

Code of practice for thermal insulation of pipework and equipment in the temperature range of $-100\text{ }^{\circ}\text{C}$ to $+870\text{ }^{\circ}\text{C}$

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Committees responsible for this British Standard

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- 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 Association
- 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

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- British Chemical Engineering Contractors' Association
- Chemical Industries Association
- Engineering Equipment and Materials Users' Association
- Heating and Ventilating Contractors' Association
- Polyethylene Foam Insulation Association

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Foreword

This Code of practice has been prepared by Technical Committee RHE/9 under the direction of the Engineering Sector Board. It supersedes BS 5970:1992, which is withdrawn.

Combustion of fossil fuel is a major cause of the “greenhouse effect”, the term given to global warming caused by the build-up of greenhouse gases in the atmosphere, principally carbon dioxide, which inhibits the re-radiation of heat from the Earth. This Code of practice acknowledges that the application of thermal insulation will lead to a reduction in these greenhouse gases.

The code explains the basic principles that should be followed in selecting insulating systems for specific requirements. It is not practical 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 under general considerations, selection of insulating materials and systems, site considerations, methods of application, finishes, inspection, testing and maintenance, guarantees and 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 which are the subject of contractual arrangement rather than of technical importance.

As a Code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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 118, an inside back cover and a back cover.

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1 Scope

This Code of practice describes aspects of thermal insulation for pipework and equipment in the temperature range $-100\text{ }^{\circ}\text{C}$ to $+870\text{ }^{\circ}\text{C}$. The installation techniques described in this standard can be used outside the temperature range indicated, however, it is recommended that for such applications specialist advice should be sought. Specialist applications, such as road and rail transport vehicles and marine and offshore installations etc., can be subject to additional provisions not covered by this standard.

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 Code of practice.

NOTE 2 Specifications corresponding to parts of this Code of practice are given in BS 5422.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of this Code of practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 476-6, *Fire tests on building materials and structures — Part 6: Method of test for fire propagation for products.*

BS 476-7, *Fire tests on building materials and structures — Part 7: Method of test to determine the classification of the surface spread of flame of products.*

BS 806, *Specification for design and construction of ferrous piping installations for and in connection with land boilers.*

BS 1710, *Specification for identification of pipelines and services.*

BS 2654, *Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.*

BS 3177, *Method for determining the permeability to water vapour of flexible sheet materials used for packaging.*

BS 3533, *Glossary of thermal insulation terms.*

BS 3958-3, *Thermal insulating materials — Part 3: Metal mesh faced man-made mineral fibre mattresses.*

BS 3958-6, *Thermal insulating materials — Part 6: Finishing materials — Hard setting composition, self-setting cement and gypsum plaster.*

BS 3974-1, *Specification for pipe supports — Part 1: Pipe hangers, slider and roller type supports.*

BS 3974-2, *Specification for pipe supports — Part 2: Pipe clamps, cages, cantilevers and attachments to beams.*

BS 3974-3, *Specification for pipe supports — Part 3: Large bore, high temperature, marine and other applications.*

BS 5241, *Rigid polyurethane (PUR) and polyisocyanurate (PIR) foam when dispensed or sprayed on a construction site.*

BS 5422, *Method for specifying thermal insulating materials on pipes, ductwork and equipment (in the temperature range -40 to $+700\text{ }^{\circ}\text{C}$).*

BS 5588-9, *Fire precautions in the design, construction and use of buildings — Part 9: Code of practice for ventilation and air conditioning ductwork.*

BS 5908, *Code of practice for fire precautions in the chemical and allied industries.*

BS 7021, *Code of practice for thermal insulation of roofs externally by means of sprayed rigid polyurethane (PUR) or polyisocyanurate (PIR) foam.*

BS 7572, *Code of practice for thermally insulated underground piping systems.*

BS EN ISO 7345, *Thermal insulation — Physical quantities and definitions.*

BS EN ISO 12241, *Thermal insulation for building equipment and industrial installations — Calculation rules.*

BS EN 12664, *Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Dry and moist products of medium and low thermal resistance.*

BS EN 12667, *Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Products of high and medium thermal resistance.*

BS EN ISO 8497, *Thermal insulation — Determination of steady-state thermal transmission properties of thermal insulation for circular pipes.*

3 Definitions

For the purposes of this Code of practice, the definitions given in BS EN ISO 7345 and BS 3533 apply, together with the following.

3.1
finishing materials
materials used for covering thermal insulation, whether applied in a factory or on site

3.2
coating
aqueous dispersion or solution in organic solvent of a polymeric plastics compound, of consistency for application by brush or spray in thicknesses of about 1 mm or less. The coating usually “dries” in situ by evaporation of the liquid carrier

3.3
paint
suitably filled dispersion of powders in an organic drying oil or similar vehicle that hardens to form a substantially continuous film on drying

3.4
polymeric plastics compound
compound formed by the reaction of simple organic molecules (monomers) having groups that will react to form compounds of higher molecular weight

4 Exchange of design data

NOTE In all cases it is important that all aspects of **4.1**, **4.2** and **4.3** should be agreed between purchaser and manufacturer or contractor before a contract is drawn.

4.1 Information to be supplied by the purchaser

4.1.1 General

The purchaser should specify 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 the information recommended in **4.1.2**, **4.1.3**, **4.1.4**, **4.1.5**, **4.1.6** and **4.1.7**.

4.1.2 Details of plant to be insulated

The details of the plant to be insulated should be 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 can 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 and associated clearances;
- lengths of each size of pipe;
- number and type of pipe fittings, e.g. flanged joints, valves, tees, bends with radius and angle;
- surface orientation and height;

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.

4.1.3 Operating conditions

The temperature conditions should be as follows:

- a) normal working temperature for each portion of the plant to be insulated;
- b) maximum or minimum temperature for each hot surface, if different from a);
- c) the range of ambient air temperatures, velocities and for condensation control, relative humidities. 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 transfer calculations are based on the manufacturers declared value of thermal conductivity and unless otherwise recommended, refer to the conditions of ambient still air at a temperature of 20 °C. When making use of these theoretical values, allowance has to be made for the effect of these operating conditions at site and for supplementary heat transfers such as occur through supports, hangers, valve control wheels and other fittings. It is important to note that “thermal efficiency” (see 33.6) is not included.

4.1.4 Preparation of surfaces

Special requirements, e.g. for the removal of works-applied coatings or finishes, or for the application at site of paint or other coatings to the surface to be insulated, should be clearly specified. (See also clause 24.)

4.1.5 Types of fittings and supports

The types of fittings and supports and which of these are to be provided by the contractor, should be specified (see 8.4 and clause 24).

4.1.6 Type of insulation

The type of insulation material(s) including any specific physical properties required should be in accordance with the recommendations of clause 6 and clause 7.

4.1.7 Type of surface covering

The function and physical properties of the surface covering required should be in accordance with the recommendations of clause 9 and clause 10.

4.1.8 Special service

Any special service requirements, for example, resistance to compression, resistance to fire, resistance to abnormal vibration, should be in accordance with the recommendations of clause 6 to clause 11. If there is any special hazard from contact with chemicals or oils on the plant, attention should be drawn to this.

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

The following are examples of deciding factors in the thickness of insulation:

- a) specified temperature on outer surface of insulation system (personal protection, condensation control); specified heat transfer per unit dimension, linear or superficial (see note to 4.1.3); (process control);
- b) economic thickness (see BS 5422);
- c) specified conditions of temperature for the surfaces to be insulated (see note¹⁾);
- d) specified conditions of fluid at the point of delivery;
- e) special thickness requirements (temperature maintenance);
- f) frost protection.

When insulating for more than one purpose, the most stringent design parameter(s) should apply.

4.2 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 4.1;
- b) the manufacturer's declared value of thermal conductivity (λ) for the temperature used; 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 specified;
- 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 specified) with which the following are in accord:
 - 1) insulating material;
 - 2) reinforcement (if any);
 - 3) fixing devices and finishes.

4.3 Drawings and documentation

If requested, the insulation contractor should provide drawings and documentation showing details as follows:

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

¹⁾ Insulation to provide specified conditions at the boundary surfaces of the containment system can be required for reasons such as:

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

5 Factors affecting planning and programming

5.1 Because 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 be used to control the work on site.

5.2 Examples of factors that could affect the insulation contractor's work are as follows:

- 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.

6 Typical characteristics of insulating materials and systems

6.1 Thermal conductivity

For determination of design thickness see clause 33. A material of low thermal conductivity should be selected 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 inert gas filled rigid plastics foams increases with age and it is usual to specify this in terms of initial value and aged value.

NOTE Reference can be made to relevant British Standards for the determination of initial and aged values, for example, BS 5608 for PUR and PIR foams and BS 3927 for Phenolic foam.

It is the normal practice of manufacturers to provide tables or graphs showing how the thermal conductivity of each product varies with temperature. Temperatures above ambient are 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.

NOTE 1 An air space is much less effective for thermal insulation purposes than a space of similar dimensions filled with one of the conventional insulating materials. This fact is of particular significance at higher temperatures.

Test conditions should be in accordance with BS EN 12664 or BS EN 12667 (for flat products) or BS EN ISO 8497 (for pipe insulation products) and methods of calculating required thicknesses of insulation are specified in BS 5422.

NOTE 2 Some physical properties of thermal insulating materials in particular thermal conductivity and strength, are dependent on the direction in which they are measured.

NOTE 3 BS EN 12664 can be used to measure samples whose thermal resistance is not less than $0.1 \text{ m}^2 \text{ K/W}$ and BS EN 12667 specifies simpler procedures for specimens whose thermal resistance is not less than $0.5 \text{ m}^2 \text{ K/W}$.

6.2 Physical forms

Insulation is usually supplied in one of the following forms:

- pre-formed (slabs or sections);
- rigid;
- flexible;
- plastic composition;
- sprayed and blown;
- loosefill;
- 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.

6.3 Bulk density

The bulk density, which for most thermal insulating materials falls within the range 10 kg/m^3 to 320 kg/m^3 . Materials of high bulk density should be selected for use in high temperature applications; whereas materials of low bulk density should be selected for use in low temperature applications.

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.

6.4 Suitability for service temperature

The temperature at which the material is used should be within the range for which it will provide satisfactory long-term service under conditions of normal usage. (See 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 many factors that can result in deterioration under conditions of service including, for example, linear shrinkage under heat, loss of compressive strength during heating, and the effects of vibration and possible self-heating phenomena. When establishing maximum operating temperatures for pre-formed high-temperature insulation, particularly that in the form of pipe sections, insulation should be selected to withstand moderate loads and vibration whilst in service.

NOTE Some knowledge of the compressive strength both before and after heating can 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 °C	Normal bulk density kg/m ³
1.	Alumina 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
2.	Body soluble ceramic fibres	—	—	—	—
3.	Calcium silicate	Plastic composition	Granular	1 000	160 to 320
		Slabs/lags	Granular	1 010	160 to 320
		Pre-formed pipe sections	Granular	800	190 to 260
4.	Cellular glass	Slabs and pipe sections	Cellular	400	130 to 160
5.	Insulating compositions	Plastic composition	Granular	1 000	250 to 1 100
6.	Magnesia	Plastic composition	Granular	310	180 to 220
		Pre-formed slabs	Granular	310	180 to 220
		Pre-formed pipe sections	Granular	310	180 to 220
7.	Melamine and polyimide	—	—	—	—
8.	Mineral wool (glass)	Rigid slabs/lags	Fibrous	230	15 to 100
		Pre-formed pipe sections	Fibrous	400	60 to 100
		Flexible mats	Fibrous	230	15 to 35
		Lamella mat	Fibrous	230	20 to 40
9.	Mineral wool (rock)	Loose wool	Fibrous	850	50 to 150
		Resin-bonded slabs/lags	Fibrous	750	20 to 200
		Inorganically-bonded slabs/lags	Fibrous	1 100	80 to 150
		Pre-formed pipe sections	Fibrous	230	Up to 45
		Flexible mats	Fibrous	850	90 to 130
		Wired mattresses	Fibrous	850	30 to 48
		Lamella mat	Fibrous	230	140
		Pipe section mat	Fibrous	650	240 to 250
10.	Mineral wool/cement/binder	Sprayed	Fibrous	650	100 to 300
11.	Perlite	Loosefill ^b	Granular	870	40 to 150
		Pre-formed slabs and sections	—	—	—

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

NOTE 2 For typical thermal conductivity values see Figure 1.

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.

Table 1 — Typical insulating materials for use at temperatures higher than ambient (*concluded*)

Ref.	Material	Physical forms	Type	Approximate maximum operating-temperature ^a °C	Normal bulk density kg/m ³
12.	Phenolic rigid foam	Pre-formed slabs and pipe sections and foamed in situ	Cellular	120	35 to 200
13.	Polyurethane rigid foam	Pre-formed slabs and pipe sections, sprayed, and foamed in situ	Cellular	110	30 to 160
14.	Polyethylene	Pre-formed pipe sections	Cellular	80	30 to 40
15.	Polyisocyanurate rigid foam	Pre-formed slabs and pipe sections and foamed in situ	Cellular	140	30 to 60
16.	Polyurethane flexible foam	Blanket, slab and pipe sections	Cellular	70	30 to 65
17.	Silica, microporous	Loosefill ^b	Fibrous	1 000	50
		Blanket, felt	Fibrous	1 000	50 to 50
		Cloth, tapes	Fibrous	1 000	500 to 800
		Opacified aerogel slatted blanket	Granular	950	200 to 300
18.	Stainless steel	Plain and dimpled foil	Reflective	760	—
19.	Synthetic rubber	Flexible pre-formed pipe sections, flexible slabs and rolls	Cellular	105	60 to 100
20.	Vermiculite	Loosefill ^b pre-formed slabs and sections	Granular	1 100	50 to 150
21.	Vermiculite/cement	Sprayed	Granular	1 100	320
22.	Vermiculite/sodium silicate	Slabs	Granular	1 000	450
NOTE 1 Above 230 °C, compressive strength of organically-bonded materials can be reduced.					
NOTE 2 For typical thermal conductivity values see Figure 1.					
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.					

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

Ref.	Material	Physical forms	Type	Approximate maximum continuous operating-temperature ^a °C	Normal type density kg/m ³
1.	Phenolic foam	Pre-formed slabs and pipe sections	Cellular	120	35 to 200
2.	Polystyrene foam extruded	Pre-formed slabs, pre-formed pipe sections	Cellular	80	15 to 35
3.	Baked cork	Pre-formed slabs, pre-formed pipe sections	Cellular	60	100 to 200
4.	Granulated baked cork	Loosefill ^b	Granular	60	80 to 150
5.	PVC expanded	Pre-formed 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 ^b	Granular	980	50 to 150
14.	Perlite	Loosefill ^b	Granular	870	40 to 150
15.	Synthetic rubber	Flexible slabs, flexible pipe sections	Cellular	105	60 to 100
16.	Polyethylene	Pre-formed pipe sections	Cellular	80	30 to 40

NOTE 1 For typical thermal conductivity values see Figure 1.

NOTE 2 Care is necessary in interpreting the minimum continuous operating-temperatures in this table. These are based on manufacturers' claimed values and can 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.

^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 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.

6.5 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 can occur.

NOTE When insulating plastics pipe, the thermal expansion coefficients of plastics are generally much higher than those of metals.

6.6 Resistance to compaction

NOTE Some types of insulation materials, particularly those with low compressive strengths such as loosefill materials and un-bonded mattresses can be liable to compact under the influence of vibration and thermal cycling.

6.7 Resistance to water vapour penetration and to water absorption

Whilst closed-cell materials, e.g. cellular glass, can 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, because if water is allowed to penetrate and freeze, the cells of the insulation can rupture and the material can be permanently damaged. The material itself should be preferably of low water vapour permeability.

6.8 Mechanical strength, resilience and durability

6.8.1 Mechanical strength and resilience

NOTE In general, insulating materials are mechanically weak and strength normally decreases after heating. This refers to the general performance of insulants compared to solid materials. There are significant differences in the mechanical properties of insulation materials of different generic types and densities within a given type. In particular, some materials have a low compressive strength and may be easily damaged, for example, by foot traffic. When deciding which type of insulation to use, compressive strengths should be compared as well as comparing other material properties such as thermal efficiency.

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.

6.8.2 Compressive strength and resilience

NOTE It has already been explained in 6.8.1 that insulating materials are generally mechanically weak in general performance compared to solid materials.

There are several significant differences between the mechanical properties of insulating materials of different generic types and diversity within a given type. In particular, some materials have a low compressive strength and may easily be damaged, for example, by foot traffic. When deciding which type of insulation to use, this factor should be compared as well as comparing other material properties, such as thermal efficiency. Insulation systems should also be chosen for their durability in withstanding damage.

6.8.3 Durability

The selection of an outdoor system should also be made on the basis of its durability in withstanding the effects of sunlight and other environmental elements.

6.9 Fire and explosion hazards

6.9.1 General

The fire performance of the particular insulant should be chosen in the context of the design requirements of the application for which it is intended. For further guidance, reference should be made to BS 5422, the current Building Regulations [1] and the fire prevention authorities.

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, can 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 can ignite spontaneously. (See 10.6.)

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.

Not all the thermal insulating materials in common use are non-combustible. Some of them, often used for refrigeration systems, are entirely of organic composition and thus can constitute a fire hazard, or they can emit smoke and toxic fumes. Designers of thermal insulation systems should therefore consider the process conditions and the plant arrangement before deciding whether or not the proposed thermal insulating material might contribute to the spread of fire, however initiated, and they should vary their choice of material accordingly.

6.9.2 *Materials*

In the absence of special requirements, the characteristics of thermal insulating systems with respect to fire should conform to BS 5422.

6.9.3 *Finishes*

Some protective finishes in common use are combustible and can produce substantial quantities of smoke on ignition, e.g. bituminous compounds, many plastics polymers, some impregnated cloth and tapes, as well as cotton cloth or bandages. There are fire-retarding compounds and anti-oxidant materials that can be applied to flammable finishes.

NOTE Fire protection afforded by such compounds is usually of short duration and that they afford temporary rather than permanent protection in a fire situation.

6.9.4 *Aluminium cladding*

NOTE Under certain conditions, aluminium cladding can constitute a hazard in the event of fire in large process plant or the immediate vicinity, when it is possible for the aluminium to melt and ignite adjacent materials. In a major fire, molten incandescent aluminium can be scattered over a wide area.

6.9.5 *Galvanized accessories*

In the event of a fire in the vicinity of the insulated plant, molten zinc from galvanized accessories can drop on to and penetrate austenitic steel pipework or plant immediately below. (See 6.15.5.)

6.9.6 *Electric earth bonding*

In flammable atmospheres, particularly with long runs of insulated pipework, external metal cladding should be connected to earth in order to avoid possible build-up of static electricity. (See 27.1.)

6.9.7 *Self-ignition*

Some insulating materials that contain bonding agents, can constitute a fire risk through the phenomenon of internal self-heating, despite being used within the service temperature specified for the material. Evidence of this self-heating can be a transient rise in temperature above the theoretical value for specific locations within the insulation system. This hazard can be accentuated if air can enter into material of low bulk density, or by convection currents induced with insulated vertical pipework. The phenomenon is a complicated one, being associated with local concentration of organic bonding material, the thickness of insulation, and the temperature of the insulated surface, together with its orientation. If excessive, this internal rise in temperature can constitute a fire hazard, particularly if the surrounding atmosphere is flammable or if there are flammable materials in the immediate vicinity. (See BS 2972.)

6.9.8 *Hazards from contaminants*

6.9.8.1 A number of dangerous fires have occurred in situations where non-combustible insulating materials have become accidentally contaminated by oil, chemical or other spillage. The chemical and physical processes involved are complicated and conditions could be hazardous unless precautions are taken in accordance with 6.9.8.2 to 6.9.8.8.

6.9.8.2 Three distinct situations have been observed following the spillage of contaminant on to heated thermal insulation:

- a) no reaction;
- b) a small rise of temperature within the body of the insulation material, followed by a slow decline of temperature;
- c) a small rise of temperature, followed by a period of steady-temperature and then a relatively rapid rise to values associated with combustion. At this stage, fire can be initiated if flammable materials are present; in other circumstances the thermal insulating material can smoulder or even glow with heat and thereby constitute a source of ignition for other materials in the vicinity. This sequence of temperature rise can be initiated even though the insulated hot-face temperature is well below the flashpoint of the spillage material.

6.9.8.3 It has been observed that the factors influencing the initiation of a self-heating reaction include:

- a) the type and physical state of thermal insulating material and spillage material;
- b) the concentration and quantity of spillage material;
- c) the shape and dimension of the hot-face and of the thermal insulation;
- d) the temperature of the inner surface of the insulation material;
- e) the facility with which the insulation system allows the spillage material to spread and to penetrate; when these factors approach a critical combination, a small change in one of them can initiate a transition from a small rise in temperature to a rapid rise, possibly leading to ignition;
- f) the ready availability of a source of air, i.e. either entrained or external when there is no surface seal.

6.9.8.4 The consequences of fire in an insulation system are most dangerous in locations where highly flammable or low-flashpoint materials, or both, are stored or processed, i.e. normally classified as fire hazard areas. In these circumstances the choice of an insulation system should be preceded by self-ignition experiments in a laboratory.

6.9.8.5 In all circumstances it is advisable that a high standard of plant maintenance and vigilance should be aimed for to minimize the risk of accidental contamination by spillage or leaks.

6.9.8.6 Where an impervious finish is applied to provide protection against an otherwise dangerous combination of insulating material and spillage material, it should be appreciated that the finish can be rendered ineffective by accidental, and possibly unobserved, mechanical damage.

6.9.8.7 The presence of flame-retardants and anti-oxidants in the body of the insulating material should not be regarded as fully protective because these compounds merely postpone, rather than preclude, the development of self-heating reactions once other critical conditions are established.

6.9.8.8 Precautions should be taken, to prevent fire hazards in air-conditioning ductwork, in accordance with BS 5422, BS 5588-9 and BS 5908. Reference should also be made to the Building Regulations [1].

Thermal insulation applied to ductwork within a building should in all cases be free from substances that, in the event of fire, would generate appreciable quantities of smoke, and noxious or toxic fumes.

In all cases, before finally specifying insulating materials for use in an air-conditioning system, the local building and fire authorities should be consulted.

6.10 Resistance to vermin, fungus and moulds

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 can be attacked by these agencies. Finishing with non-absorptive materials is recommended.

6.11 Health hazards

6.11.1 Reference should be made at all times to the current requirements of health and safety legislation, and to codes of practice and guidance notes, and to instructions from manufacturers.

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

6.11.3 WARNING NOTE Chemical fumes arising from the in situ foaming or spraying of organic insulating materials, e.g. phenol-formaldehyde resins, isocyanurates 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.

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.

6.11.4 NOTE With certain resinous coatings, adhesives and epoxy-resin components can cause dermatitis and other skin complaints, which can occur after brief contact, long exposure leading to allergy. Associated solvents can cause damage to the eyes and skin irritation, therefore goggles and gloves should be used when necessary.

Barrier cream and adequate washing facilities should be provided. Protection should be provided against respiratory hazards when these materials are sprayed.

6.11.5 Precautions should be taken when using fibrous insulences that cause skin irritation. For detailed advice on the subject, the following publications of the Health and Safety Executive (HSE) should be referred to.

- EH 44 “Dust in the workplace. General principles of protection” [2].
- EH 46 (Guidance note) “Man-made mineral fibres” [3].

6.11.6 When insulating materials are handled, mixed or removed, 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” [4];
- EH 44 “Dust in the work place. General principles of protection” [2].

6.11.7 Before any stripping work is carried out the type of insulating material used, should be identified and relevant precautions should be taken (see clause 31).

6.12 Removal and replacement

When removal and replacement or abutment to insulation containing asbestos or refractory ceramic fibre is to be undertaken, precautions should be taken to safeguard against any health hazards associated with these activities (see also 31.3).

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

6.13 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 K)].

NOTE 1 The value of heat capacity will vary with mean temperature even though it is given in terms of unit increment of 1 K.

NOTE 2 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 can be convenient to refer to heat capacity per unit volume, [J/(m³·K)], but this value will be typical only for a representative product, i.e. at a specific bulk density.

6.14 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 6.10).

6.15 Corrosion

6.15.1 General information

NOTE An insulated metal surface can 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 can be specific or general.

General corrosion can 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 60 °C.

Most thermal insulating materials contain traces of water-soluble chlorides. Additionally, some organic-foam insulating materials contain chlorinated organic compounds that can form soluble chlorides when heated in the presence of water. Both can give rise to stress-corrosion cracking in susceptible 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 cause 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 can contain sufficient chloride to be potentially dangerous.

6.15.2 Assumptions and precautions

The mechanism of corrosive attack on metals is a complicated one that can vary with different metals and with different environments, but it is reasonable to assume that all corrosion is electrochemical in nature. It can be general or specific and can also depend on the normal operating conditions and the effect of thermal recycling.

The following precautions should be observed.

- a) Use only dry insulating systems.
- b) Keep water out of the system.
- c) Protect the metal surface, especially if the plant is likely to be heated to a temperature above 50 °C at any time, e.g. for sterilizing or cleaning.
- d) Where the consequences of stress-corrosion attack are potentially serious, seek specialist advice.

The information given in **6.15.3**, **6.15.4** and **6.15.5** should be used for general guidance. Where specific corrosion problems arise due to the interaction of insulation and metal in a particular environment, specialist advice should be sought.

6.15.3 Oxidation, acidic, alkaline and galvanic corrosion

6.15.3.1 Oxidation

Iron and carbon steel corrodes (rusts) on exposure to air in the presence of moisture. This can be particularly dangerous with insulated plant required to operate at temperatures below the dew-point of the surrounding air, or on which the insulating material is allowed to remain wet over long periods. Therefore, only dry insulating material should be used, and it should be kept dry until an effective vapour barrier, or weatherproof finish if above the dew-point, has been applied. (See clause **24** and **25.1**.)

Various methods are available for depositing protective films on the surface of iron and steel, e.g. galvanizing, aluminizing, etc., and these can improve the resistance to oxidation. Attention should be paid to the possible effect of change of conditions in service. Thus, at temperatures over about 65 °C under conditions of high humidity, the zinc and iron of galvanized steel can undergo reversal of polarity, so that the iron can become sacrificial rather than the zinc surface film. In any case galvanized steel reinforcement should not be used at temperatures above 350 °C. (See **24.5.2**.)

Oxidation, with severe scaling and possible loss of mechanical strength, can occur when a metal is heated to relatively high temperatures in air, e.g. 460 °C and above for carbon steel, a condition that can occur due to the incorrect use of thermal insulating material on the external surface of refractory-lined equipment. This can raise the metal temperature to a dangerous level. If it is essential to have both internal and external insulation, care shall be taken to avoid high temperatures, which might reduce the strength of the metal.

The formation of white deposits of oxide on the surface of zinc and certain types of aluminium sheet, particularly under moist conditions, can be unsightly rather than detrimental to the metal. These can be eliminated by cleaning, followed by painting as necessary. In the case of aluminium the formation of oxide deposits can be obviated by the use of an electrolytic oxidation pretreatment. (See also **27.1** and **28.1**.)

6.15.3.2 Acidic corrosion

This type of attack is most prevalent with carbon steels, although many of the non-ferrous metals are also vulnerable. A typical example is the condensation of the acidic gases inside a metal flue when the temperature is allowed to fall below the dew-point of the contained gas; firing with heavy fuel oils or sulfite residues can be particularly troublesome, and special attention should be paid to vulnerable areas of thin metal, e.g. metal expansion bellows. In most cases the use of an adequate thickness of insulating material to prevent internal condensation will be an effective safety measure.

As most insulating materials absorb water in the event of unsatisfactory or damaged weatherproofing, there is a serious risk of corrosion from wet insulation. The risk is increased in the presence of chlorides, nitrates and sulfates which can be introduced with rain water.

Acidic corrosion on the surface of carbon steel can result from the decomposition of halogenated compounds in certain types of organic plastics insulating materials. Normally this occurs when the products are heated in the presence of moisture; the attack should be minimized by suitably painting the base metal prior to the application of insulating material. It should be remembered that even refrigeration plant can be heated on occasions, e.g. for defrosting, and that consequent decomposition of halogenated compounds can occur.

Acidic corrosion can also take place on copper pipes. This can take the form of pinhole corrosion which can occur more rapidly.

The leakage of acidic gases through areas of faulty welding or faulty joints can result in corrosive attack on insulated metal surfaces, and this is the more dangerous because it is hidden from view. Corrosive attack on unprotected underground pipework can be dangerous, and effective measures should be adopted to avoid this.

6.15.3.3 Alkaline corrosive attack

Some non-ferrous metals can be attacked by alkalis extracted from certain types of insulating material under moist conditions, e.g. those that contain appreciable amounts of sodium silicate. Similar effects can occur with copper, brass, etc., and with zinc coating on galvanized surfaces. Aluminium sheet used to protect calcium silicate is also vulnerable. Protective measures should include keeping water out of the system and painting the metal surface or using a factory-applied moisture barrier.

6.15.3.4 Bimetallic (galvanic) corrosion

It is well known that direct contact between many dissimilar metals in the presence of moisture, particularly in a marine environment or near the sea, can result in rapid corrosion of one of the metals. PD 6484 states: "When two different metals are in electrical contact and are also bridged by water containing an electrolyte (e.g. water containing salt, acid, combustion product), current flows through the solution from the anodic or baser metal to the cathodic or nobler metal. As a result, the nobler metal tends to be protected, but the baser metal can suffer greater corrosion. In the past, schedules of electrode potentials have been published which have been of value in drawing the attention of designers to the dangers of bimetallic corrosion. Such schedules can, however, be misleading, because the potential difference between metals, although it is the prime driving force of the corrosion current, is not a reliable guide to the rate and form of corrosion suffered at any particular contact. In particular, statements claiming that specific differences of potential as safe or unsafe are unreliable."

It is important that the compatibility of dissimilar metals for screws, rivets, welded attachments, and even bands, should receive careful attention.

Where potential for bimetallic corrosion is unavoidable, the metals should be isolated from each other, e.g. by plastics washers, insulation tape, bitumen mastic, or a paint of adequate film thickness.

NOTE The occurrence and extent of bimetallic corrosion between any two metals depends, in general, upon two factors:

- a) the difference in electrode potential of the two metals;
- b) the ratio of the anode to cathode surface areas.

The degree of corrosion can, however, be modified if either of the metals is capable of forming a protective film. Aluminium and stainless steel are both metals capable of forming protective oxide films that modify their electrode potentials. Under mildly corrosive conditions it is therefore possible to have bimetallic contact between the two metals without corrosion. If, however, the same two metals are exposed to severely corrosive environments such as a very badly polluted industrial atmosphere or continual immersion in sea water, the aluminium will corrode anodically. Corrosion of aluminium also occurs if the aluminium is coupled to a 13 % chromium steel that does not form a passive film as easily as does 18/8 chromium-nickel stainless steel.

6.15.4 Stress-corrosion cracking

6.15.4.1 Action of water-soluble chlorides and other halides on austenitic alloy-steels

Austenitic steels can be sensitive to corrosive attack by soluble inorganic halides in the presence of oxygen and moisture, especially when at the same time the alloy is stressed. This type of cracking has been defined as “degradation at a rate greater than that which would occur if either the stress or the corrosion were acting independently or successively”. See 6.15.1 concerning the possible liberation of water-soluble halides from certain organic foams.

The action is not likely to be significant at temperatures below 50 °C and it will be most severe in the temperature range from 50 °C to about 160 °C. The attack requires the presence of moisture, so that precautions should include the provision and maintenance of an effective waterproof finish to the insulation system. Additionally, as far as possible, personnel should avoid touching austenitic steel surfaces with bare hands, and the surfaces should not be scratched or indented in any way as local damaged areas can form a starting point for the development of cracks in the metal.

To provide protection, aluminium foil of not less than 0,06 mm thickness should preferably be applied to the austenitic steel surface so that the insulation can be applied over the foil, which should be arranged to shed water, with an overlap of not less than 50 mm at the joints. The melting point of aluminium is 660 °C, so that foil should not be used if the temperature of the alloy can approach this value under service conditions; a limit of 500 °C is recommended. At temperatures over 300 °C, the risk of the ingress of water to the metal surfaces is not likely to be serious, except during plant shut-down and at start-up periods.

As an alternative protective system, where the use of aluminium foil is impracticable, specially compounded paints for this type of resistance application can be used.

NOTE Unlike aluminium foil these paints cannot provide galvanic protection but act solely as a physical barrier.

The instructions of the manufacturer should be followed closely and the temperature limitation of the paint should not be exceeded. Paints containing metallic zinc should not be used. See also 6.15.5 for the importance of keeping metallic zinc away from austenitic steel.

Certain insulation materials contain additives that are used to inhibit stress-corrosion cracking, but it is preferable that they should be used with previous recommendations.

6.15.4.2 Stress-corrosion attack on other metals

Many alloys, when subjected to the combined effects of stress and corrosion under conditions specific to the individual alloy, can develop cracking, although the incidence cannot be frequent under normal operating conditions.

Carbon steel (mild steel) can be attacked by soluble nitrates present as contamination in water from external sources, under conditions of mild acidity and temperatures above about 80 °C. Commercial thermal insulating materials do not generally contain nitrates, but these can be present in the environment. Thus, water of any kind should not be allowed to penetrate and, above all, to saturate insulation systems where contaminants can concentrate at the metal surface. As a general rule, the danger of cracking from this type of attack is remote, but painting of the surface should be adopted as a precaution where the consequences of fracture of the metal could be serious.

Non-ferrous metals, notably the aluminium-zinc, aluminium-zinc-magnesium alloys, and various copper-zinc alloys can be sensitive to stress-corrosion attack, particularly in the presence of moisture and of alkalis. Precautions should be taken to exclude moisture from the system and, if necessary, the surface of the metal should receive a protective coating.

6.15.5 Attack by liquid metals

Although thermal insulating materials themselves do not contain zinc, this metal is commonly associated with securing and reinforcing materials, usually as a protective coating, e.g. galvanized carbon steel.

The melting point of zinc is 419 °C and at temperatures above 450 °C molten zinc diffuses and penetrates stainless steel, although embrittlement is unlikely to occur until a temperature of about 750 °C is reached. The depth of penetration will depend on the time and temperature of the exposure, and the structure and composition of the steel. It will also depend on the degree of applied stress. In the absences of stress it is unlikely that very rapid embrittlement will occur.

Below 750 °C, the influence of stress upon the rate of diffusion and penetration is relatively small. At temperatures above 750 °C, however, the tensile stress in the steel brings about rapid penetration, and cracking can occur in a matter of minutes or even seconds in the area of contamination. Zinc is volatile at such high temperatures and, whilst the major hazard arises from molten zinc, there is evidence that embrittlement can even be caused from the gaseous phase.

As it is thought that embrittlement arises from interaction between zinc and nickel in the steel, it can be expected that the austenitic chromium-nickel family of stainless steels will be particularly susceptible to zinc embrittlement.

NOTE Intergranular penetration can also result from contact with copper, lead and aluminium under certain conditions of temperature and stress.

Under no circumstances should galvanized steel be welded and, additionally, contact between galvanized accessories, e.g. galvanized wire netting, and steels that are intended for use at service-temperatures above 350 °C should be rigorously avoided.

Paints containing metallic zinc should not be used as surface protection for insulated austenitic steel surfaces.

Embrittlement also can occur if molten zinc is allowed to drop on to heated alloy-steel surfaces, e.g. under conditions of external fire. This is of particular importance when the plant is under stressed conditions, particularly if the contents are flammable.

6.15.6 Attack on plastics pipes and equipment

Certain types of plastics pipework and equipment can be susceptible to solvent stress cracking. These solvents can be present in certain adhesives, welding agents, paints, sealants and coatings. Reference should be made to the plastics manufacturer.

Some plastics can be adversely affected by the action of plasticizers within certain organic insulants.

6.16 Chemical resistance

The thermal insulation system as installed 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.

6.17 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 incorporate 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.

7 Selection of thermal insulating materials

7.1 General

The decision to select an insulating material for a specific application will depend on the following factors.

a) **Hot surfaces:**

- 1) cold-face temperature (min. and max.);
- 2) hot-face temperature (max. and min.);
- 3) ambient temperature (aged);
- 4) thermal conductivity;
- 5) thickness of insulation required;
- 6) mechanical strength;
- 7) health hazard (see **6.11**);
- 8) fire hazard;
- 9) differential thermal movement;
- 10) protection from water ingress;
- 11) protective covering and finish;
- 12) compatibility with atmosphere and possible spillages;
- 13) design plant life.

b) **Cold surfaces:**

- 1) cold-face temperature (min. and max.);
- 2) warm-face temperature (max. and min.);
- 3) ambient temperature and humidity;
- 4) thermal conductivity (aged);
- 5) thickness of insulation required;
- 6) mechanical strength;
- 7) health hazard (see **6.11**);
- 8) fire hazard;
- 9) differential thermal movement;
- 10) vapour sealing;
- 11) protective covering and finish;
- 12) compatibility with atmosphere and possible spillages;
- 13) design plant life;
- 14) cost (including that for application and finish).

7.2 Types available

NOTE 1 The terms used are explained in BS 3533.

NOTE 2 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 in accordance with **7.2.1** to **7.2.10**.

7.2.1 Pre-formed

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.

For specialized types of application it can 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 are moulded or prefabricated valve and flange covers, prefabricated flexible mattresses, lined metal valve and flange boxes.

7.2.2 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 pre-formed materials only by the ease with which they can be bent or compressed to shape.

7.2.3 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.

7.2.4 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.

7.2.5 Spray-applied

This type consists of granular, foamed or fibrous material that adheres to the surface when applied by means of a spray-gun. An adhesive can be included in the original mix or it can be applied through a separate nozzle during the application process.

7.2.6 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.

7.2.7 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 pre-formed material or encapsulated.

7.2.8 Reflective insulation

This is foil or thin sheet material of low emissivity that can 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 can be closed or open.

7.2.9 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.

7.2.10 Insulating concretes

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

7.3 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 for the lower temperature ranges, i.e. below ambient temperature.

NOTE 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 can enable the use of materials of relatively high permeability to water vapour.

Figure 1 shows typical thermal conductivity values for insulating materials used at above and below ambient temperatures.

7.4 Typical dimensions

7.4.1 General

Pre-formed insulation and factory-made mattresses of the sizes shown in 7.4.2 and 7.4.3 are readily available but individual manufacturers can often supply a wider range and should be consulted.

7.4.2 Pre-formed insulation

The dimensions of pre-formed 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 (including pipe section mattresses)*
 - Length 0.6 m to 2.0 m.
 - Width 0.6 m to 1.5 m.
 - Thickness 10 mm to 100 mm in increments of 5 mm, 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 5 mm, 10 mm to 12.5 mm.
- c) *Bevelled, or radiused and bevelled, lags*
 - Length 0.6 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 5 mm, 10 mm to 12.5 mm.

7.4.3 Mattress insulation

The dimensions for mattress insulation should typically be as follows:

- a) length up to 7.0 m;
- b) width up to 1.2 m;
- c) nominal thickness 25 mm to 100 mm.

7.5 Applicability of thermal insulating materials

7.5.1 General

NOTE 1 For various reasons, many commercial thermal insulating materials are only for use within a restricted range of temperatures, whereas others can 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 manufacturers.

As a general rule, it is convenient to distinguish between an insulation system that is particularly 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 can well be the dominant factor for applications at temperatures below the dew-point of the ambient air.

NOTE 2 Materials used above their recommended maximum service-temperatures can degrade with possible detrimental effects.

Where insulation is located in areas liable to flooding, an insulation system capable of drying out should be applied in accordance with BS 7572. Buried pipes should also be insulated in accordance with BS 7572.

7.5.2 Refrigeration and general cold work

7.5.2.1 The thermal resistance of the insulating material should be compatible with design or process control, and 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 pre-formed material, or for foamed in situ products.

7.5.2.2 An alternative is a sealed double-skin construction in which the annular space is filled with a loosefill material.

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 can be reduced appreciably, thus increasing the effectiveness of the insulation system. Microporous insulating materials would be of value for small installations of this type.

7.5.2.3 Where the plant is to operate 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 barrier.

7.5.2.4 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 an adhesive, tape or bands (see **25.2.1**). Additionally, all cavities should be filled with vapour barrier/joint sealant. Thermal bridges, for example, at through-metal supports, should be avoided wherever possible.

7.5.2.5 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 can 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 **25.2.1** and Figure 2 for contraction joints.)

7.5.2.6 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 load-bearing thermal insulation, e.g. cellular glass, expanded plastics, resin impregnated wood or high-density cork should be used. If wood or other absorbent material is used, it is important that this should be kept dry during service.

For pipe supports, it is preferable for these to be of the same thickness as the insulation to enable the vapour barrier to be easily continued and maintained.

7.5.2.7 Many insulating and ancillary materials used for the insulation of low temperature plant are classified as combustible and therefore potential fire hazards (see **6.9**, **10.6** and **33.3**).

7.5.2.8 Insulating materials, joints sealers and vapour barriers that can be exposed to liquid oxygen, e.g. by direct spillage, leakage, or by the partial condensation of air, should be of inorganic composition and should be 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 **6.9**). Care should be taken when fixing the outer metallic cover not to penetrate the vapour barrier.

7.5.2.9 When selecting insulating material for the protection of pipes of small diameter against frost conditions, heat tracing should be used where the thickness of insulation is impracticable (see BS 5422).

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 **33.7.1**.)

7.5.2.10 It can be convenient to use different types of insulating material for a portion of the plant if the operating temperature is below the limiting-temperature for the preferred insulating material. In such cases the inner layer, to perform at the lower temperature should be used in sufficient thickness to maintain the temperature at the interface with the main insulant at an acceptable level.

7.5.3 For normal ambient and elevated temperatures

NOTE 1 Although flexible materials can be used for plant of both regular and irregular shape, they are relatively easily deformed by superimposed loads, for example, by the weight of finishing material. Thus, to ensure reliable thermal effectiveness in service, it may be necessary to provide additional support from the plant surface for any substantial protective layer, independently of the insulating material itself.

However, a flexible fabric-covered mattress can have specific advantages for locations where frequent removal of the insulation is required, e.g. for valves or access manhole covers.

7.5.3.1 Certain types of plant with double-skin construction, for example, reaction or storage vessels, can 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, for example, by the provision of internal spacer supports to prevent settlement under service conditions.

7.5.3.2 For irregular shapes of plant it is possible 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 can be substantial.

Because 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 plastic composition to minimize the risk of corrosion from soluble salts in contaminated water. (See 6.15.4.2.)

7.5.3.3 NOTE Low thermal conductivity values, together with lightweight, are characteristic of many types of foamed in situ insulating materials, which normally involve the mixing of reactive chemicals, for example, for the production of polyurethane, isocyanurate and phenolic foam. Such materials are of particular value for filling the annular spaces between the containment surfaces of a lightweight structure as, in many cases, they can increase the mechanical stability of the structure. It should be possible to use a similar process for the production of pre-formed insulating shapes.

Care should be taken to ensure that the foamed material is used only within the correct temperature range and that it does not add to the fire hazard in the insulated plant.

7.5.3.4 NOTE 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 for 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.

7.5.3.5 Metallic surfaces are more effective than non-metallic surfaces in reducing absorption or emission of radiant heat, but allowance should be made for heat loss due to edge effects.

NOTE Reflective metal foils can 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 are particularly useful for certain applications in the nuclear industry.

7.5.3.6 Insulating boards can be substantially of organic composition, e.g. made from wood fibre cane, or they can 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 can have one or both surfaces covered with aluminium foil to reduce thermal transmission. When a choice is to be made from various types of board for a specific application, attention should be paid to fire hazard, moisture absorption, and the upper limiting-temperature, as well as to the thermal conductivity under the required conditions of use.

7.5.3.7 Insulating fire brick and related pre-fired or formed rigid shapes should be used in locations where the insulation has to be self-supporting or partially load-bearing or where it is to be exposed directly to hot gaseous products, for example, 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.

7.5.3.8 Significant advantages over insulating fire brick can be gained in lesser thicknesses and/or lower heat losses by the use of calcium silicate insulating blocks or slabs. The high crushing strength of calcium silicate blocks, combined with a low thermal conductivity, makes them useful in partially load-bearing applications, and they should be used as a back-up to fire bricks where they have to resist crushing movement due to expansion at high temperature (see 7.5.3.11).

7.5.3.9 High temperature resistant fibre should be used in applications where low thermal mass and high resistance to thermal shock are important, such as in annealing furnaces or those used intermittently. Greater resistance to abrasion and mechanical damage 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.

7.5.3.10 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.

NOTE Many lightweight insulating concretes can undergo appreciable changes in volume with variations of moisture content, and their mechanical strength can be reduced on heating.

7.5.3.11 It can 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, for resistance to 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 6.4).

8 Selection of securing materials

8.1 General

Insulation systems can be permanently secured directly to the plant by means of adhesives, by mechanical means, or by a combination of both. Alternatively the insulation can be installed as a removable module. (See also clause 23 and clause 24.)

8.2 Adhesives

8.2.1 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⁾ [5] and to HSE Guidance Note EH 40 "Occupational exposure limits"³⁾ [4].

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 can 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.

NOTE Adhesives of nominally similar type can differ in their resistance to water, in their behaviour under conditions of fire, and in their resistance to temperature variation.

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

³⁾ Available from The Stationery Office Limited, PO Box 276, London SW8 5ET.

8.2.2 Classification according to use

Adhesives for insulation can be classified as follows.

— *Insulation bonding adhesives* (see Table 3). Used for securing pre-formed 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 pipe work 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 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.

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

8.2.3 Application characteristics

Important properties that affect the use of insulation, are as follows:

- a) build, i.e. resistance to 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 might affect the use of insulation are as follows:

- a) flashpoint;
- b) toxicity;
- c) temperature and humidity range (for application);
- d) range of bonding times;
- e) curing time;
- f) stability in storage;
- g) possibility of corrosive attack;
- h) danger from attack by solvents.

NOTE 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.

8.2.4 Service properties

8.2.4.1 General

Properties which might affect the behaviour of the adhesive after installation are specified in 8.2.4.2 and 8.2.4.3.

8.2.4.2 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.

Table 3 — Insulation bonding adhesives for pre-formed 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 in accordance with this section together with any special chemical resistance or other requirements.	

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.

For service-temperatures of above $+150^{\circ}\text{C}$, the most widely used adhesives are based on filled sodium silicate solutions, which are not resistant to water or high humidity. When assessing the required service-temperatures, attention should be given to the possibility that there can be periodic departures from the assumed conditions, e.g. through steam-cleaning requirements or variations of boiler operation. There are now high temperature adhesives based on silicon for use up to 200°C .

8.2.4.3 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 are usually 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 can 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 can 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.

8.2.5 Mechanism of curing

8.2.5.1 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. 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 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 can 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 can 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 ensure success.

Some water-based gap-filling adhesives with high solids content, or heavily filled solvent can 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.

8.2.5.2 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 can 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.

8.2.5.3 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.

8.2.6 *Types and typical properties*

8.2.6.1 *General*

The materials referred to, with summaries of properties, in 8.2.6.2 to 8.2.6.12 should not be regarded as an exhaustive list; the particulars are 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 adhesives in a variety of ways. Other ingredients, such as fillers, plasticizers, anti-oxidants, tackifiers, etc., are added to achieve the required 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 recommended in this section.

8.2.6.2 *Bitumens*

These are low-cost thermoplastic materials of mineral origin, generally of dark colour and with poor elasticity and strength. At operating-temperature they can 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 can cause softening. The addition of rubber improves the flexibility and the bond strength.

They are flammable, of low acute toxicity, and can 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 can be supplied as aqueous emulsions or as “cut-backs” with organic solvents.

8.2.6.3 *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 polysulfides 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 can be toxic, and inhalation of spray can be harmful.

8.2.6.4 *Natural rubber*

Cements based on natural rubber are available in a range of colours, depending on the rubber stock and the filler used. They can have flammable or non-flammable solvents. Adhesives are also available on a basis of rubber latex and these are relatively non-toxic; they can 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.

8.2.6.5 *Neoprene-phenolic*

These adhesives can be used as unvulcanized dispersions to give good bonds up to a temperature of 100°C (or 140°C intermittently); two-part mixes can 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 can 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.

8.2.6.6 *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.

8.2.6.7 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.

8.2.6.8 Reclaimed rubbers

These are low-cost adhesives available with flammable or non-flammable solvent. The maximum service-temperature is 70 °C, but they can be used intermittently up to 100 °C if not required to be load-bearing. 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.

8.2.6.9 Styrene-butadiene-based (SBR) cements

These are an important class of adhesives. They can contain either flammable or non-flammable solvent and normally are combustible when dry, although the resistance to spread of flame can be improved. Their resistance to heat is similar to that of adhesives based on natural rubber.

8.2.6.10 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 can be flammable, when tested in accordance with BS 476-7, the dry adhesive should achieve a class 1 spread of flame. The dry adhesives have good chemical resistance and have secondary vapour barrier properties.

8.2.6.11 Rubber latex/hydraulic cement

This range of two-component adhesives is used for service-temperatures ranging from –40 °C to +90 °C. Usually they are of heavy consistency with a high solids content. They are useful as gap-filling adhesives with excellent tolerance to substrates of high moisture content.

8.2.6.12 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 °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.

8.3 Mechanical securements

8.3.1 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 **6.15.5**).

8.3.2 Welded attachments are used mainly on vertical 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 can be varied locally to control thermal movement (see **24.3.2**, **26.1.3** and Figure 2 to Figure 10). Care should be taken to avoid danger from attack by liquid metal (see **6.15.5**).

Site welding of securing and fixing devices should not be undertaken without first consulting 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.

8.3.3 For large tanks which can be subjected to significant wind loadings, bolted fittings should only be used with attachments which are welded or fastened by means which provide equivalent restraint.

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.

8.3.4 Banding and wire securements are used mainly to hold materials firmly to the plant to be insulated; they can 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 **24.4.1**).

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

8.4 Combination

In certain circumstances, mechanical fixing devices for cladding can be attached by the use of adhesives. In such cases, mechanical strength is very important especially for large tanks where the cladding can be subjected to substantial wind forces, and it is essential to follow the manufacturers instructions to get the optimum cure (see **24.2.5**).

8.5 Insulation hangers

A range of insulation hangers is available consisting of a metal or plastics base, to which a spindle 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.

9 Selection of vapour barriers

9.1 General

9.1.1 Condensation of water vapour occurs on surfaces at temperatures below the atmospheric dew-point, due to the water vapour being 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 permeable insulating material that can be applied to the cold surface, thus increasing the thermal conductivity of that material, with impairment of its insulating properties.

The purpose of the vapour barrier is to reduce, and if possible to prevent, the ingress of water vapour into the insulating material. Thus, the barrier should always be applied to the warmer surface of the material (see **33.8.1**). It can 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 **9.1.2**).

NOTE Because of the lack of precise knowledge and of variations in practical application, any quantitative recommendations are to be taken as approximate guidance only. Care needs to be taken to ensure that the vapour barrier does not reduce the fire performance of the complete system below specified limits.

9.1.2 The amount of water in the vapour phase, retained in air, is reduced as the temperature of the air decreases, the vapour condensing when the temperature falls to the dew-point; the saturation vapour pressure of water in the atmosphere increases with increase in temperature.

Where the outer surface temperature of insulation is higher than the plant on which it is used, and some part of the insulation is at a temperature below the dew-point of the ambient air, there is a water vapour pressure differential across the insulation. This differential will tend to force the vapour towards the cold surface of the plant where it will condense. If the plant temperature is below freezing point, the condensed water will turn into ice.

9.1.3 As a rough guide, the thermal conductivity of water is about 20 times that of a typical good-quality dry insulating material, and that of wet ice can be up to 3,5 times that of water. This means that internal condensation and ice formation will appreciably reduce the effectiveness of the thermal insulating material. Additionally, the increase in volume of the moisture on freezing can disrupt the physical structure of the thermal insulating material.

9.1.4 Insulating materials that consist substantially of closed-cells possess an inherent resistance to the passage of water vapour, but open-cell insulants and loosefill porous materials are readily permeable to water vapour. Even with materials that have good resistance to the transmission of water vapour, differential movement of plant and insulation can cause joints in the latter to open, thus allowing moisture to penetrate towards the underlying surface. Joint-sealing compounds can also fail to exclude water vapour completely, in which case the contained water or ice can form strongly conducting paths from the surface of the plant to the ambient air.

9.1.5 As a general rule, all insulation on plant working any time at sub-ambient temperatures should have a “vapour barrier” layer over the outer (warm face) surface unless the insulation has sufficient integral vapour resistance and the joints are adequately vapour sealed. This barrier should be resistant to the passage of water vapour and it should be applied to the dry insulation immediately the latter has been fitted. The properties of the vapour barrier should have attained their optimum values before the plant is operated.

The effectiveness of the vapour barrier is expressed in terms of the rate at which water vapour is transmitted through it under defined conditions, e.g. by a “permeability” value or a “permeance” value. Permeability relates to the rate of transmission through unit thickness (normally 1 m) of the material whereas permeance relates to the total rate of transmission through the actual thickness of a particular material, as applied.

The SI units are as follows.

Permeability: grams per second per meganewton vapour pressure difference, for one metre thickness: $\text{g}\cdot\text{m}/(\text{s}\cdot\text{MN})$.

Permeance: grams per second per meganewton vapour pressure difference: $\text{g}/(\text{s}\cdot\text{MN})$.

NOTE Whereas “permeability” is a characteristic of a given material, “permeance” relates only to a particular layer of known thickness after application. Typical values for some vapour barrier layers are recommended in Table 4 and conversion factors to other units in Table 5.

9.1.6 Essentially, the vapour pressure of the ambient air depends on the actual moisture content, which can be related to the combined effects of the dry-bulb temperature and the percentage relative humidity at the particular barometric pressure.

For example, air at a temperature of 20 °C (dry-bulb) and 52.6 % r.h. will exert approximately the same pressure (1 230 N/m²) as air at 10 °C and 100 % r.h. (i.e. saturated); the dew-point in each case will be 10 °C and the actual moisture content will be approximately 0.007 67 kg/kg dry air. These values are for a barometric pressure of 1 013 mbar⁴⁾.

If now we assume the insulated cold metal surface to be at a temperature of –17 °C the vapour pressure at that surface would be 125 N/m² so that, for ambient air as above, the vapour pressure difference would be (125 to 1 230) = 1 105 N/m² approximately. The pressure for unsaturated water vapour can be determined from Figure 11 by multiplying the saturation pressure at the required temperature by a factor r.h./100 where r.h. is the percentage relative humidity.

9.1.7 Even a good quality vapour barrier is not guaranteed to exclude water vapour entirely, although it will diminish the rate of water vapour penetration proportional to its permeance value.

It is necessary to distinguish between the behaviour of insulation and vapour barriers over porous structures, for example, non-metallic walls, and the corresponding behaviour over non-porous surfaces, for example, metallic pipework and vessels. Although the present code does not relate to building structures, it is important to remember that when moisture penetrates into a porous structure it is probable that it will re-evaporate through the colder surface, especially if air movement can be arranged. On insulated metal surfaces, condensed moisture tends to remain at the cold surface unless it is possible to make provision for it to be collected and drained away; more usually it accumulates at the metallic surface and saturates the insulating material, with consequent danger of increase in thermal conductivity and the possibility of corrosive or electrolytic attack on the metal surface.

If the condensation is transient or periodic the water can evaporate later, in which case it can be satisfactory to apply a breather coat to the outer surface, instead of the vapour barrier. If, however, the condensation is likely to be of long duration it is essential to apply an efficient vapour barrier.

⁴⁾ 1 mbar = 100 N/m = 100 Pa.

With insulation of inherently low permeance, it can be convenient to apply a vapour barrier of higher permeance than would apply otherwise if, by doing so, superior mechanical resistance and easier application is achieved; incorrect methods of application can spoil otherwise good quality vapour barrier materials. For very low temperatures, the use of multiple vapour barriers can be justified.

9.1.8 For below ambient operation it is preferable that the vapour barrier layer should not be exposed to mechanical damage if it is susceptible to easy perforation. Frequently it is possible to use a tough outer finish, e.g. sheet metal, GRP sheeting or vinyl-acrylic copolymer, as a protective layer over a more vulnerable barrier material. This tough weatherproof outer finish should be either white or a pale colour with a high sheen to reduce solar absorption. Alternatively, polished sheet metal can be applied as protection over a vulnerable vapour barrier coat or film.

9.1.9 The compatibility of the vapour barrier material with the chosen insulation should be established, for example, solvent-based materials should not be used directly over polystyrene.

Table 4 — Typical values for water vapour permeance

Material	Thickness mm	Permeance (maximum) g/(s·MN)
(A) Liquid-applied	—	—
<i>(1) Emulsion-based</i>	—	—
Bitumen emulsion	3.2	0.046
Rubber/bitumen emulsion	3.2	0.003
Homopolymer emulsion	0.4 to 1.6	0.057 to 0.029
Copolymer/polymeric emulsion	0.8	0.008
<i>(2) Solvent-based</i>	—	—
Bitumen mastic	0.8 to 3.2	0.000 2 to 0.000 6
Polymeric mastic	0.5 to 3.2	0.017 to 0.002 5
Elastomeric mastic	1.6	0.003 5
<i>(3) Non-solvented</i>	—	—
Epoxide resin	0.5	0.003
(B) Dry membrane/sheet	—	—
<i>(1) Aluminium foil-based</i>	—	—
Foil/kraft (FK)	0.008 (foil)	0.024
Foil-scrim-kraft (FSK)	0.008 (foil)	0.024
Foil polyethylene-glass reinforcement	0.02 (foil)	0.000 8
Foil	0.02 to 0.05 (foil)	0.000 8
<i>(2) Compounded sheeting</i>	—	—
Polyisobutylene (PIB)	0.8	0.001 5
Rigid PVC (UPVC)	0.35	0.002
Elastomeric, fire resistive	0.06	0.001 5
<i>(3) Single polymer sheeting</i>	—	—
Polyethylene	0.05	0.004
Polyester	0.025	0.004

Table 5 — Water vapour permeance conversion table

	g/(s·MN)	g/(cm²·s·mbar)	g/(m² 24 h·mmHg)	lb/(ft²·h·atm) (see note 2)	gr/(ft²·h·mbar) (see note 4)	gr/(ft²·h·inHg) = 1 perm	Temperate g/(m²·24 h)	Tropical g/(m²·24 h)
g/(s·MN)	1	1×10^{-2}	1.152×10	7.471×10^{-2}	5.161×10^{-1}	1.749×10	2.052×10^2	5.149×10^2
g/(cm²·s·mbar)	1×10^8	1	1.152×10^9	7.471×10^6	5.161×10^7	1.749×10^{10}	2.052×10^{10}	5.149×10^{10}
g/(m²·24 h·mmHg)	8.681×10^{-2}	8.681×10^{-10}	1	6.486×10^{-3}	4.481×10^{-2}	1.517	1.782×10	4.472×10
lb/(ft²·h·atm) (see note 2)	1.339×10	1.339×10^{-7}	1.542×10^2	1	6.909	2.339×10^2	2.747×10^3	6.896×10^3
gr/(ft²·h·mbar) (see note 4)	1.937	1.937×10^{-8}	2.233×10	1.447×10^{-1}	1	3.388×10	3.975×10^2	9.980×10^2
gr/(ft²·h·inHg) = 1 perm	5.719×10^{-2}	5.719×10^{-10}	6.590×10^{-1}	4.275×10^{-3}	2.951×10^{-2}	1	1.174×10	2.948×10
Temperate g/(m²·24 h)	4.874×10^{-3}	4.874×10^{-11}	5.613×10^{-2}	3.641×10^{-4}	2.515×10^{-3}	8.514×10^{-2}	1	See note 3
Tropical g/(m²·24 h)	1.942×10^{-3}	1.942×10^{-11}	2.236×10^{-2}	1.450×10^{-4}	1.002×10^{-3}	3.392×10^{-2}	See note 3	1
NOTE 1 To convert units in the first column to the units shown in the heading, multiply by the factor given at the intersection of the appropriate row and column.								
NOTE 2 This was the term used by the building industry.								
NOTE 3 No conversion from temperate to tropical is shown for the reasons given in clause 47 of BS 2972:1989.								
NOTE 4 The symbol “gr” refers to grains (1 gr = 15.4 g).								