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 temperatures of -40°C to $+100^{\circ}\text{C}$, and normally they are flammable in the wet state. These materials are often recommended for use as dual joint-sealant/adhesives, and they can be compounded to give vapour barrier properties.

7.3 Mechanical securements

7.3.1 The securing materials in this category generally can be classified as welded attachments, bolted fittings, or banding and wire securements. Care should be taken to avoid bimetallic contact between metals of appreciably different electrochemical properties (see 32.16.2.4).

7.3.2 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 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 23.3.2, 32.8 and Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6). Care should be taken to avoid danger from attack by liquid metal (see 32.16.4).

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 cladding used.

7.3.3 Bolted fittings should only be used 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 cladding materials. (See Figure 5, Figure 6 and Figure 7.)

NOTE 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.

7.3.4 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 should depend on the materials chosen and on the design parameters of the insulation system (see 23.4.1).

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.

7.4 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 23.2.5.)

7.5 Insulation hangers

A range of insulation hangers is available consisting of a metal or plastics base, to which a spindle of suitable length is attached. The base can be perforated for attachment to substrates with a separate high-performance adhesive or supplied plain with a self-adhesive pad depending on application.

Once the hangers are correctly assembled and positioned, the insulation is impaled on the spindles and retained in position with a self-locking washer. The system should be used strictly in accordance with manufacturers' instructions. Close attention should be given to the weight of the insulation and environmental temperature factors such as solar gain, a particular problem associated with external cladding.

8 Selection of vapour barriers

8.1 General

Condensation of water occurs 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.

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 **32.14.2**). 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 **32.15.**)

8.2 Vapour barriers for use over insulation applied to surfaces below dew point

Since it is essential to prevent the deposition of moisture, with the consequent risk of ice formation within the insulation material in those zones that are below freezing point, an effective vapour barrier should be used. 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 **32.15.7.**)

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.

8.3 Vapour barriers for use over insulation applied to 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 **32.15.6.**)

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.

9 Selection of finishing materials, including ultimate treatment of finish

9.1 General

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 should have a firm base to which it can be applied effectively. Conversely, if a self-supporting metal cover is adopted, softer materials may be suitable.

For the insulation of plant at subambient 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 should 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 should 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.

9.2 Classification of finishing materials

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 with or without anti-corrosion finish;

- 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.

Typical insulation finishes are shown in Table 4.

Table 4 — Typical insulation finishes

Finish type (see 9.2)	Primary finish	Secondary finish
a)	Hard-setting composition	Paint (optional)
a)	Self-setting cement	Paint (optional)
a)	Gypsum plaster	Paint (optional)
a)	Plastics sheet reinforced with glass fibre (GRP)	
b)	Aluminium foil (or foil laminate)	{ Self-finish Lacquer
b)	Aluminium sheet	{ Self-finish Anodized Organic polymer coating
b)	Mild steel	{ Galvanized Aluminized Al-zinc coating Organic polymer coating Paint
b)	Stainless	Self-finish
b)	GRP sheet	Self-coloured
b)	UPVC sheet	Self-finish
b)	Polyisobutylene sheet	Self-finish
b)	Roofing felt	{ Self-finish Aluminium foil-faced Solar reflective paint Bitumen
c)	Liquid solutions and dispersions	Self-coloured
d)	Scrim (glass or cotton)	Self-finish
d)	Calico	{ Self-finish Polymeric emulsion Paint
d)	Condenser cloth	{ Self-finish Polymeric emulsion Paint

9.3 Reasons for use of finishing materials

The contribution of the finishing material to the thermal effectiveness of the insulation system is, in general, negligible but usually a finish should be used for one of the following reasons:

- a) to give appropriate protection against mechanical damage;
- b) to protect against water, ice, snow, airborne deposits, sunlight or ozone;
- c) to assist in identifying the pipe or vessel, which 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;
- d) to give protection against excessive moisture, corrosive vapour, etc. in the atmosphere;
- e) to give protection against spillage of oils and other flammable liquids;
- f) to improve appearance or to provide a surface that can be cleaned easily;
- g) to retard, or if possible to prevent, the spread of flame;
- h) to protect against chemical attack, vermin, and mould growth.

9.4 Typical uses for finishing materials

9.4.1 The characteristic properties of the four main types of finishing materials (see **9.2**) should be considered when choosing an insulation system for particular applications.

9.4.2 With the exception of gypsum plaster, which substantially is self-drying and therefore useful for work at subambient temperatures, the finishing materials of group **9.2 a)** should be used mainly over preformed insulation on pipework and plant that can be heated for drying out. In all cases some form of metal mesh reinforcement should be used and the final dry thickness should be sufficient to resist accidental mechanical damage.

NOTE All the typical finishes of this group 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.

9.4.3 Sheet materials of the types indicated in **9.2 b)** are mainly of value for large uniform areas of plant or for long lengths of pipework. Metal sheet is 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. It is essential that the aluminium should be isolated from dissimilar metals.

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, the contact surface should be protected with bitumen, suitable paint or a polymeric plastics compound before site application.

It should be noted that 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 should, if wished, 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 should be used mainly over insulation on flat surfaces; the method of fitting should 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.

9.4.4 Solutions or dispersion coatings of the types indicated in **9.2 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 **9.2 a)**. Alternatively, they may be applied over the sheet materials of the type described in **9.2 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 should normally be 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 man-made 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.

9.4.5 It should be noted that 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 [see **9.2 d**]. 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.

9.5 Finishes for refrigeration work

Where the preferred finish is 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 should be suitably reinforced.

Advice should be obtained from the manufacturers concerned regarding the choice and method of application of vapour sealing material. (See **32.15**.)

9.6 Finishes to improve fire protective properties

9.6.1 Many finishes in common use are non-combustible, e.g. glass fabric, metal cladding and foil-face 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 stage of a fire, thus obstructing a means of escape and creating a firefighting 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.

9.6.2 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, but there should be 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 increasing the amount 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 **5.9** and **32.12**.)

The results obtained from the surface-spread-of-flame test will, for the same applied finish, vary in practice depending on the insulation system used. General guidance on the effect of thermal characteristics on the performance of assemblies is given in Appendix B of BS 476-7:1987 and Appendix B of BS 476-6:1989.

9.6.3 Steel cladding should be used in preference to aluminium where there is a serious risk of development of large fires due to the low melting point of aluminium.

9.7 Finishes for use over pipes in enclosed spaces, ducts, subways and beneath buildings

The appropriate choice can be made from the finishes recommended in **9.4**. (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.

9.8 Ultimate treatment of finish

9.8.1 General

Additional treatments may be desirable for the finishes described in **9.4**, e.g. for identification purposes, for colour blending with the environment or to provide additional corrosion and chemical resistance.

9.8.2 Painting

9.8.2.1 Painting as a final finish

The distinction between paints, polymeric 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.

9.8.2.2 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 coatings are also available. Hard-setting composition, self-setting cement, gypsum plaster, and all woven fabrics applied directly to the insulating material, may receive an 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.

9.8.2.3 Outdoor applications

Paint or polymer 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 primers should preferably be used for self-setting cement finishes on account of possible alkaline reaction. (See 26.1.3 and 27.3.2.) Paints based on chlorinated rubber, epoxy resin or polyurethane provide good protection over many insulation finishes, particularly in corrosive atmospheres.

It should be noted that aluminium and galvanized mild steel may require a primer before the application of certain undercoats and gloss paints. Bituminous paints should be used over roofing felt.

9.9 Identification of the contents of a system

BS 1710 recommends methods of identification of pipe lines and services. It gives examples of colour identification and suggests methods of incorporating ground colour, bands, and indications of direction of flow, etc.

10 Selection of thermal insulating systems

10.1 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 limitations that may be imposed by the purchaser. Where optimum effectiveness cannot be obtained, as a result of economic or other limitations, the insulation contractor should advise the purchaser to this effect, giving the reasons for his opinion. There should be adequate quality control at all stages of manufacture of materials and at all stages of their storage and application at site.

The required life of the insulation systems should be considered because this affects the annual cost and hence the economic thickness. If the plant has only a short life, an inexpensive insulation system may be adequate; if the plant has a longer life, a more expensive insulation system with longer life should be considered as being perhaps 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 insulation should be the prime consideration. (See 32.2 for economic thickness.)

10.2 Extent of system

When selecting a thermal insulating system, the following should be considered:

- a) the attachments to the surface to be insulated;
- b) initial protection of the surface to be insulated (see 32.16);
- c) means of securing the insulation system to those attachments, where appropriate, or to the surface directly;
- d) the types and thicknesses of the insulating materials to be used;
- e) vapour barrier;
- f) reinforcing materials;
- g) protection against weather;
- h) protection against mechanical damage.

10.3 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), and to vessels, tanks, and large curved surfaces.

The components of the system should be appropriate to the specific requirements of use. Different types of system are likely to be required for the following ranges of application:

- a) refrigeration;
- b) chilled and cold water supplies, industrial use;
- c) central heating, air conditioning, and domestic hot and cold water supplies;
- d) process pipework and equipment;
- e) dual-temperature systems, e.g. refrigeration with occasional use at higher temperatures;
- f) heat transfer fluid systems.

10.4 Factors for consideration

10.4.1 General

The main controlling factors that should be considered at an early stage are outlined in 10.4.2 to 10.4.12.

10.4.2 Temperature

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

10.4.3 Mechanical stability

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

10.4.4 Resistance to degradation

This requirement can have wide implications, from resistance to vermin and microbiological attack, to freedom from fire hazard. Also it includes 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.

10.4.5 Thermal effectiveness

Manufacturers' quoted thermal conductivity values should not be regarded as a reliable guide to the thermal effectiveness of a complete insulation system. Attention should be paid to detail at design stage to ensure the effectiveness of the complete system.

10.4.6 Type and dimensions of the plant to be insulated

The size and configuration of the plant has an important bearing on the suitability of a particular insulating system. Particular care should be taken with large flat areas, especially when elevated temperatures may cause extensive thermal movements.

10.4.7 Compatibility of the components of the system

Care should be exercised to avoid the use of adhesives and finishing compounds which are not compatible with other materials in the system.

Also corrosion problems should be avoided, e.g. those caused by electrochemical action between dissimilar metals under possible humid conditions.

10.4.8 Total weight of the system

The total weight of the insulating system should be considered at the design stage to ensure adequate support is provided.

10.4.9 Space for insulating system

Sufficient space should be provided during plant design to enable the chosen insulating system to be correctly installed and maintained.

10.4.10 *Potential hazard to health*

Certain types of fibrous insulating materials, notably asbestos, and certain finely divided aggregate such as crystalline silica, can be a hazard to health when inhaled into the lungs. While only asbestos-free insulation is 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.

10.4.11 *Corrosion hazards*

Insulating materials may contain soluble salts. Precautions should be taken to minimize risk of corrosion to substrate (see **32.16.**)

10.4.12 *Fire hazard*

It is possible to provide some form of protection for insulation that would otherwise be a fire hazard 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 5422 and BS 5908.)

Section 3. Site considerations

11 Basis and method of presenting schedule of work

11.1 Well before work at site begins, 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 purchaser should also indicate at the enquiry stage any special conditions he knows to exist. 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.

11.2 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 oil, grease and rust, painting, etc.

11.3 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 detail of such omissions should be provided by the purchaser to the contractor.

11.4 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 should be approved by the purchaser.

11.5 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.

11.6 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. Any additional cost should be agreed at the same time.

11.7 If a contractor is called upon to repair or modify previously completed work, 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.

11.8 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.

12 Packaging and transport to site

12.1 Suitable methods of packing

It is desirable that insulating materials should be packed in cartons, crates, bags or shrink film wrapping to minimize mechanical damage and to provide adequate weather protection and to avoid contamination. Preferably insulating materials should not be unpacked at site until required for immediate use.

12.2 Protection against crushing

Stacking of packed insulation should be limited in accordance with the nature of the material (see 14.3, 14.4, 14.5 and 14.6).

12.3 Packing of plastic compositions and finishing compositions or cements

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

12.4 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 required by the purchaser, the manufacturer's identification reference should be shown.

Where required by the purchaser 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.

13 Labour and supervision

The contractor should provide labour adequately trained and skilled in the use and application of the materials and equipment they are required to handle for a specific contract. The purchaser should indicate at the enquiry stage any special labour conditions he knows to exist.

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

14 Provision of storage space and protection and safety during storage

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

14.2 All materials should be stored in a dry atmosphere under cover and inspected at periods not exceeding 3 months.

14.3 Cartons containing preformed sections or segments should be stored end-up.

14.4 Cartons or packs containing slab insulation should be stored flat.

14.5 Bags containing mattress insulation should be stacked flat and not more than four high.

NOTE Referring to 14.3, 14.4 and 14.5, stacking height needs to be limited to prevent damage to the lower layers.

14.6 Metal sheets should be delivered as single sheets or in bundles, dependent on the type of handling facilities in the stores.

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

14.7 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.

14.8 When storage for longer than 3 months is contemplated the supplier should be consulted for recommendations on packaging the sheets prior to storage.

14.9 Adhesives, coatings and mastics should be stored under cover in a dry atmosphere with temperature not below 5 °C. It is important, particularly with two-part adhesives, mastics, coatings or foam systems, that the shelf life and the recommended storage condition should be verified.

15 Provision of power, water, light, heat and accommodation for personnel

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

15.1 Power and water

Power and water are normally 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.

15.2 Light and heat⁴⁾

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.

15.3 Accommodation and storage⁴⁾

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.

16 Provision of access equipment

It should be clearly stated at the initial stage whether the contractor is, or is not, responsible for providing his own access equipment.⁴⁾

NOTE Attention is drawn to national and local safety regulations covering access equipment.

17 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.

18 Observance of site safety and security regulations

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

⁴⁾ 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.

18.2 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.

NOTE 1 Fires have occurred during site work involving storage and use of insulation and ancillary materials, including packaging.

NOTE 2 Guidance Notes issued by HSE, which are periodically updated, give practical guidance on many aspects of fire safety.

19 Protection of adjacent equipment and surfaces

The protection of equipment and surfaces should be the responsibility of the contractor.

Items of a fragile nature should not be installed before insulation is applied.

20 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.

21 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 health hazard exists. (See 5.11.)

Section 4. Methods of application

22 General

22.1 Insulating materials should be kept dry in store and during erection.

22.2 Apart from certain loadbearing materials, most types of insulating materials should be left supported or reinforced when applied; they also should be secured to the surface to be insulated. For these reasons, fixing accessories should, if necessary, be attached to the piping or equipment before commencing application of the insulating materials.

22.3 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.

22.4 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.

22.5 As a general rule insulation work should be carried out with the plant off-load. In certain cases it may be advisable to apply finishing material at operating temperatures.

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

22.7 The junction between removable and permanent insulation should be so arranged as to be readily discerned, e.g. by identification signs.

23 Surface preparation and accessories

NOTE Accessories comprise attachments, insulation supports, securing devices, and reinforcement.

23.1 Surface preparation

23.1.1 Piping and equipment should be clean, dry and free from grease, dirt, loose rust and scale. In some cases the surface should be coated (see **32.16**). This coating should not be applied until all welded attachments have been fixed in position. However, if the coating has to be removed for the welding of additional attachments the coating should be made good prior to the application of the insulation.

23.1.2 Other forms of surface protection should be provided for specific situations, e.g. wrapping austenitic stainless steel surfaces with aluminium foil to protect against stress corrosion. (See **32.16.3.1**.)

23.2 Attachments

23.2.1 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 fittings 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. 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. (See clause **17**.)

23.2.2 Attachments for application by welding gun may conveniently have flux in the contact end or edge, but pins of 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 should be considered.

23.2.3 Angles, flat cleats, and similar large attachments, where used, may be secured by electric arc welding or gas welding. A procedure appropriate to the materials, the thickness of the component, and that of the attachment should be used. Pins and studs should normally be attached using a gun welding system.

23.2.4 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, and would require subsequent stress relieving; the attachments would then be fitted to the pads at site. (See Figure 5(a).)

23.2.5 For the choice and methods of attachment of plastics or metal support clips by means of adhesive, the adhesive 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, but the surface should be free from contaminants, and the weight and temperature limitations should not be exceeded.

23.2.6 Typical attachments for gun welding are 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 80 mm².

23.2.7 It should be noted that the use of hand-welding technique may permit the application of attachments with larger contact areas than those indicated in **23.2.6** 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 should 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.

23.2.8 In order to avoid mechanical damage to the stud during transit or during erection of the plant, a thick threaded nut should be welded on to the surface to be insulated, thus providing a fixture into which a threaded stud may be screwed at a later stage.

23.2.9 The locations of attachments depend on the weight of insulation to be attached, as well as on the size and orientation of the surface, and on the degree of vibration to which the plant may be subjected under service conditions; for large surfaces, recommended average spacings are:

vertical surfaces	450 mm square spacing;
upward-facing surfaces	600 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.

23.2.10 Welded attachments should preferably penetrate into the insulating material only to the minimum extent necessary to achieve effective support. The cross-sectional area of the attachments should be the minimum consistent with the required mechanical strength in order to avoid excessive heat transfer or cold bridging by metallic conduction.

23.2.11 It is important to remember that a welded attachment is subjected to the same extent of thermal movement as the insulated surface, with the resultant possibility of tearing the insulation or finish, and care should be taken to avoid this, for example by expansion or slip joints.

23.3 Insulation supports

23.3.1 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, should 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 Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.)

23.3.2 Supports for insulation and any associated cladding in the absence of requirements to combat the effects of wind force 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 rest on stud or cleat attachments welded in the appropriate locations to the surface to be insulated. (See Figure 5 and Figure 6.) Angle supports, where used, should be bolted to the welded attachments on the plant, or they should rest loosely on top of floating flat rings; in the latter arrangement short angle pieces may be used to secure external metal cladding to which they are fastened, either by bolts or by rivets. (See Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7, also **7.3.2**.)

23.3.3 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 **23.4.2**). 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.

23.3.4 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 should 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. These studs 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.

23.3.5 Generally, support angles should not penetrate the insulation to a distance greater than its total thickness less 10 mm unless through-metallic connection between cold and hot surfaces of the insulation can be avoided by interposing a pad of insulating material between the inner welded supporting angle and the insulation support system. This is of particular importance with insulation over refrigerated plant, or when the external finish over hot insulation is of sheet metal.

On large-diameter tanks direct support of the cladding from the tank surface is desirable to accommodate wind loading considerations (see **25.3.2.6** and Figure 39 and Figure 40).

23.3.6 The cross-sectional area of each insulation support should be not greater than that necessary to achieve the required mechanical stability, so that heat transfer and cold bridging can be reduced to a minimum. In appropriate cases the support may be non-metallic, e.g. plastics or wood.

23.3.7 Additional supports should be used for the insulation on the ends of vessels of over 1.5 m diameter. Pins of 5 mm diameter should be provided on a triangular pitch of approximately 300 mm. The length of the pins should be equal to the thickness of insulation except on the bottom of vessels where the bottom is protected by a skirt in which case the pins should be 10 mm greater than the thickness of insulation.

Horizontal vessels of 2.0 m diameter and above should have attached, on the longitudinal centre line, a type 1 insulation support. The method of attachment should be specified on the drawing or data sheet. (See Figure 5 and Figure 6.)

23.4 Securement

NOTE Methods include tie wires, lacing wire, bands, clips washers, nuts, etc.

23.4.1 Unless the insulating material can be secured directly to the surface to be insulated, e.g. by means of adhesive (see **7.2**, **24.2** and **24.3**), some form of mechanical accessory should, if necessary, be used 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 **23.2** and **23.3**. 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 can 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.

23.4.2 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.

23.4.3 Lacing wire and tie wire is normally made 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 **32.16.2** for temperature limitations.) Typically, the sizes of wire should be 1 mm diameter for general use, or 1.5 mm for heavier use. For refrigeration work plastics tapes should be used instead of wires. Other soft wires should be considered for special applications.

23.4.4 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.

23.4.5 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. Bands should be corrosion-resistant, either by virtue of the nature of the metal or by a surface treatment. Plastics bands should be sufficiently robust to withstand prolonged conditions of service. Special forms of rapid-fastening securing strip can be useful for special duties. 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 condition of service.

23.4.6 Flexible insulating mattresses that have wire mesh covering integral in their construction, and have intersurface ties, should be impaled over the main attachments and further secured by tightly fastening together adjacent edges of the outer covering mesh. The lacing wires for this purpose should be of similar metal and diameter 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 32.16.2.4.)

23.4.7 If split-pin or fork-stud attachments have been used, the insulation should be secured by bending the prongs of the fork arrangements, 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 3 mm in diameter or 3 mm square and the lengths should be such that the prongs can be depressed below the outer surface of the insulating material.

23.4.8 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.

23.5 Reinforcement

23.5.1 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. The main uses for the metallic reinforcement are with spray-applied fibrous insulation, wet-applied finishing compositions, and wet finishing cements, but they should also be considered for retaining dry fibrous insulation and various types of preformed materials.

The mesh size of wire netting should be normally either 25 mm or 40 mm, with wire of 1 mm diameter, but the mesh may be reduced for use over flexible fibrous materials. Expanded metal should 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.

23.5.2 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 for protection against corrosion during storage and prior to application on site. (See 32.16.2.1.)

23.5.3 Where substantial mechanical strength is required, e.g. for resistance to compression, square-pattern reinforcing mesh should be considered, 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. 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.

23.5.4 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.

23.5.5 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 vapour-proof mastics.

24 Cold insulation: application for systems operating in the temperature range – 100 °C to ambient temperature

24.1 General

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

24.1.2 Insulation should preferably be carried out on surfaces which are above the dew point temperature of the ambient air at the time of application.

When insulation has to be applied to surfaces below the dew point temperature or below freezing the surface should be de-iced and wiped dry before the insulation is applied. In general this practice is not recommended and should only be adopted for small areas or as a temporary measure.

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

- a) the suitability of all materials for the design conditions under which the plant will operate, including purging and steam cleaning where the material will on occasion be subjected to elevated temperatures;
- b) the compatibility of adhesives, pipe coatings, joint sealants and vapour barrier coatings with insulating material and mechanical supports and with each other where necessary.

24.1.4 Where skewers are used as an aid to applying insulation materials they should be made from wood or plastics and be wholly within the insulation.

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

24.1.6 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.

To maintain the integrity of the system, preformed insulation may be applied using adhesive or bedding compound (see **7.2**).

Where two or more layers of insulating material are required (see **24.3.1**) or the operating temperature is below – 20 °C the insulating material 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 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) should be considered. 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 **32.8.3**.)

24.1.7 It is essential that the vapour seal should be designed as an integral part of the insulation system and applied as soon as possible so as to keep the insulation dry. (See Figure 15 and Figure 16.) The vapour barrier is a technical requirement and should not be used as the final surface finish, if it is likely to be easily damaged.

24.1.8 Where insulants of an abrasive nature are to be used (e.g. cellular glass) an anti-abrasion bond coating should be used.

24.2 Adhesives and fastenings

24.2.1 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.

24.2.2 Many adhesives do not continue to operate effectively at very low temperatures. If they are used as an aid to erection, mechanical support should also be provided. The manufacturer's advice on the effective temperature range of the adhesive should be sought.

24.2.3 Wherever possible, additional mechanical support should be used in the form of banding, insulation pins or suitable self-adhesive tapes.

24.3 Typical erection methods

24.3.1 Using preformed insulating materials

When preformed insulating materials are used, two-layer construction should preferably be used for surfaces operating at temperatures below – 10 °C; all joints should be staggered.

24.3.2 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 should have the molten adhesive mopped on to the appropriate surfaces as it is impractical to dip these into a bath of matter adhesive without contamination of the outer surfaces.

To improve the adhesion of hot-dip bitumen adhesives, the substrate should be given a priming coat of bituminous paint. Precautions should be taken to ensure that the temperature of the molten bitumen is not higher than the recommended maximum temperature of the insulant to be used.

24.3.3 Using solvent-based adhesives

These may be based on bitumens, resins or rubbers. The adhesives should be applied by brush or trowel in accordance with the manufacturer's instructions. Where necessary, appropriate time should elapse before the bond is made. The piece of insulating material should be positioned precisely where an impact type of adhesive is used.

NOTE Some adhesives permit the piece of insulating material to slide before final adhesion is effected.

24.3.4 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 reused. The compounds should be used for bedding the insulating material against the substrate 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 should be securely held by mechanical means. (See 24.2.3.)

24.3.5 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 compatible with insulation finish. It is important that the joining faces should be pressed tightly together.

24.3.6 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 high-density material, of adequate compressive strength should be used, or, alternatively, metal cradles should 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, Figure 11 and Figure 12.

24.3.7 Vessel supports

Vessel supports should be subject to similar considerations as apply for pipes.

24.4 Pipework and fittings

24.4.1 Pipework

(For general considerations see 24.1.) 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 to act as an anti-abrasive lining; this bore coating should be allowed to dry before the section is fitted. Preformed sections should be erected as detailed in 24.3.1.

Bends should be insulated with preformed bends. Where preformed bends are not available, bends should be cut lobster-back fashion and secured as for straight piping, with one tie per segment.

24.4.2 Flanges, valves and other fittings

Provision should be made to permit the removal of bolts. Fittings should be insulated with moulded or prefabricated flange/valve boxes but if these are not available they should be insulated with oversize sections of the same material and thickness as the insulation on the adjacent pipework. (See Figure 13 and Figure 14.)

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. The insulation system should be vapour sealed to ensure that the flange or valve insulation can be removed without damage to the vapour barrier on the adjacent pipework.

(See Figure 15, Figure 16, and Figure 17.) Cavities formed between the insulation and the fitting should be filled with loosefill insulation material or non-setting compound or a mixture of both which should be easily removable for access purposes.

24.5 Vessels and large curved surfaces

(For general considerations see 24.1). The types of insulating materials normally specified for low-temperature applications are available in a range of physical forms which may be used for curved surfaces, but preformed insulation is most commonly used, such as:

- radiused and bevelled lags;
- plain lags;
- slotted slabs with the slots on the inner face.

Other types of insulation may be applied as loosefill granules, foam dispensed or sprayed.

(See Figure 16, Figure 17 and Figure 18.)

Each layer should be firmly secured either by adhesive or bands or a combination of both. Large slabs should be secured by 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 should 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 vapour-tight cover strips should then 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.

24.6 Storage tanks

24.6.1 General

(See also section 8.) It is essential that base, sidewalls, roof and protrusions should be insulated and that there should be a continuous vapour barrier over the outer surface of the insulation.

24.6.2 Corrosion protection

It is essential that the recommendations given in 24.1.1 and 25.3.2 are followed.

24.6.3 Nozzle connections and manholes

It is essential that the vapour seal over the nozzle connections and manholes should be integral with the vapour seal on the shell and roof.

24.6.4 Base of tank

It is essential that the base of the tank should be insulated to prevent frost heave. The insulation may be used alone, or in conjunction with a heating system.

The insulation should have loadbearing properties adequate to support the weight of the tank and contents unless the tank is adequately supported.

The base insulation system should be designed to ensure a continuous vapour barrier can be provided between the base insulation and shell insulation.

Suitable insulation systems include:

- a) preformed slabs of materials (see Table 2) applied with adequate vapour barriers;
- b) sprayed polyurethane with suitable vapour barrier;
- c) foaming-in-situ of polyurethane or isocyanurate into a cavity formed by metal cladding or plastic sheet.

NOTE Double-skinned tanks are used for the storage of cryogenic liquids, therefore insulation for these tanks is usually perlite applied as a loose fill between the two sheets.

24.7 Air-conditioning ductwork operating below ambient temperature

24.7.1 Whilst this subclause 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 25.4, where appropriate, apply. (See BS 5588-9 for construction of ductwork, and 9.6 and 32.12 for fire hazards.)

24.7.2 Ductwork is mainly constructed from galvanized steel but other materials are also sometimes used, e.g. aluminium, stainless steel and plastics such as GRP or PVC.

Ductwork situated indoors may be located where it is concealed from view behind false ceilings and in voids or it may be exposed to view at high or low level. Therefore a suitable finish for indoor ducting should incorporate one or more of the following:

- provide adequate vapour barrier for the design conditions;
- be robust enough to withstand mechanical damage or cleaning where necessary;
- have a visual appearance suitable for the location.

Ductwork situated outdoors should have a weatherproof finish.

24.7.3 Where a protective finish has been applied to the substrate of the duct, care should be taken to ensure that it is not damaged. If it is damaged, the contractor should notify the purchaser, so that the coating can be made good before insulation is applied. If the insulation is to be adhered to the ducting, the compatibility between the adhesive and the protective coating or the fabric of the duct should be checked with the adhesive manufacturer.

24.7.4 Ductwork which has been lined internally with acoustic insulation may not require additional thermal insulation applied to its outer surface.

24.7.5 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 5 mm cover. (See BS 5422 for thicknesses.) Insulation over 50 mm thick should be applied in two layers, with staggered joints.

24.7.6 Materials that are suitable for insulating ductwork operating in this temperature range should be used (see Table 2).

24.7.7 The insulating material may be secured to the surface of the duct by means of a suitable adhesive (see 24.2). This may be 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, or by the use of bands on non-rectangular ducting. 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.

24.7.8 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 0.05 g/(s MN). (See Figure 19.) The vapour barrier 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 32.15.)

24.7.9 Insulation may be used which has a factory-applied vapour barrier adhered to its surface. All joints in the vapour barrier should be sealed, either by bonding the overlaps, where provided, with adhesive or by sealing with matching self-adhesive tape. If plain unfaced slabs are used and wrapped with the vapour barrier facing on site, the overlaps of the facing should not be directly over the joints in the slabs.

Consideration should be given to the fact that the conditions encountered on many sites where insulation is applied are adverse to the successful adhesion of self-adhesive tapes which may tend to delaminate. This problem should, if it occurs, be eliminated by priming the surface of the vapour barrier jacket with a thin brush coat of a compatible contact adhesive prior to application of the tape.

Alternatively the securing and protection of the insulation may be by means of a polymeric vapour barrier coating which should usually be applied in two coats and reinforced with a membrane of cotton or open-weave glass fabric between coats, the first coat being used to adhere the membrane to the insulation.

24.7.10 Typical alternative insulation schemes, using organic polymer slabs or bonded mineral fibre of suitable bulk density, are:

- | | |
|--|--|
| a) concealed from view | as described in 24.7.8 ; |
| b) exposed to view, but not readily accessible | as described in 24.7.8 and painted in a colour to match decoration of surroundings; |
| c) exposed to possible mechanical damage | as described in 24.7.8 but enclosed in metal sheet; |
| d) exposed to weather | 1) as described in 24.7.8 but with all laps sealed;
2) finished with roofing felt and wire netting, with all laps sealed;
3) finished with a vapour barrier coating of polymeric mastic or bitumen, applied by hand or by spray gun; and additional weather coating with scrim reinforcement if required. |

24.7.11 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 BS 5588-9 and BS 5422 and Approval Document B2/3/4 of the Building Regulations. (See also **32.12**.)

24.8 Flat and irregular surfaces (including machinery)

(For general considerations see **24.1**.) For erection against fiat surfaces the basic recommendations given in **24.5** should be followed.

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

In the erection of cold boxes a supporting structure should normally be used. The insulation manufacturer's advice should be sought if freestanding 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.

25 Hot insulation: application for systems operating in the temperature range above ambient to 870 °C

25.1 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 **7.3**.)

25.2 Pipework

25.2.1 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 preformed 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. Figure 20, Figure 33, and Figure 35 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 Figure 21 and Figure 33.) 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.