ENGINEERING STANDARD

FOR

THERMAL INSULATIONS

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1. SCOPE

This Engineering Standard covers the minimum requirements for thermal insulation of pipework, vessels, tanks and equipment in the temperature range of -100°C to +650°C but excludes structural insulation of buildings, fire proofing structures, refractory lining of plants and all external underground mains.

On the basis of the temperature the thermal insulating is divided into two different systems as follows:

a) Hot system, which is applicable in the temperature range of +5°C to 650°C.
b) Cold system, which is applicable in the temperature range of -100°C to +5°C.

The Standard is intended for use in the oil, gas and petrochemical and similar industries mainly for refineries, chemical and petrochemical plants and gas plants.

The Standard gives minimum requirements for insulation system, including insulation materials of sufficient quality and thicknesses, weather proofing and finishing.

Finally discussion is given on the design basis of thermal insulation including selection of system and, corrosion under thermal insulation and general application of insulation. Also characteristics and selection of insulation and accessory material have been presented.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor.

BSI (BRITISH STANDARD INSTITUTION)

BS 5970 (1981)	"Code of Practice for Thermal Insulation of Pipework and Equipment (in the Temperature Range -100°C to +870°C)"
BS 5422 (1990)	"Specification for the Use of Thermal Insulating Material"
BS 2654 (1989)	"Manufacture of Vertical Steel Welded Non-Refrigerated Storage Tanks with Butt Weld Shell for Petroleum Industry"
BS 4275	"Recommendation for the Selection and Maintenance of Respiratory Protective Equipment"

IPS (IRANIAN PETROLEUM STANDARD)

E-TP-100	"Paints"
E-TP-101	"Surface Preparation"
C-TP-701	"Installation of Thermal Insulation"
M-TP-710	"Thermal Insulation Materials"

3. DEFINITIONS AND TERMINOLOGY

- Aluminum foil

Thin sheet of rolled aluminum (0.15 mm thick and under).

- Asbestos

The generic name for those silicate minerals that cleave naturally into fibers, the three important forms being chrysotile (white asbestos), crocidolite (blue asbestos), and amosite.

- Blanket

Insulation of the flexible type, formed into sheets or rolls, usually with a vapor-barrier on one side and with or without a container sheet on the other side.

- Block (Slab)

Rigid or semi-rigid insulation formed into sections, rectangular both in plan and cross section usually 90-120 cm long, 15-60 cm wide and 2.5-15 cm thick.

- Board

Rigid or semi-rigid insulation formed into sections, rectangular both in plan and cross section, usually more than 120 cm long, 60-75 cm wide and up to 10 cm thick.

- Calcium silicate insulation

Hydrated calcium silicate with added reinforcing fibers.

- Canvas

A closely woven fabric of cotton, flax, hemp, or jute characterized by strength of firmness.

- Cellular glass (foamed glass)

A lightweight expanded glass with small cells, preferably non-intercommunicating, produced by a foaming process.

- Ceramic fiber

Fibrous material, loose or fabricated into convenient forms, mainly intended for use at appropriate elevated temperatures. The fibers may consist of silica (SiO_2) or of an appropriate metal silicate, e.g., alumino-silicate. Alternatively, they may be formed synthetically from appropriate refractory metal oxides, e.g., alumina, zirconia.

- Cork board

Performed material composed of granulated cork bonded by heating under pressure, with or without added adhesive.

- Expanded metal

Metal network made by suitably stamping or cutting sheet metal and stretching it to form open diamond-shaped meshes.

- Expansion joint

An arrangement in an insulation system to minimize the risk of cracking due to thermal movement.

- Fibrous insulation

Insulation constructed from fiber, naturally occurring or manufactured that incorporate single or composite filaments generally circular in cross section and length considerably greater than the diameter.

- Flexible insulation

A material that tends to conform to the shape of the surface against which it is laid, or is so designed as to alter its manufactured shape to accommodate bends and angles.

- Foamed in-situ plastics

Cellular plastics produced in situ and foamed by physical or chemical means.

- Glass cloth

Fabric woven from continuous filament or staple glass fiber.

- Glass fiber (Glass wool)

Mineral fiber produced from molten glass.

- Lacing wire (Tie wire)

Light gage wire, single or multistrand, used for lacing together adjacent edges of mattresses or of metal covering, or for securing insulating material on substantially flat surfaces.

- Lags

Preformed rigid insulation for longitudinal application to cylinders larger than those for which pipe section are available. There are three types as follows:

a) Plain lags

Lags having rectangular cross section, for use on cylinders of such diameter that this shape conforms sufficiently closely to the surface.

b) Bevelled lags

Lags similar to plain lags, but with one or more edges bevelled.

c) Radiused and bevelled lags

Bevelled lags with faces curved to fit the surface of the cylinders (sometimes known as curved and bevelled lags).

- Loose-fill insulation

Material in the form of powder, granules, foamed, expanded or exfoliated aggregate or loose or pelleted fibers, used in the dry state as a filling for cavities, casings or jackets.

- Mastic

A relatively thick consistency protective finish capable of application to thermal insulation or other surfaces, usually by spray or trowel, in thick coats, greater than 0.75 mm.

- Mattress

A flexible construction comprising an insulating material faced on one side or both sides, or totally enclosed with fabric, film, paper, wire netting, expanded metal or similar covering attached mechanically to the insulating material.

- Metal cleading / jacketing

Sheet metal fitted as a protective finish over insulation.

- Mineral fiber

A generic term for all non-metallic inorganic fibers.

- Mineral wool

A generic term for mineral fibers of a woolly consistency, normally made from molten glass, rock or slag.

- Mitred joint

A joint made by cutting (mitring) preformed pipe sections to fit around bends in a pipeline.

- Pipe sections

Sections of insulating material in cylindrical form suitable for application to pipes.

- Plastic composition

Insulating material in loose, dry form, prepared for application as a paste or dough by mixing with water, usually on site, and normally setting under the influence of heat applied to the internal surface.

- Preformed insulation

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

- Rock wool

Mineral wool produced from naturally occurring igneous rock.

- Securing bands

Bands of metal (suitably treated as may be necessary to minimize corrosion), or of plastics material, used for securing insulation to pipes or other structures.

- Self-setting cement

Finishing material, based on Portland cement, that is supplied as a dry powder and, when mixed with water in suitable proportions, will set without the application of heat.

- Sprayed insulation

An adherent coating of insulating material.

- Thermal conductivity

The thermal transmition through unit area of a slab of a uniform material of unit thickness when unit difference of temperature is established between its faces [W/(mK)].

- Thermal insulation

A material or system that has the property of resisting the transfer of heat.

- Vapor barrier

A vapor check with water vapor permeance not exceeding 0.067 g/(s MN), when tested in accordance with BS 2972.

- Weather barrier (weather coat)

A material or materials which when installed on the outer surface of thermal insulation, protects the insulation from the ravages of weather, such as rain, snow, slect, wind, solar radiation, atmospheric contamination, and mechanical damage.

4. PURPOSE OF THERMAL INSULATION

Thermal insulation may be applied for one or combination of the following purposes.

4.1 Saving of energy by reducing the rate of heat transfer.

4.2 Maintenance of process temperature.

4.3 Prevention of freezing, condensation, vaporization or formation of undesirable compounds such as hydrates.

4.4 Protection of personnel from injury through contact with equipment.

4.5 To prevent condensation on surface of equipment conveying fluids at low temperature.

4.6 To avoid increasing the temperature of equipment from outside fire.

4.7 To conserve refrigeration.

5. DESIGN

5.1 Exchange of Design Data

5.1.1 Information to be supplied by the purchaser

The purchaser should state either:

a) Precise details of the insulation requirements; or

b) the service conditions for which the insulating materials are required so that the insulating contractor can make recommendations.

In the case of (b) the Purchaser should provide the relevant information detailed in 5.1.1.1 and 5.1.1.2.

5.1.1.1 Details of plant to be insulated

a) Location

Whether indoors, outdoors but protected, outdoors exposed to weather, enclosed in ducts or trenches below ground level, under ground and under water.

b) Difficult or unusual site conditions that will influence the selection or application of insulating materials, or both, e.g., in regard to transport, scaffolding, weather protection or excessive humidity.

c) Type of material to be insulated, with details of special or unusual materials.

d) Dimensions of surfaces

If these are adequately detailed on drawings, preferably colored to indicate areas to be insulated, the provision of copies of the drawings may be sufficient; otherwise detailed information will be required, e.g.:

- Surface dimensions of flat or large curved areas;
- external diameters of pipes;
- lengths of each size of pipe;
- number and type of pipe fittings, e.g., flanged joints, valves, tees, expansion bends.

e) Details of any pipework sections that are to be trace heated, of the trace-heating method and of the arrangements of insulation required.

f) Details of any sections to be left uninsulated to facilitate testing, e.g., welded and flanged joints.

g) Confirmation, with details, that heat will be available in insulated pipework for drying out any plastic insulating material or finishing composition used by the contractor.

5.1.1.2 Temperature conditions

a) Normal working temperature for each portion of the plant to be insulated.

b) Maximum temperature for each hot surface, if higher than (a).

c) Ambient temperature

Where a specified temperature is required on the outer surface of the insulation (see Note 1) it may be necessary also to give the conditions of ambient air for which the surface temperature is to be calculated, e.g., velocity of air passing over the surface (see also Note 2).

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

Notes:

1) A specified temperature on the surface of the insulation may be required for the following:

a) To protect personnel, e.g., local insulation of hot pipes;

b) to provide local comfort condition's, e.g., at control panels and in operating galleries;

c) to provide a means of indicating the effectiveness of the insulation. This is deprecated, as the surface temperature will depend upon the diameter over the insulation, on the ambient conditions, and on the nature of the outer surface. Pipes of small diameter will show relatively low surface temperatures, but high unit rates of heat loss; air flow over the outer surface will tend to reduce the surface temperature but will increase the unit rate of heat loss; a polished metal surface will show appreciable increase in surface temperature compared with a non-metallic finish although the unit rate of heat loss will be reduced.

2) Normally, the theoretical heat loss will be based on the manufacturer's declared value of thermal conductivity and, unless otherwise stated, it will refer to conditions of ambient still air at 20°C. When making use of these theoretical figures, therefore, allowance has to be made for the effect of the ambient conditions at site and for supplementary heat losses such as will occur through supports, hangers, valve control wheels and other fittings. It should be noted that "thermal efficiency" 5.4.5 is not included.

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

5.1.1.3 Preparation of surfaces (see IPS-C-TP-101)

Special requirements, e.g., for the removal of works-applied protective paint or lacquer, or for the application at site of paint or other protective coating to the surface to be insulated, should be clearly stated.

5.1.1.4 Types of fitting and supports

Types of fittings and supports (e.g., welded attachments, bolted fittings) and whether or not these are to be provided by the purchaser.

5.1.1.5 Type of insulation required

a) Main insulation for each portion of plant, e.g., preformed, plastic composition, flexible, loosefill, insulating concrete.

b) Insulation for bends, flanges, valves, hangers and other fittings.

5.1.1.6 Type of finish required

For example, hard-setting composition or self-setting cement, weatherproofing compound, sheet metal.

5.1.1.7 Special service requirements

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

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

For example:

a) Specified temperature on outer surface of insulation (see Note 1 to 5.1.1.2).
b) Specified heat loss per unit dimension, linear or superficial (see Note 2 to 5.1.1.2).
c) Economic thickness (see Note 1).
d) Specified conditions of temperature for the surfaces to be insulated (see Note 2).
e) Specified conditions of fluid at point of delivery.
f) Special thickness requirements.

Notes:

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

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

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

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

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

5.1.2 Information to be supplied by the manufacturer or contractor

a) Information pertaining to the relevant portions of 5.1.1.

b) The manufacturer's declared value of thermal conductivity (λ) appropriate to the temperature of use, plus the corresponding bulk density. The manufacturer's declared value should include any necessary commercial tolerances. When the thermal conductivity is liable to change on aging, the aged value should be stated.

c) Limitations of use, physical and chemical.

d) The overall thickness, with details of the thickness of the individual layers.

e) Information regarding the surface preparation.

f) The appropriate section of the code (to be specified) with which the following are in accord:

1) Insulating material.
2) Reinforcement (if any).
3) Fixing devices and finishes.

5.1.3 Drawings

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

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

5.2 Factors Affecting Planning and Programming

See IPS-C-TP-701.

5.3 Selection of Thermal Insulating Systems

5.3.1 Optimum effectiveness

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

5.3.2 Extent of system

A thermal insulating system shall be understood to include the following:

5.3.2.1 The required attachments to the surface to be insulated.

5.3.2.2 Means of securing the insulation system to those attachments, where appropriate, or to the surface directly.

5.3.2.3 The types and thicknesses of the insulating materials to be used.

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

5.3.2.5 Reinforcing materials.

5.3.2.6 Finishing materials.

5.3.3 General

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

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

5.3.3.1 Refrigeration (-100°C up to +5°C).

5.3.3.2 Chilled and cold water supplies, industrial use.

5.3.3.3 Central heating, air conditioning, and domestic hot and cold water supplies (10°C up to 200°C).

5.3.3.4 Process pipework and equipment (from ambient temperature up to 650°C).

5.3.3.5 Dual temperature systems, e.g., refrigeration with occasional use at higher temperatures.

5.3.4 Factors for consideration

The main controlling factors that shall be considered at an early design stage are outlined as following:

5.3.4.1 Temperature

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

5.3.4.2 Mechanical stability

The system, including the insulating material, the method of fixing, and the finishing material, has to be capable of giving effective service during the required life period of the installation. At all times the system shall have good resistance to vibration, mechanical damage and thermal movement, and it should retain its physical effectiveness and stability in service.

5.3.4.3 Resistance to degradation

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

5.3.4.4 Thermal effectiveness

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

5.3.4.5 Type and dimensions of the plant to be insulated

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

5.3.4.6 Compatibility of the components of the system

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

5.3.4.7 Total weight of the system

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

5.3.4.8 Potential hazard to health (see 7.1)

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

5.3.4.9 Corrosion hazard (see 5.7)

As no insulating materials, with the possible exception of multiple-foil stainless steel, are substantially free from soluble chlorides, adequate protective measures shall be adopted as an essential part of the insulation system when the surface to be insulated is sensitive to chloride attack, e.g., austenitic steels. In such cases these precautions may include covering the surface with aluminum foil, or treatment with suitable protective compound. (See IPS-E-TP-100.)

5.3.4.10 Fire hazard (see 7.1 and 5.4)

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

5.4 Design Considerations

5.4.1 General

Thermal insulation for plant and equipment is too often considered at so late a stage in the design and erection sequence that the insulation contractor has to submit a scheme under pressure of time. The ultimate cost of insulation should be an important factor but it is by no means the only one and the designer will base his considerations on having the right material, in the right amount, and in the right place.

Purchase, delivery and application at the right time are not the main concern of this section but guidance is given for assessing the influence that design considerations will have on the choice of the right material in the right amount. It is unlikely that any problem will arise for which all the factors discussed here will need to be considered but every factor is dealt with in sufficient detail to ensure that it will be of practical value when required.

Followings are technical information to help when selecting the appropriate insulating system for most requirements.

5.4.2 Economic thickness

Where the sole object of applying insulation to a portion of plant is to achieve the minimum total cost during a specific period, the appropriate thickness is known as the economic thickness.

To some extent the relevant calculations are unsatisfactory as they relate only to money values rather than to the conservation of energy and they require assumptions that are mainly arbitrary. The principle is to find at what thickness further expenditure on insulation would not be justified by the additional financial saving on heat to be anticipated during the period (the "evaluation period"). An increase in the amount of insulation applied will raise the initial installed cost, but it will reduce the rate of heat loss through the insulation, so reducing the total cost during the evaluation period. (See Appendix A for calculation and 5.5 for relevant table under specific condition.)

5.4.3 Applications for which economic thicknesses are not appropriate

Technical requirements should take precedence over economic considerations when the insulating material is required for the following purposes.

5.4.3.1 To maintain fluid inside a plant system within specific temperature limits, e.g., refrigeration plant, or plant containing fluid of low "freezing point".

5.4.3.2 To ensure that a fluid in a pipe has specified physical properties at the point of delivery.

5.4.3.3 To avoid danger to personnel, e.g., from items of plant at low temperature, or items of plant carrying low-grade heat such as drains and waste gases.

5.4.3.4 To control thermal movement of items of plant, particularly those exposed to high temperatures.

5.4.3.5 To limit the temperature of portions of hot plant in order to avoid damage by excessive temperature.

5.4.3.6 To prevent condensation of moisture on the external surface of the insulation of "cold" plant, and to maintain the internal temperature of a system above a specified minimum in order to avoid corrosive attack, e.g., from condensation of acidic products resulting from the combustion of heavy fuel oil.

5.4.3.7 To improve ambient comfort conditions. (see 5.5 for relevant tables).

5.4.4 Effect of air spaces

An air cavity, bounded normal to the direction of flow of heat, can act as an insulating material, but its efficiency may vary in accordance with the influence of many factors, of which the following are the most important.

5.4.4.1 Width of the cavity between the boundary surfaces.

5.4.4.2 Extent of ventilation of the cavity.

5.4.4.3 Nature of the boundary surfaces.

5.4.4.4 Mean temperature of the boundary surfaces.

5.4.4.5 Effect of barrier sheets that may be interposed in the path of the flow of heat.

5.4.4.6 Orientation of the cavity.

5.4.5 Thermal efficiency

Thermal efficiency as applied to insulation does not represent a self-evident idea; it is not a question of energy being partly used constructively, and partly rejected or wasted. Nevertheless the term has had some popular use for a long time for expressing the effectiveness of some particular piece of insulation in preventing heat loss from some particular surface in given design conditions. Dimensions are not automatically defined, and this effectiveness of insulation, or thermal efficiency, may be written simply as the ratio

$$\frac{\textbf{heat flow without insulation} \ - \ \textbf{heat flow with the insulation}}{\textbf{heat flow without insulation}}$$

or expressed as a percentage.

This ratio has been used in specifications to instruct the designer or supplier what the insulation requirement is. It is unusual to define anything other than the supposed temperature of the hot surface and possibly the wind speed, and certainly not the many other factors that also influence the heat loss from a surface.

5.4.6 Specified conditions at the point of delivery

When it is necessary that a fluid shall emerge from a pipeline or duct system under specified physical conditions, the selection of insulating material and the thickness applied require special consideration that shall take into account the rate of mass flow and certain physical properties of the fluid to be conveyed through the system; economic considerations may well become of secondary importance.

5.4.7 Protection of boundary surfaces

Although the more conventional applications of insulating materials are concerned with restricting loss of heat to the surroundings or gain of heat from those surroundings, dependent on whether the ambient temperature is less or greater than that of the surface to be insulated, it may be necessary to apply insulating materials to an area of plant for other reasons, the principle ones being:

5.4.7.1 To control the extent of thermal movement of the portion of plant.

5.4.7.2 To protect the boundary material from excessively high or low temperatures.

5.4.7.3 To regulate the temperature of an area of plant to prevent deterioration.

5.4.7.4 To protect personnel.

5.4.8 Clearance between insulation and the surrounding surfaces

5.4.8.1 One of the chief problems when insulating complex plant is to provide for adequate access, and it is of prime importance that this shall be taken into account when designing the plant and pipe layout.

5.4.8.2 A minimum clearance of 25 mm beyond the full extent of thermal movement shall be allowed between insulated plant and structural or other insulated surfaces, except where the shielded depth is greater than 300 mm. In such cases, or where pipe banks against walls or ceilings are involved, the designer shall envisage the sequence of the fixing of the insulating material and its finish and shall make all necessary provision.

5.4.9 Provision for differential thermal movement

5.4.9.1 Hot surfaces

Due to the difference in expansion coefficients of metals and insulating materials it is necessary to make allowance for the differential movements between the hot surface, the insulant and the finish.

As a guide it is recommended that such allowances or expansion joints be inserted at the following intervals:

TEMPERATURE (°C)	SPACING INTERVALS (m)
Up to 200	5
200 to 300	4
300 to 400	2.7
Over 400	2

Above 250°C preformed sections or flexible insulation shall be applied in two layers and that joints in individual layers shall be staggered.

At the junction between preformed insulating materials and fixed steel work, the joint area shall be packed with mineral fiber to accommodate differential thermal movement. With a metal finish it is customary to fit sliding joints. When a plaster-type finish is applied, and expansion joint shall be provided by cutting at a circumferential joint in single layer or in the outer layer of a double-layer system. These joints shall be covered with mineral-fiber cloth, secured in place, or as a muff in the same way as at a flange. As a rough approximation, radial expansion of pipes and vessels covered with plaster-type finishes is acceptable without longitudinal expansion joints if the value of D x t is less than 250 for pipes or vessels up to 1.5 m in diameter over insulation or 500 if over 1.5 m. (D is diameter in meters and t is temperature in °C.)

5.4.9.2 Sliding and bellows expansion joints

The insulation shall not interfere with the operation of the expansion joints. For this reason, the bellows or joint is usually fitted with a metal cage, fastened at one end only, on which the insulation can be secured. Care shall be taken to see that mild-steel tie rods, etc., are not enclosed within the insulation where they may attain too high a temperature or cannot be adjusted.

5.4.9.3 Cold surfaces

Insulating materials for use at sub-ambient temperatures may have coefficients of thermal movement that not only vary with different materials, but also differ appreciably from the corresponding movements of the pipe or item of equipment to which they are fitted. In some cases the insulating material will be sufficiently compressible to accommodate this differential movement but, with long straight length at extreme temperatures or with non-compressible insulation, contraction joints will be required. These may take the form of a 12 mm gap in the insulation that is packed with a flexible insulation. Contraction joints shall be provided immediately below insulation support rings on vertical pipes and at suitable intervals on horizontal pipes. Joint intervals shall be chosen with due regard to the pipe and insulation materials and the operating temperature. The joints shall be covered with a preformed insulation vapor seal shall accommodate movement of this joint.

5.4.9.4 Plastics pipe

In the unlikely event that plastics pipe requires thermal insulation attention is drawn to the fact that the thermal expansion coefficients are generally much higher than those of metals.

5.4.10 Provision for preventing settlement and cracking

On vertical surfaces provision shall be made for insulation supports to take the dead weight of the insulation. These shall project halfway through the insulation thickness or in the case of multilayer work to a line halfway through the thickness of the outer layer. These supports may take the form of flat bars, angles or studs as appropriate (see 7.2.3.3.). Preferably, provision should be made for tying back any reinforcement for the finishing cement.

Clay-based compositions, bitumen emulsions and other similar finishes shall only be applied to "hot" plant when heat is available for drying out the whole insulation from within.

5.4.11 Insulation of pipes in ducts and subways

5.4.11.1 Pipes in internal ducts and trenches are normally insulated after hydraulic testing and, in the case of pipes for heating services, before heating is commenced; therefore plastic insulation is not normally used.

5.4.11.2 Insulation is recommended for steam, condensate, heating and hot-water supply mains, in order to conserve heat and to avoid high ambient temperatures. It is not usually necessary to insulate cold water pipes, fire mains, etc., against frost when they are enclosed in a duct, unless insulation is required to prevent surface condensation. The formulae given in Appendix B are applicable for heat-transfer calculations.

5.4.11.3 To prevent condensation of moisture, chilled-water and refrigeration pipes will generally require insulation and adequate vapor seal.

5.4.11.4 For hot-water heating, and for steam, hot-water and cold-water services, effective insulation can be provided by using preformed or flexible insulating materials.

5.4.11.5 For internal ducts where the pipes are hidden from sight, it may not be necessary to apply further finish; where a neater appearance is required it may be advisable to finish with textile fabric or with a thin sheet material. Painting of the finished surface may be necessary, and identification can be provided in accordance with IPS-E-TP-100.

Note:

Where pipes are to run underground external to buildings consideration shall be given not only to the insulation required but also to the protection necessary to prevent the penetration of ground water to the insulating material and the pipe.

Advice should be sought on the extent of water penetration so that consideration can be given to the protection methods to be used for protecting the insulation.

5.4.12 Fire hazards

Not all the thermal insulating materials in common use are non-flammable. Some of them, often used for refrigeration systems, are entirely of organic composition and thus may constitute a fire hazard, or they may emit smoke and toxic fumes.

Designers of thermal insulation systems shall 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 shall vary their choice of material accordingly.

5.4.13 Insulation against freezing

5.4.13.1 There is no known insulation that will prevent freezing of liquid in pipes and vessels under all conditions. If the outside temperature remains low enough for long enough, and the movement of liquid through the pipe or vessel is slow, then no insulation, however thick, will prevent internal freezing.

5.4.13.2 Insulation will retard the onset of freezing and if the intervals during which the liquid is static are short enough freezing may be avoided. If more heat is supplied from the liquid passing through the system than is lost through the insulation together with the associated losses through supports and hangers, freezing can be avoided.

5.4.13.3 When fluids are static in pipes or vessels and the ambient temperate is below the freezing point of the contained fluid, the only sure way to prevent freezing is to supply heat to the system, e.g., by means of tracer pipes or electric heating elements, which should be fitted before the particular item of plant is insulated. The amount of heat thus supplied per unit period of time shall be sufficient to replace that lost from the system during the same period. Each problem of insulation against frost conditions shall receive individual consideration, and due regard shall be paid to the climatic conditions of the area concerned.

5.4.14 Protection against surface condensation

5.4.14.1 Condensation takes place on piping and equipment held at temperatures below the dew point of the ambient air.

5.4.14.2 Although the application of the insulation can prevent condensation at the surface, it will not necessarily prevent the moisture being drawn through the insulation itself, and frequently the dew point will be reached at some distance inside the layer of insulation. It is therefore imperative that a vapor barrier be applied on the warm side on the insulation layer. If an insulating material is applied to a cold surface in humid conditions without a vapor barrier, the insulation can become saturated, its heat-insulating properties impaired and also, probably, its mechanical strength. If the cold surface is at a temperature lower than freezing point, the moisture will freeze and tend to rupture and break away the insulation.

5.4.14.3 The object of the vapor barrier is to prevent ingress of moisture. It may be desirable that the thickness of insulation be chosen so that the outside surface temperature of the insulation remains above the dew point. This requirement tends to increase the thickness above the range normally considered for hot insulation work. An adequate space shall be provided for the extra thickness, and due regard should therefore be given to the spacing of pipes and equipment to allow room for insulation.

5.4.14.4 Certain cold-insulation materials have in themselves a high resistance to the passage of water vapor, even so they will require a vapor seal, and all joints have to be adequately sealed.

5.4.14.5 To avoid condensation on plant situated out of doors, the finish has to be vaporproof as well as weatherproof and it shall be remembered that watertight coatings are not necessarily vaportight.

5.4.15 Vapor barriers

Information and recommendations on vapor barriers are given in 5.4.15.1 to 5.4.15.15 but, because of lack of precise knowledge and because of variations in practical application, any quantitive recommendations are to be taken as approximate guidance only.

5.4.15.1 The ability of air to hold water in the vapor phase is reduced as the temperature decreases, the vapor condensing when the temperature falls to the dew point; the saturation vapor pressure of water in the atmosphere increase with increase in temperature.

Where the 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-vapor pressure differential across the insulation. This differential will tend to force the vapor towards the cold surface of the plant where it will condense and, if the temperature is below freezing point, the condensed water will turn into ice.

5.4.15.2 As a rough guide, the thermal conductivity of water is about three times that of a typical good quality dry insulating material, and that of wet ice may be up to twenty 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 mechanical structure of the material.

5.4.15.3 Insulating materials that consist substantially of closed cells possess an inherent resistance to the passage of water vapor, but open-cell insulants and loosefill porous materials are readily permeable to water vapor.

Even with materials that have good resistance to the transmission of water vapor, 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 also may fail to exclude water vapor completely, in which case the contained water or ice may form strongly conducting paths from the surface of the plant to the ambient air.

5.4.15.4 As a general rule, all insulation on plant working at sub-ambient temperatures shall have a "vapor barrier" layer over the outer (warm face) surface. This barrier shall be resistant to the passage of water vapor and it shall be applied to the dry insulation immediately the latter has been fitted and before the plant is cooled.

The effectiveness of the vapor barrier is expressed in terms of the rate at which water vapor is transmitted through it under defined conditions, i.e., by a "permeability" figure or a "permeance" figure. 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. SI Units are:

Permeability:

Grams per second per meganewton vapor pressure difference, for one meter thickness: gm/(s MN).

Permeance:

Grams per second per meganewton vapor pressure difference: g/(s MN).

It shall be noted that 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 vapor-barrier layers are given in Table 1.

TABLE 1 - TYPICAL VALUES FOR WATER-VAPOR PERMEANCE

MATERIAL	APPROXIMATE THICKNESS	PERMEANCE (MAXIMUM) (FOR CONVERSION FACTORS SEE APPENDIX D)
Water-based emulsions	mm	g/(s MN)
Polymeric mastic emulsion	1.6	0.029
Bitumen emulsion, mineral	3.2	0.046
Bitumen emulsion, fibrated	3.2	0.005
Rubber latex/bitumen emulsion	3.2	0.003
Solvent-based "CUT-BACKS" and resins		
Asphalt mastic	3.2	0.0006
Polymeric mastic	3.2	0.0025
Polymeric mastic	0.5	0.017
Bitumen mastic	3.2	0.0008
Epoxide resin	0.5	0.003
Elastomer-based mastic	1.6	0.0035
Miscellaneous		
Aluminum foil/kraft paper laminate (0.009 mm foil)		0.0024
Aluminum foil/kraft paper laminate (0.018 mm foil)		0.0008
Bitumen-impregnated tape	2.0	0.0057
PVC tape (self-adhesive)	0.18	0.068
PVC tape (self-adhesive)	0.25	0.057
Aluminum foil (self-adhesive), plain or reinforced	0.018	0.0008
Polyethylene sheet	0.05	0.004

5.4.15.5 Essentially, the vapor pressure of the ambient air will depend on the actual moisture content, which may be related to the combined effects of the dry bulb temperature and the percentage relative humidity at the particular barometric pressure. Thus, for example, air at 20°C (dry bulb) and 52.6% rh will exert approximately the same pressure (1230 N/m²) as air at 10°C and 100% rh (i.e., saturated); the dew point in each case will be 10°C and the actual moisture content will be approximately 0.00767 kg/kg dry air. These figures are for a barometric pressure of 1013 m bar.

If now we assume the insulated cold metal surface to be at a temperature of -17°C the vapor pressure at that surface would be 125 N/m² so that, for ambient air as above, the vapor pressure difference would be (1230-125) 1105 N/m² approximately.

5.4.15.6 Even a good-quality vapor barrier is not likely to exclude water entirely, although it will diminish the rate of water-vapor penetration proportional to its permeance value. In essence, only the time factor will be relevant; ultimately the insulation will become wet if the plant is maintained at a low temperature for long enough.

It is necessary to distinguish between the behavior of insulation and vapor barriers over porous structures, e.g., non-metallic walls, and the corresponding behavior over non-porous surfaces, e.g., metallic pipework and vessels.

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 the other hand, with insulated metal surfaces condensed moisture tends to remain at the cold surfaces 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 may evaporate later, in which case it may be satisfactory either to apply a "breather coat" to the outer surface, or even to dispense with the vapor barrier completely. If, however, the condensation is likely to be of long duration it will be essential to apply an efficient vapor barrier.

As an example, based on a permeance of 0.001 g/(s MN) for the vapor barrier and assuming a vapor pressure difference of 1105 N/m² as in 5.2.15.5 one could expect a rate of accumulation of water within the insulation in total of 0.095 N/m² per 24 h, or approximately 34.7 g/m² per year. With insulation of inherently low permeance, it may be convenient to apply a vapor barrier of higher permeance than would apply otherwise if, by doing so, superior mechanical resistance and easier application is achieved; in correct methods of application can spoil otherwise good-quality vapor-barrier materials. For very low temperatures, the use of multiple vapor barriers may be justified.

5.4.15.7 For refrigeration work it is preferable that the vapor-barrier layer shall 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 or vinly-acrylic copolymer, as a protective layer over a more vulnerable barrier material. This outer finish conveniently could be suitable for the final application of a high-gloss white paint to reduce solar absorption. Alternatively, polished metal sheet may be applied as protection over a vulnerable vapor-barrier coat or film. Care shall be taken to ensure that the vapor-barrier does not add seriously to the fire hazard of the complete system.

5.4.15.8 The compatibility of the vapor-barrier material with the chosen insulation shall be established, e.g., solvent-based materials shall not be used directly over polystyrene.

5.4.15.9 Materials suitable for use as vapor barriers are as follows.

5.4.15.9.1 Wet-applied vapor-barriers comprise cut-back bitumens, bitumen emulsions with or without elastomer latex, vinyl emulsions, and solvent-based polymers. Frequently these are reinforced by means of cotton scrim cloth or open-mesh glass fabric.

5.4.15.9.2 Glass fabric or hessian sheet or tape, impregnated with lanolin or petroleum jelly, can be used, especially where removable insulation and finish is required.

5.4.15.9.3 Elastomer sheets provide for contraction and other movements whilst maintaining good resistance to the transmission of water vapor; joints shall be sealed with an appropriate adhesive and the overlaps shall be of adequate dimensions.

5.4.15.9.4 Polyvinyl chloride, polyethylene, polyisobutylene, or other plastics tapes or sheets are of special value for wrapping bends on insulated pipes, or where a colored descriptive finish is required.

5.4.15.9.5 Epoxy and polyester resins give good resistance against mechanical damage, together with protection against the weather and against chemical finish.

5.4.15.9.6 Sheet metal can give good protection, provided that the joints are overlapped and sealed, with additional securing devices to maintain the system in vaportight condition.

5.4.15.9.7 Metal foils, if used alone, shall be sufficiently thick to exclude penetration by "pin holes", or they shall be laminated to building paper, building sheet or plastics film. The joints shall be of adequate overlap and they shall be sealed by a suitable waterproof adhesive or mastic.

5.4.15.10 It is important to note that under certain conditions trapped moisture in a construction, e.g., in a cavity, may be allowed to vent or disperse by the use of a so-called "breather material". This is a material that will permit the passage of water vapor but not of liquid water. There are two essential types: the first an aqueous emulsion coating and the second a breather paper. Cut-back dispersions, elastomer sheets and metal sheet do not permit "breathing".

5.4.15.11 Frequently, circumstances will arise when a flame-resisting finish is required over insulation for "cold work". The choice shall be made from sheet metal, a fire-resistant mastic, and a normal type of vapor barrier super-coated with a self-setting mineral-fibred cement, reinforced as may be necessary. Under certain conditions, an outer finish of sheet metal may cause hazard by preventing easy access for fire suppression if ignition should occur in the main layer of insulating material.

5.4.15.12 Before the vapor barrier is applied, the insulation shall be smooth, regular and even. All internal and external corners shall be rounded off.

5.4.15.13 Where possible, supports for pipes and vessels shall be external to the insulation and the vapor barrier. Where this is not possible the vapor barrier shall be returned to the support and effectively sealed. Where insulation is required to be removable, e.g., at flanged joints, manholes, etc., the main insulation shall be cut short of the fitting and the vapor barrier shall be sealed directly to the pipework or shell of the vessel. The removable portion of the insulation shall then be fitted as a separate item, with its vapor barrier overlapping and being sealed to the main vapor barrier.

5.4.15.14 Where the operating temperature of the plant may cycle above and below that of the ambient air, it is more difficult to design an effective vapor barrier. If the period of operation below ambient temperature is short, or if the difference in temperature is small, it may be advisable to omit the vapor barrier and to use a porous coating that will permit evaporation of the condensed water when the temperature is raised; but this type of arrangement will result in low efficiency when the plant is working under cold conditions.

For operating conditions where the temperatures of cycling involve wide fluctuations it may be advantageous to use multilayer insulation with a vapor barrier over each layer. Each vapor barrier shall be returned over the edges of the insulating material to the metal surface of the pipe or vessel, and sealed to each other at regular intervals so that the individual layers of insulation are enclosed in separate compartments. With this type of arrangement the correct selection of material for the various vapor barriers may be critical on account of possible restriction by limiting temperatures.

5.4.15.15 As a general rule, a vapor barrier will be required over the insulation on all plant working at temperatures below the relevant "dew point" of the ambient air. (See Appendix D, Fig. 1.)

Pipework and equipment essentially provides a non-permeable base surface that, if excessive accumulation of water is to be avoided, theoretically will require the lowest possible permeance for an insulation system. However, constraints such as flammability, durability and chemical resistance will often preclude the selection of components with the lowest water-vapor permeance. Field experience often shows that a suitable selection of mastics and coating compounds, in conjunction with insulating materials of adequately low permeance rating, can give good practical service, provided that they are associated with good joint-sealing technique and, especially for very low temperatures, with the use of mild-layer sealants or vapor barriers. The lower portions of the shaded zone will be appropriate where membrane, sheet or laminated vapor-barrier materials are installed, or where the insulating material is of relatively high permeability. With systems of this type it is necessary to ensure that there is adequate sealing and protection against mechanical damage under service conditions, with ample allowance of safety factors.

5.4.16 Mechanical design must incorporate insulation requirements for preventing water ingress such as: (See BS 2654, Appendix B for recommendations for the design and application on insulation.)

- A continuous welded water-retaining collar shall be installed around all protruding parts of vessels and columns. These collars shall be included in the manufacturer's drawings.

- Edges of tank roofs shall be provided with rainwater shields.

- Handrailings on insulated tank roofs shall be installed at the side of the roof edge instead of on top of it.

- The number of supports and fixings penetrating the insulation shall be reduced to an absolute minimum.

- Fixings to walls and roofs shall be of round shape (pipe) instead of an angle steel and shall be installed with a slight outward slope.

- Angle steel used as vacuum/compression rings of columns shall be installed with the vertical part downwards.

- Valves and flanges shall be located in the horizontal part of pipelines instead of the vertical.

- Nameplates shall not interfere with insulation and shall be relocated.

- Installation of gratings on top of columns, vessels, tanks and over piping, where applicable, to avoid damage to insulation.

5.4.17 Care shall be taken to avoid contact between dissimilar materials which might cause galvanic corrosion.

5.4.18 Studs, pins, clips, or other attachments shall not be field welded to the postweld heat treated vessels (including tanks) or piping without written authorization by employer.

5.4.19 Expansion and contraction joints shall be provided below vessel insulation support rings and in piping as required. Contraction joints on cold piping shall be at flanged joints if possible.

5.4.20 A summary of the insulation requirements for equipment on hot service and cold service are given in Tables 2 and 3 respectively.

TABLE 2 - SUMMARY OF INSULATION REQUIREMENTS FOR EQUIPMENT ON HOT SERVICE

TYPE OF EQUIPMENT	FORM OF INSULATION	FINISH	INSULATION SUPPORTS
Storage tanks shells only	Slab, mattress or foamed in situ plastics	Corrugated or plain metal sheet	Welding studs, pins, or self support cage
Spheres	"	Plain metal sheets, or hard setting compound	"
Vessels, vertical	Slab or mattress	Corrugated metal sheet	Support rings 12" max. vertical pitch, studs, lugs, cage
Vessel, horizontal	"	Plain or reeded metal sheet	Studs, lugs, cage if required
Vessel, sheltered	"	Hard setting compound or sheet metal	"
Mainhole covers Exchanger ends	Insulation slab or blanket completely enclosed in a metal skin		Lugs if required
Piping, vertical	Rigid sections, lags, or mattress	Plain or reeded metal sheet	Rings or lugs, 12" max. vertical spacing
Piping, horizontal	"	"	Nil for rigid sections, rings or lugs for mattress
Piping, sheltered	"	Hard setting compound or sheet metal	"
Bends	Rigid sections and lags	Metal sheet or hard setting compound	Rings and lugs
Steam valves and flanges external	Box packed with insulation, strip wrap, blanket	Fabricated removable box, moulded box	Self fixing
Steam valves and flanges sheltered	"	" , or sewed canvas	"
Valves, oil	Nil	Nil	Nil

TABLE 3 - SUMMARY OF INSULATION REQUIREMENTS FOR EQUIPMENT ON COLD SERVICE

TYPE OF EQUIPMENT	FORM OF INSULATION	FINISH	INSULATION SUPPORTS
Storage tanks Spheres Spheres (LPG)	Slab, block or foamed in situ plastics " Block	Corrugated or plain metal sheet or mastic Plain metal sheets, or mastic Reinforced mastic	Self support cage, bands " Adhesive and bands
Storage tanks (double walled)	Loose fill (dry inert gas pressurised)	"	"
Vessels, vertical Vessel, horizontal Vessel, sheltered	Slab block or foamed in situ plastics " "	Plain or reeded metal sheets, mastic " "	Self support cage or bands " "
Manhole covers, exchanger ends, valves & fittings	Slab, loose fill or foamed in situ in removable or mouldable box	Metal sheet or mastic	
Piping, vertical Piping, horizontal Piping, sheltered	Slab sections, pre-insulated foamed in situ " "	Plain metal sheets; mastic " Hard setting compound	Rings 12" max. vertical spacing; bands Bands "

In all cases a vapor seal is required over the insulation.

5.5 Thickness of Insulation

5.5.1 The required thickness of insulation for any specific application depends upon the characteristics of the insulating material and the purpose of the equipment. When the sole object is to achieve the minimum total cost, the appropriate thickness is known as the economic thickness. If the economic thickness is required to be calculated the following additional information will be necessary:

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

5.5.2 Economic thicknesses for process pipework and equipment of hot insulation for various ranges of operating temperature and varieties of thermal conductivity are given in Table 4. The method used to derive Table 4 was the algebraic solution method A.3 of Appendix A and for the assumption of calculation. See BS 5422, Section 7.

5.5.3 If the designer requires that the economic thickness be determined for the conditions other than those used in Table 4, the calculation shall be in accordance with Appendix A.

5.5.4 When the base of insulation is conservation of energy the generally accepted insulation thicknesses given in Tables 5a for calcium silicate and 5b for mineral wool shall be used.

5.5.5 Appendix B gives the equations for heat transfer through flat and cylindrical insulation which relates heat flow to the insulation thickness. If the designer wishes the insulation thickness for energy conservation to be calculated for a specific conditions or different insulation materials these equations may be used.

5.5.6 Insulation thickness for personnel protection:

If economic thickness is used for hot insulation, the thicknesses given in Table 4 is sufficient for personnel protection. When the base of insulation is energy conservation, the thicknesses given in Tables 6a for calcium silicate and 6b for mineral wool shall be used.

5.5.7 The required thickness of insulation for cold services to prevent condensation on the outer surface of Insulating material shall be as given in Tables 7 and 8 for foam glass and polyurethane respectively under the stated condition of ambient temperature, relative humidity and emssivity of external surface. If the ambient conditions are different from those stated in Tables 7 and 8 the thicknesses shall be calculated in accordance with Appendix C.

5.5.8 Piping which are heat traced shall be insulated with oversizepipe insulation to include the tracer lines (see IPS-C-TP-701). Valves, flanges union and tracer line loops shall not be insulated, unless specified on the piping spool drawings. The thickness of insulation shall be in accordance with Table 9.

5.5.9 The thicknesses given in the Tables do not include the cleading or finishing, the insulation of which is neglected.

5.5.10 Where proved to be more economical, the insulation should consist of two or more layers of dissimilar approved materials provided their respective service temperature limits are appropriate for the duty. Multi layer insulation shall have the inner layers banded or taped to the pipe or equipment.

TABLE 4 - ECONOMIC THICKNESS OF INSULATION FOR PROCESS PIPEWORK AND EQUIPMENT

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)														
	+100					+200					+300				
	Thermal conductivity at mean temperature (in W/(m-k))														
	0.02	0.03	0.04	0.05	0.06	0.03	0.04	0.05	0.06	0.07	0.03	0.04	0.05	0.06	0.07
	Thickness of insulation (in mm):														
17.2	28	31	35	38	41	45	49	52	56	59	52	57	61	66	70
21.3	29	37	37	40	43	46	50	54	58	62	55	60	65	70	74
26.9	31	35	39	43	46	50	54	59	63	67	59	64	69	74	78
33.7	33	36	40	44	48	52	56	61	65	69	61	66	72	77	82
42.4	36	40	45	49	53	56	61	67	72	77	67	73	79	84	90
48.3	38	42	47	51	55	59	64	70	75	80	70	77	82	88	95
60.3	41	45	50	55	59	63	69	75	81	86	76	82	89	96	102
76.1	42	47	52	57	62	67	73	79	85	90	78	86	94	101	107
88.9	44	49	54	59	64	70	76	82	89	94	83	90	98	105	112
101.6	45	50	56	62	66	73	79	85	91	97	85	93	101	109	116
114.3	46	52	57	63	68	76	80	87	93	99	87	95	103	111	118
139.7	49	54	60	66	71	78	84	92	99	105	94	102	110	118	125
168.3	52	58	64	70	76	83	90	98	105	111	101	107	117	126	134
219.1	54	60	67	74	80	87	95	104	112	119	105	114	124	133	142
244.5	55	62	69	76	82	89	98	106	115	122	108	117	127	137	146
273	56	64	71	78	84	94	100	110	118	126	113	120	132	142	151
323.9	58	66	73	80	86	94	104	114	123	132	115	123	135	145	154
355.6	59	67	74	81	88	97	107	116	125	134	116	125	137	147	156
406.4	62	69	76	83	90	100	109	118	127	136	118	128	140	150	159
457	63	70	77	84	91	102	111	120	129	138	121	132	144	154	163
508	65	72	79	86	93	105	114	123	132	141	124	134	146	156	165
Over 508 & including flat surfaces	72	78	87	96	105	113	124	133	142	151	127	137	151	161	170

Note:

These thicknesses are sufficient for personnel protection.

(to be continued)

TABLE 4 - (continued)

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)																			
	+400					+500					+600					+700				
	Thermal conductivity at mean temperature (in W/(m-k))																			
	0.04	0.05	0.06	0.07	0.08	0.05	0.06	0.07	0.08	0.09	0.06	0.07	0.08	0.09	0.10	0.07	0.08	0.09	0.10	0.11
	Thickness of insulation (in mm):																			
17.2	64	69	74	79	83	70	81	86	91	95	89	93	98	103	107	99	104	109	114	119
21.3	68	73	78	83	88	81	86	91	96	101	93	98	103	108	118	105	110	115	126	125
26.9	73	78	83	89	94	87	92	98	103	107	100	105	110	115	120	113	118	123	128	133
33.7	76	81	87	92	97	89	95	100	106	111	103	108	114	119	124	116	121	127	132	137
42.4	83	89	96	102	107	99	105	111	117	123	114	120	126	132	137	128	134	140	146	152
48.3	87	93	100	106	112	103	109	116	122	128	119	125	132	138	143	134	140	146	152	158
60.3	94	101	108	115	121	111	118	125	132	138	128	135	142	149	156	144	151	158	165	172
76.1	99	106	114	121	127	117	124	132	139	146	135	142	149	156	163	152	159	166	173	180
88.9	103	110	118	126	133	123	130	138	145	152	141	148	156	163	170	159	166	174	181	189
101.6	106	114	123	130	136	126	134	142	150	157	145	153	161	169	177	164	172	180	187	195
114.3	109	116	126	133	140	129	137	145	153	160	149	157	165	173	181	167	175	183	191	198
139.7	116	124	133	141	149	136	146	155	163	171	158	167	176	184	190	179	187	195	204	211
168.3	124	132	142	151	159	147	156	165	174	182	170	178	188	196	205	191	200	209	218	227
219.1	130	140	151	161	171	156	166	176	186	195	180	190	200	210	220	203	213	223	233	243
244.5	135	145	156	165	175	161	171	182	192	201	186	196	206	216	226	210	220	230	240	250
273	139	149	160	170	180	166	176	188	198	207	191	202	213	224	235	217	227	238	248	258
323.9	142	153	164	174	184	171	181	193	202	212	196	207	218	229	240	223	233	244	254	264
355.6	146	157	168	178	188	177	185	197	206	216	201	212	224	235	245	230	240	251	261	271
406.4	149	160	171	181	192	181	189	202	213	223	207	218	230	241	252	234	245	257	269	279
457	153	165	176	187	196	187	196	209	220	231	213	225	236	250	261	242	254	266	278	289
508	155	168	179	191	202	191	200	213	226	237	218	231	244	256	267	248	260	273	285	296
Over 508 & including flat surfaces	158	171	182	195	205	194	207	218	230	239	228	240	250	261	270	257	271	279	293	304

Note:

For thicknesses in bold type, the outside surface temperature is likely to exceed 50°C if a low emissivity surface is used, i.e., bright metal such as polished Aluminum.

These thicknesses are sufficient for personnel protection.

TABLE 5a - HOT INSULATION THICKNESS FOR HEAT CONSERVATION CALCIUM SILICATE CENTIMETERS

NOMINAL PIPE SIZE	TEMPERATURE °C									
	66 to 149	150 to 204	205 to 260	261 to 315	316 to 371	372 to 427	428 to 482	483 to 538	539 to 593	594 to 650
4 cm & under	3.8	3.8	5.0	5.0	5.0	6.4	6.4	6.4	7.6	7.6
5 cm	3.8	3.8	5.0	5.0	5.0	6.4	6.4	6.4	7.6	7.6
8 cm	3.8	3.8	5.0	5.0	6.4	6.4	7.6	7.6	9.0	9.0
10 cm	3.8	3.8	5.0	6.4	6.4	7.6	7.6	7.6	9.0	10.0
15 cm	5.0	5.0	6.4	7.6	7.6	10.0	10.0	10.0	11.4	11.4
20 cm	5.0	5.0	6.4	7.6	7.6	10.0	10.0	11.4	11.4	11.4
25 cm	5.0	5.0	7.6	9.0	10.0	11.4	11.4	12.7	12.7	12.7
30 cm	5.0	7.6	9.0	10.0	10.0	11.4	12.7	12.7	14.0	14.0
36 cm & over	7.6	7.6	9.0	10.0	11.4	12.7	14.0	14.0	15.2	15.2
Equipment	5.0	5.0	7.6	9.0	9.0	10.0	10.0	11.4	11.4	12.7

TABLE 5b - HOT INSULATION THICKNESS FOR HEAT CONSERVATION MINERAL WOOL SLAB CENTIMETERS

NOMINAL PIPE SIZE	TEMPERATURE °C								
	66 to 149	150 to 204	205 to 260	261 to 315	316 to 371	372 to 427	428 to 482	483 to 538	539 to 593
4 cm & under	3.0	3.0	4.3	4.4	4.7	6.4	6.7	6.8	8.7
5 cm	3.0	3.0	4.3	4.4	4.7	6.4	6.7	6.8	8.7
8 cm	3.0	3.0	4.3	4.4	6.0	6.4	7.9	8.1	10.3
10 cm	3.0	3.0	4.3	5.6	6.0	7.6	7.9	8.1	10.3
15 cm	3.8	4.0	5.5	6.7	7.1	10.0	10.4	10.7	13
20 cm	3.8	4.0	5.5	6.7	7.1	10.0	10.4	12.2	13
25 cm	3.8	4.0	6.5	7.9	9.3	11.4	11.9	13.6	14.5
30 cm	3.8	6.0	7.7	8.8	9.3	11.4	13.2	13.6	16
36 cm & over	5.8	6.0	7.7	8.8	10.6	12.7	14.7	15	17.3
Equipment	3.8	4.0	6.5	7.9	8.4	10.0	10.4	12.2	13

TABLE 6a - HOT INSULATION THICKNESS FOR PERSONNEL PROTECTION

	PIPE SIZE mm OD	INSULATION THICKNESS, mm TO 300°C	OVER 300°C
To	48.3	25	38
	60.3	25	50
	88.9	25	50
	114.3	25	50
	168.3	25	50
	219.1	38	50
	273.1	38	50
	323.9	38	50
	355.6 & over	50	50
	Vessels, pumps, exchangers, etc.	38	50

Notes:

1) The above Table is based on calcium silicate insulating material, with mean thermal conductivity of approximately 0.061 W/mK @ 93°C.

2) Insulation thicknesses stated here do not include the finishing or weatherproofing materials.

TABLE 6b - HOT INSULATION THICKNESS FOR PERSONNEL PROTECTION

PIPE SIZE mm OD		INSULATION THICKNESS, mm TO 300°C	INSULATION THICKNESS, mm OVER 300°C
To	48.3	22	43
	60.3	22	57
	88.9	22	57
	114.3	22	57
	168.3	22	57
	219.1	33	57
	273.1	33	57
	323.9	33	57
	355.6 & over	44	57
	Vessels, pumps, exchangers, etc.	33	57

Notes:

1) The above Table is based on Mineral Wool Insulating material.

2) Insulation thicknesses stated here do not include the finishing or weatherproofing materials.

TABLE 7 - COLD INSULATION THICKNESS FOR ENERGY CONSERVATION / CONDENSATION PREVENTION

Pipe or Equipment mm O.D.	Normal Insulation Thickness, mm										
	25	38	50	64	75	89	100	114	125	140	150
	Minimum Temperature, °C										
To 33.4	5	-12	-32	-54	-79	-107	-137	-176	-223		
48.3	7	-7	-34	-54	-73	-98	-129	-159	-198	-259	
60.3	7	-7	-21	-37	-57	-79	-104	-129	-159	-204	-251
88.9	10	-1	-15	[illegible]	-46	[illegible]	-84	-104	-134	-162	-196
114.3	10	-1	-12	-23	-40	-57	-73	-98	-121	-143	-171
168.3	13	4	-9	-21	-32	-48	-65	-82	-98	-118	-137
219.1	13	4	-7	-21	-32	-43	-57	-71	-87	-104	-123
273.1	13	4	-7	-15	-26	-37	-51	-65	-73	-93	-109
323.9	13	4	-4	-15	-23	-34	-48	-59	-73	-87	-104
355.6	16	7	-1	-12	-21	-32	-43	-54	-68	-82	-96
406.4	16	7	-1	-12	-21	-29	-40	-54	-65	-79	-93
457	16	7	-1	-9	-18	-29	-40	-51	-62	-76	-90
508	16	7	-1	-9	-18	-29	-37	-48	-62	-73	-87
610	16	7	-1	-9	-18	-26	-37	-48	-59	-71	-82
711	16	7	-1	-9	-18	-26	-34	-46	-57	-68	-79
813	16	7	-1	-9	-18	-26	-34	-46	-54	-65	-76
914	16	7	-1	-7	-15	-23	-34	-43	-54	-65	-76
1067	16	7	2	-7	-15	-23	-32	-43	-51	-62	-73
1219	16	7	2	-7	-15	-23	-32	-43	-51	-62	-71
1524	16	7	2	-7	-15	-23	-32	-40	-48	-59	-71
1829	16	7	2	-7	-15	-23	-32	-40	-48	-57	-68
2438	16	7	2	-7	-15	-21	-29	-37	-48	-57	-65
3048	16	7	2	-7	-15	-21	-29	-37	-46	-57	-65
3658	16	7	2	-7	-15	-21	-29	-37	-46	-54	-65
FLAT	16	10	2	-7	-12	-21	-26	-34	-43	-51	-59

Notes:

1) The table is based on cellular glass (foamglass) insulating material with a thermal conductivity of approximately 0.052 W/mK @ 10°C and 0.9 emittance.

2) The Table is based on 32°C ambient, still air, 80% relative humidity.

3) Insulation thicknesses stated here do not include the finishing or weatherproofing materials.

TABLE 8 - THICKNESS OF INSULATION FOR COLD SERVICES

NORMAL OPERATING TEMP.°C	+21 TO -18°C	-19 TO -29°C	-30 TO -40°C	-40 TO -51°C	-52 TO -73°C	-74 TO -101°C	-102 TO -129°C
OUTSIDE DIAMETER OF PIPE IN mm	INSULATION THICKNESS IN mm						
12.5	25	25	40	40	40	40	40
19	25	25	40	40	40	50	50
25.4	25	25	40	40	40	50	50
38	25	25	40	40	40	50	65
51	25	25	40	40	40	50	65
76	25	40	40	40	50	65	65
102	25	40	40	50	50	65	65
152	40	40	40	50	65	75	75
203	40	40	40	50	65	75	75
254	40	40	40	50	65	75	75
305	40	40	40	50	65	75	90
356	40	40	50	50	65	75	90
406	40	40	50	65	65	75	90
457	40	40	50	65	65	75	90
508	40	40	50	65	65	75	90
610	40	40	50	65	65	75	90
762	40	50	65	65	65	75	90
914	40	50	65	65	65	75	90
over 914	50	65	65	75	75	90	100

Condition:

Relative humidity:	80%
Ambient air temperature:	32°C
Wind velocity MPH:	Zero (air film resistance 0.61)
Surface temperature, min:	28.9°C
Material:	Polyurethane - K factor 0.019 W/M°C mean temperature 23.9°C

TABLE 9 - HEAT TRACED PIPE - INSULATION THICKNESS (mm)

Pipe	9.5 mm Tubing & Electric Cable		12.5 mm Tubing		19 mm Tubing & 21.3 mm Pipe		25 mm Tubing & 26.5 mm Pipe		33.4 mm Pipe	
O.D. (mm)	One Tracer	Two Tracer	One Tracer	Two Tracer	One Tracer	Two Tracer	One Tracer	Two Tracer	One Tracer	Two Tracer
21.3	25	31.75	31.75	31.75	50	50				
26.7	31.75	31.75	31.75	38	50	50				
33.4	38	38	38	50	50	63.5				
48.3	50	50	63.5	63.5	63.5	75				
60.3	63.5	63.5	75	75	75	75	75	90	90	101.5
73.0	75	75	75	90	90	90	90	101.5	101.5	127
88.9	90	90	90	101.5	101.5	101.5	101.5	127	127	127
114.3	127	127	127	127	127	127	127	152	152	152
168.3	178	178	178	178	178	178	203	203	203	203
219.1	229	229	229	229	229	229	255	255	255	255
273.1	279	279	279	279	279	279	305	305	356	356
323.9	356	356	356	356	356	356	356	356	380	380
355.6	380	380	380	380	380	380	380	406	406	406
406.4	432	432	432	432	432	432	432	457	457	457
457.0	483	483	483	483	483	483	483	508	508	508
508.0	533	533	533	533	533	533	533	559	559	559
560.0	584	584	584	584	584	584	584	610	610	610
610.0	635	635	635	635	635	635	635	660	660	660

Notes:

1) Double traced lines calculated on 90° spacing.

2) 25 mm tubing refers to l" tubing.

5.6 Relation of System Requirements to the Design of Insulation System and to the Properties of Materials Used

5.6.1 For any specific set of installation requirements, the properties of a material determine its suitability. If there were only one, or a limited number of sets of installation requirements, selection of material would be simple, and the need for all the various types of insulations and weather-barriers reduced. However, this is not the case. Each installation must be considered, and its requirements evaluated to allow the selection of the best suited material (or materials) for the individual installation under consideration.

Not only do the installation requirements change with the individual case, but the relative importance of the requirements also vary. Some of the possible variations of the properties required of individual materials, as the installation requirements change, will be treated in the short discussion following.

5.6.1.1 In the transportation phase, weight is always a factor. Although light density material is desirable, light weight insulation is of greater importance in air craft than in ships, trucks, or railroad cars. Conversely, when insulation is used in chemical and petroleum processing plants, where fire protection is required, a higher density insulation is essential to obtain the low diffusivity necessary for fire protection.

5.6.1.2 Where insulation may be contaminated by toxic or highly combustible chemicals, the most important single requirement is that it is completely non-absorbent.

5.6.1.3 In a process where cyclic application is required, the single most important requirement is that the insulation be such that it can be quickly and economically removed and reapplied.

5.6.1.4 Other cyclic operations may require that the insulation have low mass and specific heat so that the operating temperature can be changed without an excessive amount of heat and time being lost in "heating up" the insulation.

5.6.1.5 Just the opposite property is desirable on cold storage and storage of materials which must be held at relatively constant temperatures. In these installations, in case of power failure, the insulation's' retention of the existing temperature is of utmost importance.

5.6.1.6 Even on the same installation, the specific end use of an insulation may dictate its properties. A high temperature pipe may require very rigid, strong insulation to resist the mechanical stresses imposed upon it, but the insulation used in the expansion joint should be soft, fluffy, and resilient to cushion the movements of the adjacent rigid insulation.

5.6.1.7 On low temperature installations, the single most important property is resistance to the passage of water vapor, or ability to construct the insulation system to be as near vapor-proof as possible.

5.6.1.8 Economics always enters into the selection process. If a process is critical, the most important single consideration may be reliability. If conservation of heat or power is the deciding factor, the savings per year as compared to the installed cost is the most important factor. Again, and almost opposite, when insulation is used for a temporary function such as holding the heat in while a lining is being heat cured, then the lowest possible installed cost would be decisive.

5.6.1.9 Thus, because of conflicting requirements, there can be no "all purpose" insulation. Nor is there a "perfect" insulation for each set of requirements. It is essential that the engineer evaluate the installation and determine which requirements must be fulfilled, and which are of lesser importance.

5.6.2 A list of installation requirements as related to properties of materials is presented in outline form as following to assist the engineer in his calculation.

FABRICATION PHASE

REQUIREMENT	INSULATION PROPERTIES	ADHESIVE OR BONDING CEMENT PROPERTIES
Fabrication Operation To be able to be cut, or ground to desired shape. To be able to maintain true surfaces and surfaces suitable for application and retention together with adhesives or cements. Pieces able to be handled without excessive breakage, dusting, or wear. To be able to be assembled and bonded together rapidly, accurately, and tightly. To be able to be handled in a short time after bonding assembly. To have relatively short setting, drying, or curing time so that fabricated and assembled pieces can be used in a short time.	**Rigid Insulations** Dimensional Properties Sizes and shapes, straightness and smoothness of surfaces, squareness and trueness. **Cutting properties** Hardness delamination characteristics, ease of cutting, smoothness and trueness of cut, dusting characteristics, grinding characteristics, compatibility of cut surface with adhesive or cement. **Handling properties:** Tensile strength, flexural strength, compressive strength. **Assembly properties** Surface suitability to spreading or brushing of cement or adhesive. Surface compatibility to adhesive or cement, resistance to surface shear on drying of cement or adhesive, original tack of surface to bond to surface, absorbency. **Flexible materials** Cutting characteristics, tensile strength, bonding characteristics, surface or layer delamination.	**Pre-Use Properties** Shelf life, freeze-thaw resistance, mixing or storing time. **Use properties** Troweling or brushing characteristics, surface wetting and bonding characteristics, wet adhesive strength, compatibility with surface, drying time, curing time, wet to dry shrinkage, toxicity (solvent, fumes, etc.) pot life. **Dried Properties** Adhesive strength, shear strength, temperature resistance (maximum and minimum), resistance to moisture (vapor and liquid), resistance to solvents, acids, or caustics, flexibility and elasticity.

APPLICATION PHASE

REQUIREMENT	INSULATION PROPERTIES	ACCESSORY PROPERTIES
Cutting and Fitting	**Rigid Insulations**	**Adhesive Mastics, Bonding Cements, or Sealers (Where required)**
To be able to field cut fit and place into position efficiently and accurately	**Dimensional Properties** Size and shape, straightness and smoothness of surfaces squareness and trueness, within dimensional tolerances	Brushing characteristics troweling characteristics, wet adhesion, surface wetting, gap filling, bridging, sizing and sealing, drying time, curing time, shrinkage, compatibility with insulation surface solvent toxicity
	Cutting Properties: Ease of cutting dusting resistance to abrasion and cracking	**Pins and Clips** Tensile strength pull resistance, clamping strength
	Handling Properties: Tensile strength, resistance to breakage due to load or impact, flexural strength	**Adhesives** Wet and dry adhesive strength shear strength
	Surface Properties: Smoothness, trueness, compatibility with cements or sealers which may be required	
	Non-rigid Insulation Dimensional Properties Trueness in width length, and thickness	
	Cutting Properties: Cutting characteristics dusting	
	Strength Properties: Tear strength, resiliency, flexibility	
Securement To be able to be secured in position by wires, bands, pins and clips, or adhesives as required by the installation	**Rigid Insualtion** Compressive strength hardness shear resistance tensile strength	**Fastener Properties** Wire and metal strap Hardness, ductility, tensile strength flexibility **Tape** Tensile strength, flexibility, elasticity, peel bak, adhesive strength, shear strength
Trowel Application To be able to mix quickly and efficiently trowel into position insulating cements or mastics	**Water Mix Cements** **Mixing Properties** Mixing time, consistency	
To obtain good attachment to surface and obtain even thickness and smoothness of surface required by installation	**Application Properties** Wet adhesion, build, wet coverage, dry coverage, shrinkage wet to dry, trowelability, corrosiveness to substrate metal, drying time	
	Dried Properties Compressive strength, tensile strength, flexibility **Note:** **These same properties are of importance when the troweled cements are applied over other insulation.**	
	Insulating Mastics **Mixing Properties** Consistency in can	
	Application Properties Trowelability, wet adhesion, build, wet coverage, shrinkage wet to dry, corrosiveness to substrate metal, drying time, curing time	
	Dried Properties Compressive strength, tensile strength, extensibility	

(to be continued)

APPLICATION PHASE - (continued)

REQUIREMENT	INSULATION PROPERTIES	ACCESSORY PROPERTIES
Sprayed Applications To be able to be applied to insulation on a surface by spray equipment in a fast, efficient manner, with good adhesion to surface	**Sprayed Mass Insulation During Spraying** Wet adhesion, build rebound, overspray, compaction, corrosion to substrate metal, drying time, shrinkage wet to dry, toxic dust or fibers	
To be able to obtain a reasonably smooth, even surface without sags, hills, and valleys, suitable for weather-barrier or coverings	**Temperature Limits Application** Ambient air	
To be able to obtain density and related thermal efficiency	**Dried Properties** Compressive strength, tensile strength, flexibility, dimensional tolerance, surface evenness and smoothness	
To be able to obain desired strengths for permanent installation To be able to make spray application with least amount of cost involved in clean up or cleaning of spatter or overspray	**Sprayed Foam Insulations During Spraying** Wet adhesion, spray ratio, build, reaction time, curing time, expansion ratio, density, sag, toxic fumes, corrosiveness to substrate metal	
	Limits of Application Condition of surface, temperature of surface, temperature of air, humidity of air, wind, flash point, fire point	
	After Application Dry adhesion, compressive strength, density, tensile strength, dimensional stability, surface evenness and smoothness, bridging, elongation, flexibility	
Poured Applications To be efficient, pour or ram fibrous, granular, or powder insulation into cavities, so that all voids are completely filled	Compaction, compressibility, resiliency, dusting, density, toxicity of dust	

(to be continued)

APPLICATION PHASE - (continued)

REQUIREMENT	INSULATION PROPERTIES	ACCESSORY PROPERTIES
Note: **As poured insulation require some receptacle, requirements In reference to weather-vapor-barrier or coverings will not apply to this type of insulation system.**		
Application of weather - barrier, vapor - barrier, coverings **Jackets** To be able to cut, fit, form, seal, and apply jackets over flat surface insulation, vessel insulation, pipe and fitting insulation		**Jackets** Cutting characteristics, tear resistance, forming characteristics, handleability **Jacket Accessories** **Lap Adhesives** Adhesion, shear strength, shrinkage, flexibility **Circumferential Closures** Type and means of attachment, sealing compound flexibility **Longitudinal Laps** Method of securing and sealing
Mastic Weather Barriers To be able to brush, trowel, palm, or spray smooth, even water and weather-barrier mastic or interior coating to obtain a smooth dried, film of even texture & thickness over entire surface	**All Insulations** Surface compatibility Surface suitability Smoothness Dryness Dust free Clean	**Mastics or Coatings During Application** Mixing or stirring time, consistency, brushing characteristics, troweling characteristics, palming characteristics, wet adhesion, wet covering capacity, surface wetting, gap filling, bridging sizing and sealing, shrinkage wet to dry, drying time, curing time, solvent toxicity
Reinforcing fabrics which can be cut, fitted, and formed to fit contours, to reinforce gage and bridge gaps so as to be able to obtain maximum protection and life of the mastic coating		**Limits of Application** Material temperature, air temperature, humidity of air

SERVICE PHASE

REQUIREMENT	INSULATION PROPERTIES	ACCESSORY PROPERTIES
Physical To withstand dead loads, wear, impact and mechanical damage, forces of expansion and contraction, and vibration	**All Insulation** Compressive strength, flexural strength, shear strength, tensile strength, flexibility, shrinkage, coefficiency of expansion. compaction resistance, abrasion resistance, vibration resistance	**Weather, Vapor - barrier, Coverings** Impact resistance, indentation resistance, tear resistance, abrasion resistance, flexure, elongation. tensile strength. adhesion, elasticity, shear strength
Chemical Compatibility with metal to which it is applied, resistance to atmospheric and spillage contamination	**Alkalinity, acidity, inhibitors to corrosion, acid resistance, caustic resistance, solvent resistance**	**Acid resistance, caustic resistance. solvent resistance**
Moisture Resistance to moisture in liquid or vapor form or both	**Absorptivity, adsorptivity, hygroscopicity, capillarity, vapor permeability**	Absorptivity, adsorptivity, hygroscopicity. capillarity, vapor permeability (These properties relate to a system, rather than to a material, and must include the joints and seals of jackets or films.)
Electrical To resist flow of galvanic currents	**Dielectric constant (when wet)**	Dissimilar metals in jacket and substrate, producing a potential difference which causes galvanic current to flow
Weather Resistance To resist solar radiation, rain sleet, snow, wind, and atmospheric contamination, maximum and minimum temperature	**Note:** **If properly weather-protected this function is one of the weather-barrier.**	Water resistance, solar radiation resistance, temperature stability, impact resistance, contamination resistance. wind resistance, mold resistance, freeze-thaw resistance **Note:** **Deterioration of a weather-barrier system caused by weather is a deterioration of the properties of the system.**
Safety To maintain standards of fire safety; personnel protection from burns (as controlled by insulation thickness vs. surface emittance)	**Hazard Properties** Absorptivity (of combustible toxic liquids), adsorptivity (of combustible or toxic vapors)	**Absorptivity (same)** **Adsorptivity (same)**

(to be continued)

SERVICE PHASE - (continued)

REQUIREMENT	INSULATION PROPERTIES	APPLICATION PROPERTIES
	Combustibility Flash point, flame spread, fire point, self ignition point, fuel contribution, smoke density, smoke toxicity	**Combustibility** Flash point, flame spread, fire point, self ignition point, fuel contribution, smoke density, smoke toxicity
	Melting Point	**Melting Point Emittance** (surface temperature)
To protect from fire exposure	**Protection Properties** Noncombustible Conductivity, Diffusivity, density, Specific heat Fire resistivity	**Resistance to flame**
Thermal Properties To resist service temperature	**Maximum Service Temperature** Coefficient of expansion, shrinkage	**Maximum Surface Temperature** Coefficient of expansion (metals)
Control of heat flow, control of temperature flow, heat storage		Embrittlement
Control of surface temperature	Minimum service temperature Coefficient of expansion Warpage Conductivity Diffusivity Specific heat Density Conductivity and thickness	**Minimum Surface Temperature** Reduction in elongation Emittance
Miscellaneous To resist rodents, insects, termites, etc. (particularly in building and cold storage insulation)	Vermin resistance Mold resistance	Vermin resistance Mold resistance
To be odor free	Odor	Odor
Aesthetics		Color, texture, smoothness
Maintenance Phase To resist damage in service	Physical strength Dimensional stability Temperature strength Moisture resistance (Above are general terms for individual properties listed in each of above.)	Weather resistance Abuse resistance Toughness Temperature stability (same rate)
To remove and replace	Removability Replaceability	Removeability Replaceability
Ease of maintenance	Reuseability Ease of patching Permanence of patching	Reuseability East of patching Blending of patch

5.7 Corrosion Consideration in Design and Application of Thermal Insulation

5.7.1 General

The proliferation in recent years of corrosion failures of both steel and stainless steel under insulation has caused this problem to be of great concern to the operators of petroleum-, gas-, and chemical-processing plants. Piping and vessels are insulated to conserve energy by keeping cold processes cold and hot processes hot. Once a vessel is covered with insulation and operating satisfactorily, concern for the condition of the metal under insulation usually diminishes. Thus, corrosion of steel and SCC of stainless steel begins and develops insidiously, often with serious and costly consequences many years later. To deal with corrosion under insulation effectively and economically, a systems approach must be developed that considers the metal surface, temperatures, water, insulation, and design.

Corrosion of steel under insulation did not receive a great deal of attention by the corrosion engineering community until the late 1970s and early 1980s. Although considerable attention was being given to the SCC of stainless steel under insulation (see below), steel vessels and piping were rarely mentioned. This situation existed because of the slow corrosion rate of the steel equipment, together with the fact that many large hydrocarbon-processing plants were built 10 to 20 years earlier.

The most significant turn of events, which fortunately revealed the corrosion problem to many, was the energy shortage and the resultant emphasis on energy conservation. The effort to conserve energy soon led to replacement of much of the 10 to 20 year-old insulation with more efficient systems. As the old insulations were removed, localized, often severe corrosion damage was found.

Corrosion of steel and of stainless under thermal insulation are discussed separately, because the nature of the problem, aside from the presence of insulation, is different.

5.7.2 Corrosion of steel under insulation

5.7.2.1 The problem

Steel does not corrode simply because it is covered with insulation. Steel corrodes when it contacts water and a free supply of oxygen. The primary role of insulation in this type of corrosion is to produce an annular space in which water can collect on the metal surface and remain, with full access to oxygen (air).

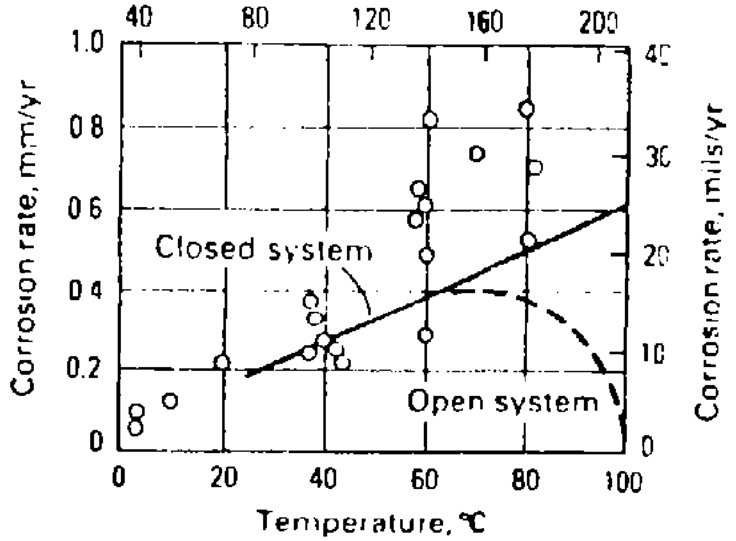
The most active sites are those where the steel passes through the insulation and on horizontal metal shapes, for example, insulation support rings where water can collect.

The other major corrosion problem develops in situations where there are cycling temperatures that vary from below the dew point to above ambient. In this case, the classic wet/dry cycle occurs when the cold metal develops water condensation that is then baked off during the hot/dry cycle. The transition from cold/wet to hot/dry includes an interim period of damp/warm conditions with attendant high corrosion rates.. In both cases, if the lines had operated constantly either cold or hot, no significant corrosion would have developed.

5.7.2.2 The mechanism

The corrosion rate of steel in water is largely controlled by two factors: Temperature and availability of oxygen. In the absence of oxygen, steel corrosion is negligible.

In an open system, the oxygen content decreases with increasing temperature to the point where corrosion decreases even though the temperature continues to increase (Fig. 1). A number of recent case histories of corrosion under insulation have been reviewed, and the estimated corrosion rates have also been plotted in Fig. 1. These filed data confirm that corrosion of steel under insulation increases steadily with increasing temperature, matching the curve for a closed system.



EFFECT OF TEMPERATURE ON CORROSION OF STEEL IN WATER. DATA POINTS ARE FROM ACTUAL PLANT MEASUREMENTS OF CORROSION UNDER INSULATION
Fig. 1

The problems of steel corrosion under insulation can be classified as equivalent to corrosion in a closed hot-water system. The thermal insulation does not corrode the steel, but, more correctly, forms an annular space where moisture collects. The insulation also forms a barrier to the escape of water or water vapors, which hastens the normal corrosion rate of wet steel.

In an attempt to determine which insulation contributes most and which contributes least to corrosion of steel, tests were conducted that compared 12 common insulation materials.

After a 1-year exposure to the elements, dousing with water, and daily heating with steam, it was concluded that, although the insulation materials that absorbed water developed higher corrosion rates than those that did not the difference between the two was not great. Therefore, efforts to select a type of insulation to prevent corrosion would not be practical. Field observation and reports from the literature confirm that corrosion of steel occurs under any and all types of insulation.

5.7.2.3 Prevention

One attempt to prevent corrosion damage involves adding a corrosion inhibitor to the insulation. Inhibitors such as Na_2SiO_3 are added for this purpose. The practical effects of such an approach are questionable. In one set of laboratory tests, inhibited insulation material was submerged in water, then set out to dry. After several cycles of wetting and drying, the insulation was found to have no benefit over uninhibited insulation of the same brand.

A corrosion inhibitor for insulation must be water soluble so that it can be dissolved and carried to the steel surface. If the insulation is waterproofed on the outside, water will enter through cracks and openings in the insulation system. This water is in the annulus and contacts only the inner surface of the insulation. The water-soluble inhibitor will soon be extracted and displaced by the water running down the vessel walls. Therefore, relying upon a consumable inhibitor for long-term protection may not be dependable.

If water entry to the insulation/steel annulus is the problem, perhaps the solution lies in more effective waterproofing. Advancements in various metal jacketing, sealants, and mastics have improved the protection of insulation materials from water, weather, and man. However, these waterproofing systems probably do not prevent water entry, because, in order to seal and prevent the annulus form breathing with temperature changes, the seal would have to be equivalent to a pressure vessel.

Waterproofing systems are designed to keep the insulation dry. They are not capable of preventing water vapor and air from contacting the annular space. In fact, a waterproofing system keeps the water vapor in the annulus and effectively produces the hot-water closed system, with attendant high corrosion rates.

Therefore, selection of insulation, inhibiting the insulation, and waterproofing of insulation are not effective deterrents to corrosion. Instead, a high-quality protective coating, correctly applied to the steel before insulation, can offer long-term protection.

In the insulation industry, a primer is sometimes used, particularly under spray-on foam insulation materials. It should be understood that the purpose of the primer is to present a clean surface for bonding of the insulation. The primer-type paints are not intended to and will not prevent corrosion by hot water. The key to specifying a paint system is to remember that it will be exposed to hot water vapors, a very severe environment for paints.

The use of inorganic zinc paint as a primer, coupled with the hot water, will not cause accelerated corrosion of the steel. Zinc and the silicate binder are both dissolved by hot water. Even if conditions favored the zinc becoming cathodic to steel, the protective coating binder would dissolve and the coating would break down.

The advisability of using inorganic zinc under other protective coatings is not as clear. Some tests seem to indicate good performance. Others show that inhibited primers with topcoats achieve maximum performance in hot-water systems. Therefore, the main criterion for a protective coating under insulation is that it resist hot water and water vapors. This severe service will also require high-quality surface preparation. For selecting the suitable paint system. See IPS-E-TP-100.

When the oxidation of carbon steel is involved various methods are available for depositing protective films on the surface of iron and steel, e.g., galvanizing, sherardizing, parkerizing, aluminzing, etc., and these can improve the resistance to oxidation, although often their main application is for accessory materials. 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 wire netting can undergo reversal of polarity, so that the iron may become sacrificial rather than the zinc surface film. In any case galvanized wire shall not be used at temperatures above 350°C.

Oxidation, with severe scaling and possible loss of mechanical strength, may occur when a metal is heated to relatively high temperatures in air, e.g., of about 400°C and above for carbon steel, the condition that may be aggravated by the incorrect use of thermal insulating material on the external surface of refractory-lined equipment. This may raise the metal temperature to dangerous levels. If it is essential to have both internal and external insulation, great care is necessary in considering the effect on the metal temperature.

The formation of white deposits of oxide on the surface of zinc and certain types of aluminum sheet, particularly under moist conditions, may be unsightly rather than dangerous. Both may be eliminated by cleaning, followed by painting as necessary or, in the case of aluminum, by the use of sheets that have received a chemical or electrolytic oxidation treatment.

5.7.3 Other forms of corrosion which is possible to occur on carbon steel and the methods of prevention are as following:

5.7.3.1 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 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 sulphite 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 adequate thickness of insulating material to prevent internal condensation will be an effective safety measure.

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

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. Also, any sulphur residues, e.g., certain slag wools, can produce acidic corrosion in the presence of moisture.

Corrosive attack on unprotected underground pipework can be dangerous, and effective measures should be adopted to avoid this. Insulating material of low capillarity can retain local concentration of water inside an insulation system. Also, the sulphate-reducing action of soil bacteria under anaerobic conditions, can produce corrosive sulphide compounds; this action is especially dangerous with pipework buried directly in the ground. Protective measures will include coating the metal surface with asphaltic compounds, and these should be reinforced with inorganic woven fabric or staple tissue. For some buried pipework systems, cathodic protection, e.g., by the use of zinc or magnesium sacrificial anodes or impressed current at intervals, may be effective, but generally specialist advice should be sought for difficult installations, particularly if there is a danger of contamination by sea water.

5.7.3.2 Alkaline corrosive attack

Some non-ferrous metals may 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 may occur with copper, brass, etc., and with zinc coating on galvanized surfaces. Aluminum sheet used to protect calcium silicate is also vulnerable. Protective measures will include keeping water out of the system and painting the metal surface as appropriate or using a factory-applied moisture barrier.

5.7.3.3 Intergranular corrosion

Normally this consists of localize attack at the grain boundaries of ferritic and some austenitic alloy steels, which arises from the internal migration and deposition of chromium carbide at sensitizing temperature over about 400°C.

Where doubt exists, it is recommended that the accessories should be selected from "stabilized" or special "low carbon" alloy steels.

5.7.3.4 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.

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, etc.) 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 may 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 since 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 area of contact. In particular, statements claiming that specific differences of potential are safe or unsafe are unreliable. Thus the use of unsuitable metals for screws, rivets, welded attachments, and even bands, should receive careful attention when such items are to be selected.

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

5.7.4 Stress corrosion cracking (SCC) of stainless steel under insulation

5.7.4.1 The problem

During and after World War II, many new petrochemical plants were built in the United States. Many of these plants contained equipment built with the new austenitic stainless steels. These alloys, such as types 304, 316, and 347, were widely used to combat process corrosion and to maintain product purity. As in all chemical processes, a large percentage of this equipment was insulated for thermal efficiency.

During this period, corrosion and materials engineers discovered some of the limitations of these stainless "wonder metals". In addition to crevice corrosion and weld decay, the engineers encountered SCC.

As the insulation systems and their weather barrier coatings aged, more incidents of SCC under insulation began to occur in the chemical-processing industry. In the following years, much work was done to investigate the problem and the counter measures.

5.7.4.2 The mechanism

Soon after the widespread use of the 18-8 austenitic stainless steels, beginning in the late 1930s, it became clear that the Cl^- ion in water could be very damaging. In addition to causing localized corrosion, such as pitting and crevice corrosion, rapid failure was seen in the form of a fine network of transgranular cracking. This pattern of cracking is very destructive and is found on the surface as well as in cross section .

The theoretical processes of chloride SCC of the 18-8 stainless steels are under investigation. However, it has been established that four conditions are necessary for SCC to develop:

- An 18-8 austenitic stainless steel.
- The presence of residual or applied surface tensile stresses.
- The presence of chlorides; bromide (Br) and fluoride (F) ions may also be involved.
- The presence of an electrolyte (water).

When these conditions are present, the occurrence of SCC is highly probable.

The stainless steel alloys susceptible to SCC are generally classified as the 18-8's. This includes the molybdenum-containing grades (types 316 and 317), the carbon-stabilized grades (types 318, 321, and 347), and the low-carbon grades (types 304L and 316L). Many variations of the basic 18-8 have been developed in order to combat SCC. These variations are higher in nickel, chromium, and molybdenum, and there are also grades with lower nickel and higher chromium (duplex stainless steels). All of these alloys are highly resistant to SCC and therefore not part of the problem of SCC under insulation.

For SCC to develop, sufficient tensile stress must be present in the material. If the tensile stress is eliminated or greatly reduced, cracking will not occur. The threshold stress required to develop cracking depends somewhat on the severity of the cracking medium. Most mill products, such as sheet, plate, pipe, and tubing, contain enough residual tensile stresses from processing to develop cracks without external stresses. When the austenitic stainless steels are cold formed and welded, additional stresses are imposed. As the total stress increases, SCC becomes more severe.

The Cl^- ion is damaging to the passive protective layer on the 18-8 stainless steels. Once the passive layer is penetrated, localized corrosion cells become active. Under the proper set of circumstances, SCC can lead to failure in only a few days or weeks. Sodium chloride, because of its high solubility and widespread presence, is the most common culprit. This neutral salt is the most common, but not the most aggressive. Chloride salts of the weak bases and light metals, such as $LiCl$, $MgCl_2$, and $AlCl_3$, can rapidly crack the 18-8 stainless steels under the right conditions of temperature and moisture content.

The concentration of chlorides necessary to initiate SCC is difficult to ascertain. Researchers have developed cracking in solutions with remarkably low levels of chlorides (<10 ppm). The situation of chlorides under insulation is unique and ultimately depends on the concentration of chlorides deposited on the external surface of the metal. The concentrating mechanism is discussed in some detail in the following paragraphs. Therefore, the amount of chlorides present becomes a debatable issue. If any chlorides are detected, there will probably be some localized sites of high concentration.

The most important condition affecting chloride concentration is the temperature of the metal surface. Temperature has a dual effect: First, elevated temperatures will cause water evaporation, which in turn concentrates the chloride salts, and, second, as the temperature increases, the rate of the corrosion reaction increases.

Finally, chlorides have been discussed because they are the most common and aggressive of the halogen family. Bromides and fluorides may also cause SCC, but are lees common and probably less aggressive.

Water is the fourth necessary ingredient in SCC. Because SCC is an electrochemical reaction, it requires an electrolyte. As water penetrates the insulation system, it plays a key role at the metal surface, depending on the equipment operating conditions.

Examination of the phenomenon of corrosion of steel under insulation provides a better appreciation of the widespread intrusion of water.

In effect, water must be expected to enter the metal/insulation annulus at joints or breaks in the insulation and its protective coating. The water then condenses or wets the metal surface, or if it is too hot, the water is vaporized.

This water vapor (steam) penetrates the entire insulation system and settles into places where it can recondense. Because the outer surface of the insulation is designed to keep water out, it also serves to keep water in. The thermal insulation does not have to be in poor condition or constantly water soaked. A common practice in chemical plants is to turn on the fire protection water systems on a regular basis. This deluges the equipment with chloride-bearing water. Some seacoast locations use seawater for the fire protection water. Hot food-processing equipment is regularly washed with tap water, which contains chlorides. All insulation system water barriers eventually develop defects. As the vessel/insulation system breathes, moist air contacts the metal surface. From the insulation standpoint, the outer covering acts as a weather barrier to protect the physical integrity of the insulation material. The outer coverings are not intended, nor can they be expected, to maintain an air-and water-tight system.

5.7.4.3 Prevention of external SCC

As an understanding of external SCC and its mechanisms developed, selection of a preventive method became much easier. Table 10 summarizes the possible methods of prevention that apply to each causative agent. As can be seen, application of a suitable protective coating system is generally the most economical method, although other methods are included and may be practical under certain circumstances.

The critical step then becomes the implementation of whichever preventive method has been selected. Assuming a protective coating has been chosen, it is necessary to convince project or operating managers of the benefits of painting stainless steel. Although painting stainless steel may at first seem unusual, experienced field personnel will usually understand the need for preventive measures.

Application of any protective coating requires a good specification and inspection. The use of manufacturer application guidelines and the knowledge of an experienced inspector are indispensable in producing an acceptable protective coating.

Fortunately, protective coatings work very well on stainless steel because the metallic substrate does not oxidize or rust. Therefore, coating adhesion failures are very rare. The main objective is to achieve a continuous coating at a reasonable cost that will resist the hot-water environment encountered under insulation (see also IPS-E-TP-100).

TABLE 10 - GUIDELINES FOR SELECTING EXTERNAL SCC PREVENTIVE

Causative agent	Preventive method	Comments	Evaluation
Austenitic stainless steel . .	Change to SCC-resistant alloy	Stainless steel alloys with > 30% Ni and the duplex stainless alloys are alternative choices but cost considerably more and may not be readily available.	Extra cost compared to other preventive methods makes this an unwise choice
Tensile stress	Thermal treatment (anneal or stress relieve)	Annealing at 1065 °C (1950 °F), followed by water quenching will distort and scale equipment severely. Stress relieving at 955 °C (1750 °F) and slow cooling will sensitize the grain structure and cause some warpage and scaling. Note: A stress-relieved vessel or pipe will be subjected to tensile stresses in assembly and under operating conditions. May override the thermal treatment	Generally not practical for piping and vessels, may be used for small individual components
	Shot peen	Shot peening converts the surface stresses to compressive stress and is a proven SCC preventive method. It is a delicate process requiring specific skills and experience. May be costly or difficult to apply in the field	Should be considered, but may be more costly and difficult to obtain than other prevention methods.
Chlorides	Remove or eliminate Cl^- ion	Because of their widespread occurrence, highly soluble chloride salts are difficult to avoid or keep off of equipment	Not practical
	Apply barrier coating to stainless steel	Use of a protective coating on the stainless steel surface can prevent Cl^- contact with the alloy. Wrap stainless steel with aluminum foil, which serves as both a barrier coating and cathodic protection anode	This is a practical [illegible] proven prevent[illegible] method Being used with success: extended life of the aluminum has not been determined
Water	Improve waterproofing to prevent water entry	No type of coating, cementing, or wrapping of insulation can keep air and water from entering the insulation system, except for constructing an external pressure shell. Note: The application and maintenance of a weather barrier is important to good insulation performance and should have a high maintenance priority.	Not practical to expect a wrap or coating to keep water out
	Apply barrier coating to stainless steel	A carefully selected protective coating can provide long-term protection for stainless steel equipment. Use of aluminum foil wrap as above Note: Use of inorganic zinc primer or paint system is not safe due to the possibility of liquid metal embrittlement upon subsequent welding or exposure to extreme heat.	This is a practical and proven preventive method Limited use, but with success

5.7.5 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 many not 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 contain nitrates, but these may be present in natural waters. Thus, it is dangerous to allow water of any kind to penetrate and, above all, to saturate insulation systems where contaminants may concentrate at the metal surface. As a general rule, the danger of cracking from this type of attack is remote, but suitable 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 aluminum-zinc, aluminum-zinc-magnesium alloys, and various copper-zinc alloys may 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, where appropriate, the surface of the metal should receive a protective coating of suitable compound.

5.7.6 Attack by liquid metals

Although thermal insulation 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.

5.7.6.1 The melting point of zinc is 419°C and at temperatures above 450°C molten zinc will diffuse and penetrate 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 absence of stress it is unlikely that very rapid embrittlement will occur.

5.7.6.2 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 will bring about rapid penetration, and cracking may 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.

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

5.7.6.4 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 about 400°C should be rigorously avoided.

5.7.6.5 Paints containing metallic zinc should not be used as surface protection for insulated austenitic steel surfaces in areas of high fire risk where the temperature can exceed 350°C.

5.7.6.6 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. GENERAL APPLICATION OF THERMAL INSULATION

6.1 Conditions in which Thermal Insulation shall be Applied

Thermal insulation shall be applied to the pipings, vessels and equipment with the following range of application and conditions:

6.1.1 Piping, vessels and equipment operating over 5°C shall not be insulated unless required for heat control or acoustical control.

6.1.2 Piping, vessels and equipment operating above 55°C shall be insulated if necessary for personnel protection.

6.1.3 All piping, vessels and equipment operating below 5°C shall be insulated to control the fluid temperature, the conservation of refrigeration or to control surface condensation.

6.1.4 Operating temperatures of this specification refers to the internal fluid or material temperature of the process system.

6.1.5 Piping, vessels and equipment which are to be insulated shall be indicated on flow diagrams, pipeline list, piping and spool drawings and on the equipment. These drawings shall also indicate the insulation classification which appears following. The specification of insulation such as thickness and material shall be shown on drawings and also by the table.

6.1.6 The insulation classification which may appear on flow diagrams and or drawings shall be defined as following:

Ih - for heat control for operating temperature above 5°C.
ST - for steam traced and insulated.
STT - for steam traced with heat transfer cement and insulated.
STS - for steam traced with spacers and insulated.
ET - for electric traced and insulated.
ETT -for electric traced with heat transfer cement and insulated.
IS - for personnel protection insulation.
Iac - for acoustical insulation.
Ias - for cycling or dual temperature service where temperatures fluctuate from 15°C to 320°C.
IC - to conserve refrigeration, surface condensation and control fluid temperatures for operating temperatures 5°C and below.
Fireproof - for all services requiring fire proof type insulation.

6.2 Personnel Protection

6.2.1 To avoid the possibility of accident caused by the touching of either hot or cold surfaces by personnel, who may be unprepared for a sudden thermal shock, it is recommended that some reasonable protection shall be given.

6.2.2 Where operating temperature of piping, vessels and equipment is above 55°C and insulation is not required for heat conservation, those portions of equipment or piping which present a hazard to operating personnel and guard rails or screens not provided shall be insulated for personnel protection. These insulated surfaces shall extend approximately 2 meters above operating levels and 1 meter from edge of platforms, walkways, and ladders. The extent of personnel protection insulation shall be clearly indicated on piping drawings. Valves, flanges and unions shall not be insulated for personnel protection.

6.2.3 Where insulation is not premitted for economical purposes or where dissipation of heat is desirable or there is the advantage of non-insulated surfaces remaining tree and visible for inspection, guards or shields shall be installed for personnel protection in lieu of insulation.

6.2.4 The extent of personnel protection, acoustical control, or fire proofing required on piping, vessels and equipment shall be indicated on drawings.

6.2.5 Contact with very cold surfaces will also result in thermal shock or skin damage and personnel protection may be required for temperatures of approximately -10°C and below.

7. CHARACTERISTICS OF INSULATING AND ACCESSORY MATERIALS

(See relevant IPS-M-TP Standards for Specification.)

7.1 Consideration in Characteristics of Insulating Materials

7.1.1 Health hazard

7.1.1.1 Every effort should be made to avoid the use of asbestos or asbestos containing materials in the insulation system. In those cases where the use of such material, is unavoidable due to the lack of technically acceptable substitute or any other means the prior agreement of the user to their use shall be obtained. Safety regulation on use and application of asbestos or asbestos containing materials shall be observed.

7.1.1.2 Reference shall be made to the appropriate instructions from manufactures for health and safety.

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

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

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

7.1.1.6 Many fibrous insulating materials can cause skin irritation. Normally this is associated with the coarser fibers, so that the same materials of smaller fiber diameter may not cause this type of irritation, although they may then have other undesirable effects. (See 7.1.1.7 and also BS 4275.) The use of barrier creams and the provision of adequate washing facilities will help to reduce the incidence of skin irritation, but tight clothing, e.g., round the neck and at the wrists, may trap fibers and thus increase local irritation.

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

7.1.1.8 The risks to health associated with the removal of thermal insulation containing asbestos are particularly well-known, especially when crocidolite (blue asbestos) is encountered (see 7.1.1.9).

7.1.1.9 Before any stripping work is carried out it is necessary to determine what type of insulating material is involved (see IPS-C-TP-701). Although the presence of crocidolite is sometimes discernible by its rich lavender-blue color, it is not correct to rely on this test alone. It is always necessary to obtain positive analysis by a responsible laboratory.

Where the Asbestos Regulations, if any, apply and where crocidolite is identified written notice has to be given to the inspector for the District at least 28 days prior to commencement of the work, or such shorter notice as the inspector may agree to accept. (For the disposal of any waste asbestos, see IPS-C-TP-701.)

7.1.1.10 Suitability for removal and replacement

When removal and replacement of insulation is to be undertaken, reference shall be made to the recommendations of IPS-C-TP-701.

7.1.2 Substitute material

The asbestos or any product containing asbestos materials shall not be applied by means of a spray process.

7.1.2.1 When required for use of an existing plant or installation, the selection of material shall be confirmed with the local management in order that account may be taken of preferences for particular materials.

7.1.3 Thermal conductivity

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

The thermal conductivities of most insulating materials vary with temperature and with bulk density, so that both these factors shall be considered. It is the normal practice of manufacturers to provide tables or graphs showing thermal conductivities for each of their standard products at a range of hot-face temperatures together with the relevant cold-face temperatures used for the tests. The information shall also include the bulk density for each material tested.

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

For very high cold-face temperatures, which could apply, for example, with the inner layer of composite insulation or with the inner layer of composite insulation or with materials exposed to high ambient temperatures on the exposed surface, special calculations are required (see BS 5970 for interface temperature and BS 5422, Appendix C). These may involve reference to mean temperatures, i.e., the arithmetic mean between the hot-face and cold-face temperatures of test; to avoid confusion, either the corresponding hot-face or cold-face temperature shall also be quoted.

7.1.4 Physical forms

Insulation is usually supplied in one of the following forms:

- Rigid boards, blocks, sheets, and preformed shapes such as pipe covering, curved segments, etc.
- Flexible boards, sheets.
- Blanket.
- Plastic composition.
- Cement.
- Loosefill.
- Mastic.
- Sprayed or metallic, e.g., crimped foil.

Each of these will be made up of granular, fibrous, flake cellular or reflective material (or a combination of these). For lists of typical materials and some of their properties, see Tables 13 and 15.

7.1.5 Forms of insulations

Forms of insulations for application on piping and equipment may be as followings:

a) For pipework on hot service, preformed rigid sections are preferred.

b) On tanks and vessels, preformed slabs or mattresses may be used on hot service, but on cold duties slabs only should normally be used. When slabs are used on vessels subject to thermal movement the fixing arrangements shall allow for this.

c) Loosefill, compatible with the insulation, may be used for filling interstices or for double skin removable cover and boxed items of equipment.

d) Foamed-in-situ, materials may be used where these can be shown to be economically advantageous. Samples of foamed materials should be taken during application for fire resistance (where required) and quality control purposes.

e) Sprayed form shall not be used without the prior agreement of the Company.

f) Consideration may be given to the use of pre-insulated pipework where this is economically justified.

7.1.6 Bulk density

The bulk density for most thermal insulating materials falls within the range 16 kg/m^3 to 320 kg/m^3 and their effectiveness depends essentially on the large numbers of minute air or gas cells that they contain and that restrict transfer of heat by convection and radiation; at the sametime, the limitation in areas of solid thermal bridges forms a good barrier to the passage of conducted heat.

Low bulk density is normally associated with low thermal conductivity in the low and medium temperature ranges, but it may also result in low compressive strength, in which case the material will not be suitable for load bearing purposes. As a general rule, increase in bulk density is associated with reduction in the size of the contained air or gas cells and this tends to maintain effectiveness of insulation at the higher service temperature.

Note:

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

7.1.7 Suitability for service temperature

The temperature at which the material is used shall be within the range for which it will provide satisfactory long-term service under condition of normal usage. Tables 13 and 15 show approximate operating temperatures for some insulations.

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

For materials to be used at elevated temperatures it will be necessary to consider the many factors that may result in deterioration under condition of service. These include linear shrinkage under heat, loss of compressive strength and of weight during heating, and the effects of vibration and possible self-heating phenomena.

In establishing maximum operating temperatures for preformed high-temperature insulation, particularly that in the form of pipe sections, the ability of insulation to withstand moderate loads and vibration whilst in service shall be considered. Some knowledge of the compressive strength both before and after heating may be of value. Additionally, the effect of long-term heating should be studied.

Where the compressive strength in service undergoes significant reduction, as in the case of banded mineral wool due to volatilization of the organic binders at temperatures above about 260°C, it may be necessary to support and protect the insulating material. Metal cleading (see IPS-C-TP-701) is convenient for this purpose; where additional strength is required the metal shall be supported from the pipe independently of the insulation, e.g., by insulated metal spiders or by suitable load bearing insulation.

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

7.1.8 Thermal expansion

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

7.1.9 Resistance to compaction

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

7.1.10 Resistance to water vapor penetration and to water absorption

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

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

7.1.11 Mechanical strength

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

7.1.12 Durability

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

7.1.13 Fire and explosion hazards

7.1.13.1 Not all the thermal insulating materials in common use are non-flammable. Some of them, often used for refrigeration systems, are entirely of organic composition and thus may constitute a fire hazard, or they may emit smoke and toxic fumes. Designers of thermal insulation systems shall 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 shall vary their choice of material accordingly.

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

Some insulating materials that contain organic bonding agents, although generally suitable for service temperature anticipated may in fact constitute a fire risk through a phenomenon of internal self heating. Evidence of this self heating may be a transient rise in temperature above the theoretical value for specific locations within the insulation system. This hazard may be accentuated if air can enter into material of low bulk density, or by convection current induced with insulated vertical pipe work. The phenomenon is complex 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 may constitute a fire hazard, particularly if the surrounding atmosphere is flammable materials in the immediated vicinity.

In flammable atmospheres, particularly with long runs of insulated pipe work, it may be advisable to take the precaution of connecting external metal cleading to earth in order to avoid possible build-up of static electricity.

7.1.13.2 In addition to the above the following recommendations shall be considered when selecting insulation materials.

7.1.13.2.1 Porous insulation materials, such as calcium silicate will have low ignition temperature when pregnant with oil (for instance mineral oil ignites at 200-300°C and higher class alcohol at 100-150°C).

7.1.13.2.2 Rockwool containing over 0.3 percent mineral oil or over 0.5 percent resin treated glass fiber felt or organic matter shall not be used for oxygen gas facilities.

7.1.13.2.3 Cold insulation materials composed of perlite or silica gel mixed with fine aluminum powder shall not be used for liquified oxygen facilities, such as air separator.

7.1.13.2.4 Organic cold insulation materials, if used, shall be weather proofed with incombustible or fire resistant materials.

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

7.1.14 Corrosion

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

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

General corrosion may occur if wet insulation is allowed to remain in contact with carbon steel surfaces for prolonged periods, particularly if acidic products are present in the water or if they can be extracted from the insulating material itself. Due regard shall also be paid to possible corrosive attack on a variety of metals, e.g., those used as finishes, that may be in contact with wet insulating materials. (See 5.7 for more detailed treatment of corrosion problems.)

7.1.14.2 To minimize corrosion the following recommendations shall be considered when selecting insulation materials.

7.1.14.2.1 All insulation materials shall be noncorrosive, weather wet or dry, and suitably inhibited for application to stainless steel surfaces.

7.1.14.2.2 In the inhibited condition, insulation materials containing more than 600 ppm chloride are not acceptable for use on stainless steel surfaces.

7.1.14.2.3 In uninhibited condition the amount of leachable chloride in the insulation material shall not exceed 10 ppm.

7.1.14.2.4 The pH of all insulation materials shall be between 6 and 9 in the wet condition.

7.1.14.2.5 Insulation composed of alkaline materials shall not be used on aluminum surfaces.

7.1.15 Chemical resistance

Thermal insulation used in process plants shall not react with chemicals present and considering the properties of the fluids to be handled, selection shall be made from among chemically resistant materials which will not cause any hazard if they absorb the fluid.

7.1.16 Optimum life

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

When the technical requirements of the application have been met, the total cost (as distinct from the initial cost) during the life of the installation is the prime consideration. (See 5.4.2 for economic thickness.)

7.1.17 Optimum heat capacity

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

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

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

7.1.18 Freedom from objectionable odor

It is of particular importance that insulating materials for use in canteens or buildings in which food is processed or served, shall be free from objectionable odor.

7.1.19 Maintenance requirements

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

7.1.20 Thermal expansions

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

7.1.21 Resistance to compaction

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

7.1.22 Resistance to vermin and fungus

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

7.2 Consideration in Characteristics of Accessory Materials

7.2.1 Vapor barriers

7.2.1.1 General

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

The purpose of the vapor barrier is to reduce, and if possible to prevent, the ingress of water vapor into the insulating material, Thus, the barrier shall always be applied to the warmer surface of the material. It may take the form of a coating or sheet material resistant to the passage of water vapor, i.e., of low permeability, and the sealing of joints and overlaps shall be effective.

Insulating materials that consist substantially of closed cells possess an inherent resistance to the passage of water vapor, but open-cell insulants and loosefill porous materials are readily permeable to water vapor. Even with materials that have good resistance to the transmission of water vapor, 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 also may fail to exclude water vapor completely, in which case the contained water or ice may form strongly conducting paths from the surface of the plant to the ambient air.

7.2.1.2 Vapor barriers for use over insulation on surfaces below dew point

Since it is essential to prevent the deposition of moisture, with the consequent risk of ice formation within the insulating material in those zones that are below freezing point, the use of an effective vapor barrier is an important technical requirement. The deposition of moisture within the insulating material could lead to eventual saturation of the material, with possible resultant mechanical and physical deterioration within the insulation system, and the risk of corrosive attack on the insulated metal surface. It is essential that the barrier shall not be used as the exposed surface finish if it is likely to be damaged during service; it should be noted that even penetration by pin-holes will impair the effectiveness of the vapor seal.

7.2.1.3 Vapor barriers for use over insulation on surfaces above dew point

If the cold surface is at temperatures below the atmospheric dew point for short periods only, any deposited moisture may evaporate later, in which case the use of a vapor barrier may not be essential, or a surface breather coat may be adequate.

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

7.2.2 Finishing materials

The contribution of finishing materials to the thermal effectiveness of the insulation system is in general, negligible, but usually a finish is desirable for one of the following reason:

a) To give appropriate protection against mechanical damage.

b) To assist in identifying the pipe or vessel. This may be achieved by painting, either with a characteristic color or by means of colored bands at intervals. This identification also may be used to indicate the direction of flow for the fluid content. (See IPS-E-TP-100 for identification color.)

c) To give protection against excessive moisture, corrosive vapor, etc., in the atmosphere.

d) To give protection against spillage of oils and other flammable liquids.

e) To improve appearance or to provide a surface that can be cleaned easily.

f) To retard, or if possible to prevent, the spread of flame.

g) To protect against chemical attack, vermin, and mould growth

h) To resist against heat in the case of metallic jacketing

7.2.3 Securing materials

7.2.3.1 General

Insulation systems may be secured by means of adhesives, by mechanical means, or by a combination of both.

7.2.3.2 Adhesives

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

7.2.3.2.2 Classification according to use

Adhesives for insulation may be classified as follows:

7.2.3.2.2.1 Insulation bonding adhesives

These adhesives are used for securing preformed slabs and sections, or flexible insulating materials to themselves and to structures such as equipment and ducts. Generally the substances in this group are of relatively heavy consistency and have good gap-filling characteristics, i.e., are of high build and have high solids content (see Table 11).

7.2.3.2.2.2 So-called 'lagging' adhesives

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

7.2.3.2.2.3 Facing and film-attachment adhesives

These adhesives are used for attaching flexible laminates, foils and plastics film to thermal insulation, and for bonding the overlaps of these materials.

7.2.3.2.3 Application characteristics

Important properties that affect use are:

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

Other properties that may require consideration are:

- Flashpoint;
- toxicity;
- temperature and humidity range (for application);
- range of bonding times;
- curing times;
- stability in storage;
- possibility of corrosive attack;
- danger from attack by solvents.

(Slow loss of water can give rise to corrosion; alkaline adhesives, e.g., sodium silicate, can attack aluminum and glass fiber; organic foams, especially polystyrene, are susceptible to attack by certain solvents.)

TABLE 11 - INSULATION BONDING ADHESIVES FOR PREFORMED SECTIONS AND SLABS

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

Note:

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

7.2.3.2.4 Service properties

Properties affecting the behaviour of the adhesive after installation are as follows:

7.2.3.2.4.1 Temperature limits

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

7.2.3.2.4.2 Adhesive strength

Because of the low bulk density and loose bonding of many insulating materials, high strength of adhesive is not usually the most important requirement. However, the adhesive strength has to exceed the cohesive strength of the insulating material by a safe margin under all conditions of service. For materials of higher bulk density and strength, stronger adhesive will be required, and these have to be adequate to carry the required load with an ample margin of safety.

7.2.3.2.5 Mechanism of curing

7.2.3.2.5.1 Solvent-based adhesives

The mechanism of curing is by the evaporation of organic or aqueous solvents or by the absorption of water into porous adherents with subsequent evaporation.

7.2.3.2.5.2 Chemically curing adhesives

The group of adhesives generally set by a chemically activated cross-linking process.

7.2.3.2.5.3 Hot melt adhesives

These are applied as hot viscous liquids and form a bond by solidification on cooling to ambient temperatures.

7.2.3.2.6 Types of adhesives

Following is the list of some adhesive as a guidance only. For some information on properties reference is made to BS 5970 and for specification see IPS-M-TP-710:

a) Bitumens.
b) Epoxy resins.
c) Natural rubber.
d) Neoprene phenolic.
e) Nitrite phenolic.
f) Polyvinyl acetate.
g) Reclaimed rubber.
h) Styrene-butadiene-based (SBR) cement.
i) Alkyd resins.
j) Rubber latex/hydraulic cement.
k) Polyurethanes.

7.2.3.3 Mechanical securements

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

7.2.3.3.2 Welded attachments are used mainly on the vertical faces of piping, or vertical and downward-facing vessels and equipment. They can be in the form of cleats, angles, pads, studs, bolts, nuts, etc., that will provide support for bolted fittings and permanent datum positions relative to each other.

7.2.3.3.3 Bolted fittings are used mainly in conjunction with welded attachments and they can be in the form of angle rings, flat rings, etc.; and such they provide the horizontal support for insulating and cleading materials.

7.2.3.3.4 Banding and wire securements are used mainly to hold materials firmly to the plant to be insulated; they may be of metal, fabric, plastics strip, etc.

8. SELECTION OF INSULATION AND ACCESSORY MATERIALS

8.1 General

Materials for insulation, fastening, jacketing and finishing shall be selected from the materials described below unless otherwise agreed by the Company. For more information on insulation materials reference is made to BS 5422. (See IPS-M-TP-710 for specification of insulation and accessory materials.)

8.2 Thermal Insulating Materials

8.2.1 Before deciding on the insulating materials to be used for any specific purposes the following factors shall be considered:

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

8.2.2 Thermal insulation material(s) shall be selected based on Table 12.

8.2.3 Miscellaneous insulation materials shall be as following:

8.2.3.1 Expansion or contraction joint material shall be loose mineral wool fiber for temperature limit of -101°C to 650°C.

8.2.3.2 Hydraulic-setting thermal insulation cement shall have asbestos free mineral fiber.

8.2.3.3 Steam tracer lead insulation tubing should comprised of an inner layer of braided asbestos tubing a middle layer of glass fiber insulation and an outer layer of braided asbestos tubing with a factory applied weather coat mastic.

8.2.4 Typical characteristics for a number of thermal insulating materials available for use mainly for temperatures higher than ambient temperatures are indicated in Tables 13 and 14 and the corresponding characteristics for typical materials particularly suitable for the temperatures lower than ambient temperatures are indicated in Tables 15 and 16. It should be noted that maximum service temperature of some lower temperature insulation materials are such that they can be used also for elevated temperatures.

Thermal conductivity values versus temperature for insulating materials are given in Figs. 2a to c.

TABLE 12 - RECOMMENDED THERMAL INSULATION MATERIALS

COMMODITY	SERVICE	RECOMMENDED MATERIAL		FORM OF THERMAL INSULATION	TEMPERATURE LIMIT °C
THERMAL INSULATION	HOT (HIGHER THAN AMBIENT TEMPERA-TURE)	MINERAL FIBER	ROCK/SLAG	1-BLANKET	600
				2-PREFORMED PIPE SECTION	600
				3-PREFORMED BOARD/SLAB	540
			GLASS	1-BLANKET	500
				2-PREFORMED PIPE SECTION	450
				3-PREFORMED BOARD/SLAB	450
		CALCIUM SILICATE		PREFORMED BLOCK AND PIPE SECTION	650
		CERAMIC FIBER		BLANKET	1150
		CELLULAR GLASS/FOAM GLASS		BLOCK AND PIPE SECTION	-268 TO 427
	COLD (LOWER THAN AMBIENT TEMPERA-TURE)	POLYURETHANE AND ISOCYANURATE		1-SPRAY APPLIED RIGID CELLULAR POLYURETHANE	90
				2-UNFACED PREFORMED RIGID CELLULAR POLYURETHANE BLOCK AND PIPE SECTION	-40 TO 107
		BAKED CORK		BOARD AND PIPE SECTION	80
		CELLULAR GLASS/FOAM GLASS		BLOCK AND PIPE SECTION	-268 TO 427

TABLE 13 - TYPICAL MATERIALS FOR HIGHER TEMPERATURE RANGES

REF.	MATERIAL	PHYSICAL FORMS	TYPE	APPROXIMATE MAXIMUM OPERATING TEMPERATURE (I) °C	NORMAL BULK DENSITY kg/m³	COMPRESSIVE STRENGTH (II)
1	ALUMINIUM FOIL	PLAIN/CORRUGATED FOIL		540		NEGLIGIBLE
2	STAINLESS STEEL	DIMPLED FOIL	REFLECTIVE	760		NEGLIGIBLE
3	MINERAL FIBRE (GLASS)	LOOSEFILL (III)	FIBROUS	540		NEGLIGIBLE
4	"	RESIN-BONDED SLABS	FIBROUS	230 TO 540 (IV)	16 TO 96	FAIR/GOOD
5	"	PREFORMED PIPE SECTIONS	FIBROUS	230 TO 540	80 TO 160	FAIR/GOOD
6	"	MATTRESSES	FIBROUS	540	48 TO 144	FAIR/GOOD
7	"	FLEXIBLE STRIP, ROPES, TWISTED YARN, WOVEN CLOTH AND TAPE	FIBROUS	230 TO 540	48 TO 96	NEGLIGIBLE
8	MINERAL FIBRE (ROCK)	LOOSEFILL (III)	FIBROUS	760 TO 950		NEGLIGIBLE
9	"	RESIN-BONDED SLABS	FIBROUS	260 TO 760 (IV)	16 TO 192	FAIR/GOOD
10	"	PREFORMED PIPE SECTIONS	FIBROUS	260 TO 700 (IV)	80 TO 144	GOOD
11	"	FLEXIBLE MATTRESSES	FIBROUS	570 TO 760	88 TO 128	FAIR
12	"	SPRAYED	FIBROUS	760	224 TO 240	GOOD
13	MINERAL FIBRE (SLAG)	LOOSEFILL (III)	FIBROUS	760		NEGLIGIBLE
14	"	BONDED SLABS	FIBROUS	760 (IV)	48 TO 320	NEGLIGIBLE/GOOD
15	"	PREFORMED PIPE SECTIONS	FIBROUS	260 TO 700 (IV)	144 TO 256	FAIR/GOOD
16	"	MATTRESSES	FIBROUS	650 TO 800	80 TO 256	FAIR
17	"	FLEXIBLE STRIP	FIBROUS	230	80 TO 160	NEGLIGIBLE
18	DIATOMITE (KIESELGUHR)	LOOSEFILL	GRANULAR NATURAL	900	192	NEGLIGIBLE
19	"		GRANULAR CALCINED	1090	160	
20	"	BRICKS AND SLABS	GRANULAR	900	640	4.1 MN/m²
21	VERMICULITE	LOOSEFILL	GRANULAR	1090	48 TO 144	NEGLIGIBLE
22	VERMICULITE/CONCRETE	SLABS AND SPRAYED	GRANULAR	430 TO 1090	320	
23	VERMICULITE/SODIUM SILICATE	SLABS AND SPRAYED	GRANULAR	890 TO 980	432	GOOD
24	85% MAGNESIA	PLASTIC COMPOSITION	GRANULAR	310	176 TO 224	FAIR
25	"	PREFORMED SLABS	GRANULAR	310	176 TO 224	GOOD (345 kN/m²)
26	"	PREFORMED PIPE SECTIONS	GRANULAR	310	176 TO 224	GOOD
27	CALCIUM SILICATE	PLASTIC COMPOSITION	GRANULAR	650 TO 1000	160 TO 320	FAIR
28	"	SLABS/LAGS	GRANULAR	650 TO 1010	160 TO 320	GOOD (345 kN/m² MINIMUM)
29	"	PREFORMED PIPE SECTIONS				
30	FOAMED GLASS	SLABS AND PIPE SECTIONS	GRANULAR	650 TO 760	160 TO 320	GOOD
31	ALUMINO-SILICATE	LOOSEFILL	CELLULAR	400	112 TO 144	16.4 MN/m² ULTIMATE
32	"	SPRAY APPLIED	FIBROUS	1260	8 TO 128	NEGLIGIBLE
33	"	BLANKET, FELT, PAPER	FIBROUS	1260	192	FAIR
34	"	ROPES, TUBES	FIBROUS	1260	50 TO 200	FAIR
35	SILICA	LOOSEFILL	FIBROUS	1260	48 TO 144	NEGLIGIBLE
36	"	CLOTH, FELT TAPE	FIBROUS	980	8 TO 128	NEGLIGIBLE
37	"	OPACIFIED AEROGEL SLATTED BLANKET	FIBROUS	980	48 TO 144	FAIR
38	PERLITE	LOOSEFILL	GRANULAR	980	192 TO 384	NEGLIGIBLE
39	POLYURETHENE RIGID FOAM	SLABS, PIPE SECTION, SPRAYED, FORMED IN SITU	GRANULAR	80	32 TO 64	NEGLIGIBLE
			CELLULAR	100	32 TO 96	GOOD
40	POLYURETHENE FLEXIBLE FOAME	BLANKET, SLAB AND PIPE SECTIONS	CELLULAR	70	32 TO 64	NEGLIGIBLE
41	ISOCYANURATE AND PHENOLIC RIGID FOAM	SLABS, PIPE SECTIONS, SPRAYED	CELLULAR	130 TO 145	32 TO 64	GOOD
42	FOAMED SLAG	LOOSEFILL	GRANULAR	900	≤400 kg/m³	GOOD

I) These are intended to apply only when one face is heated. When both faces are heated lower temperatures will apply.
II) For fibrous materials, the compressive strength will vary with the bulk density and with the binder.
III) Loosefill materials shall be packed to densities to suit the thermal conductivity required.
IV) Above 260°C compressive strength may be reduced significantly owing to volatilization of the bonding material.

Notes:

1) For typical thermal conductivity values see Figs. 2a and 2b.

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

TABLE 14 - HOT INSULATION MATERIAL SELECTION CRITERIA

CHARACTERISTICS / TYPE	FIRE RESISTIVITY	THERMAL CONDUCTIVITY	WATER-PROOFNESS	NON-CORROSIVENESS	MECHANICAL STRENGTH	CHEMICAL RESISTIVITY	PHYSICAL SAFETY	EASE OF REPAIR
ROCK WOOL	O	O 0.045	X	O	X	O	O NOTE 5	O
GLASS WOOL	O	O 0.041	X	O	X	O	O NOTE 5	O
CERAMIC WOOL	◎	O 0.046	X	O	X	O	O	O
HAIRFELT	X	O 0.053	X	O	X	X	O	◎
PERLITE	◎	O 0.061	X	O NOTE 3	O	O	O	O
DIATOMACEOUS EARTH	◎	X 0.095	X	O	X	O	O	X
CALCIUM SILICATE	◎	O 0.067	X	O	◎	O	O	O
CELLULAR GLASS	◎	◎ 0.058	◎	O	O	O	O	X
FOAMED HARD URETHANE	X	◎ 0.029	O	O NOTE 4	X	O	O NOTE 6	O

Notes:

1) Evaluation criteria: Highly superior , Superior O, Inferior X.

2) Thermal conductivities have been evaluated in steps of under 0.035, 0.035-0.07 and over 0.07 W/mK under 70°C.

3) If water is absorbed, aluminum will be attacked.

4) HCl may form if water is absorbed.

5) May cause irritation to the skin.

6) Poisonous gas is formed when subject to fire.

TABLE 15 - TYPICAL MATERIALS FOR LOWER TEMPERATURE RANGES

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

I) For fibrous materials, the compressive strength will vary with bulk density and with the binder.
II) For physical forms and properties see Table 13.

Notes:

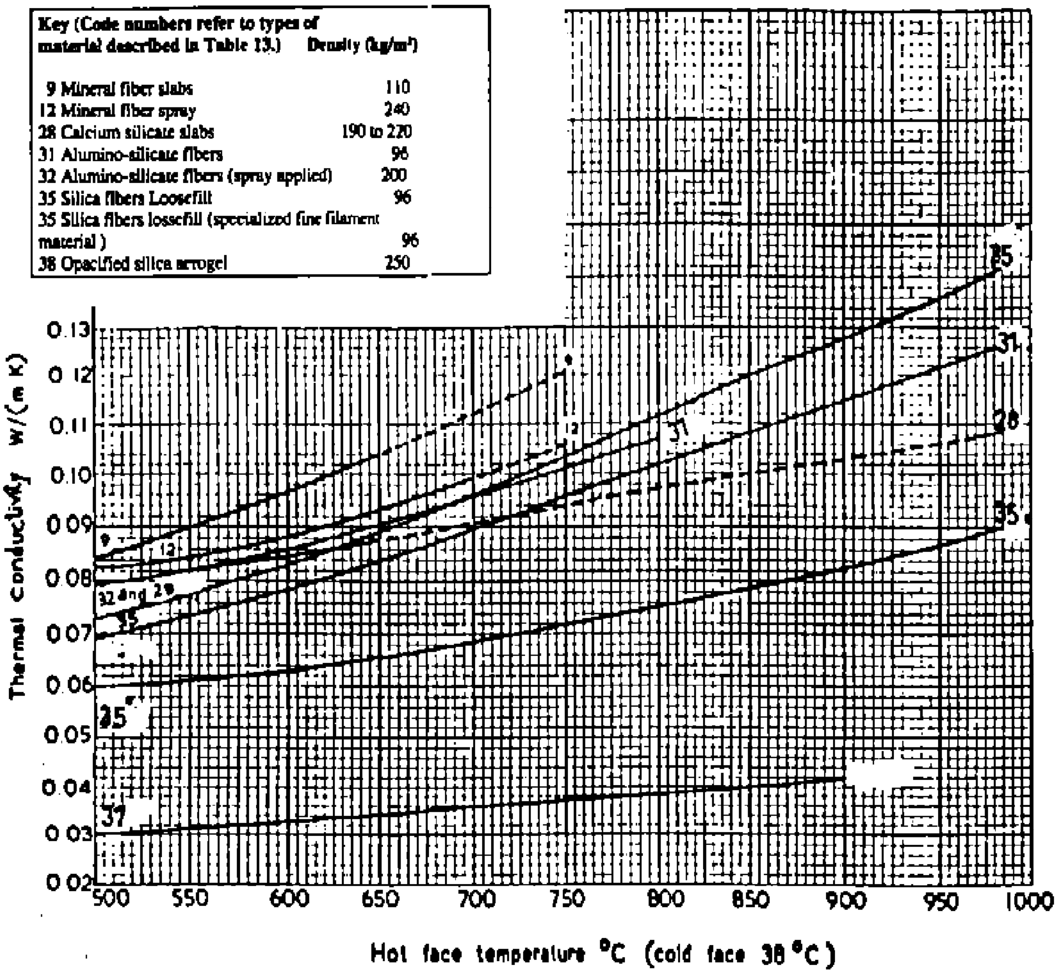
1) For typical thermal conductivity values (see Fig. 2c).
2) Care is necessary in interpreting the maximum operating temperatures in this table. These are based on manufacturers' claimed figures and may require modification (possibly considerable) in practice.

TABLE 16 - COLD INSULATION MATERIAL SELECTION CRITERIA

CHARACTERISTICS / TYPE	FIRE RESISTIVITY	THERMAL CONDUCTIVITY	MOISTURE-PROOFNESS	HEAT RESISTIVITY	MECHANICAL STRENGTH	CHEMICAL RESISTIVITY	NON-CORROSIVENESS (INERTNESS)	PHYSICAL SAFETY (ODOR & DUST)	EASE OF REPAIR
PERLITE	◎	X 0.050	X	◎	X	◎	O	X NOTE 4	X
GLASS WOOL	O	O 0.031-0.037	X	◎	X	O	O	O NOTE 5	O
ROCK WOOL	O	X 0.045-0.054	X	◎	X	O	O	O NOTE 5	O
HAIRFELT	X	X 0.041	X	◎	X	X	◎	◎	◎
CELLULAR GLASS	◎	X 0.047	◎	◎	O	O	◎	O	X
FOAMED POLYSTYRENE	X NOTE 3	O 0.033-0.037	O	X	O	X	O	O NOTE 6	O
FOAMED PHENOL	X NOTE 3	O 0.029-0.031	O	X	O	O	O	O NOTE 6	O
FOAMED HARD URETHANE	X NOTE 3	◎ 0.020-0.026	O	X	O	O	O	O NOTE 6	O
FOAMED VINYLCHLORIDE	X NOTE 3	O 0.031-0.035	O	O	◎	O	X	O NOTE 6	O

Notes:

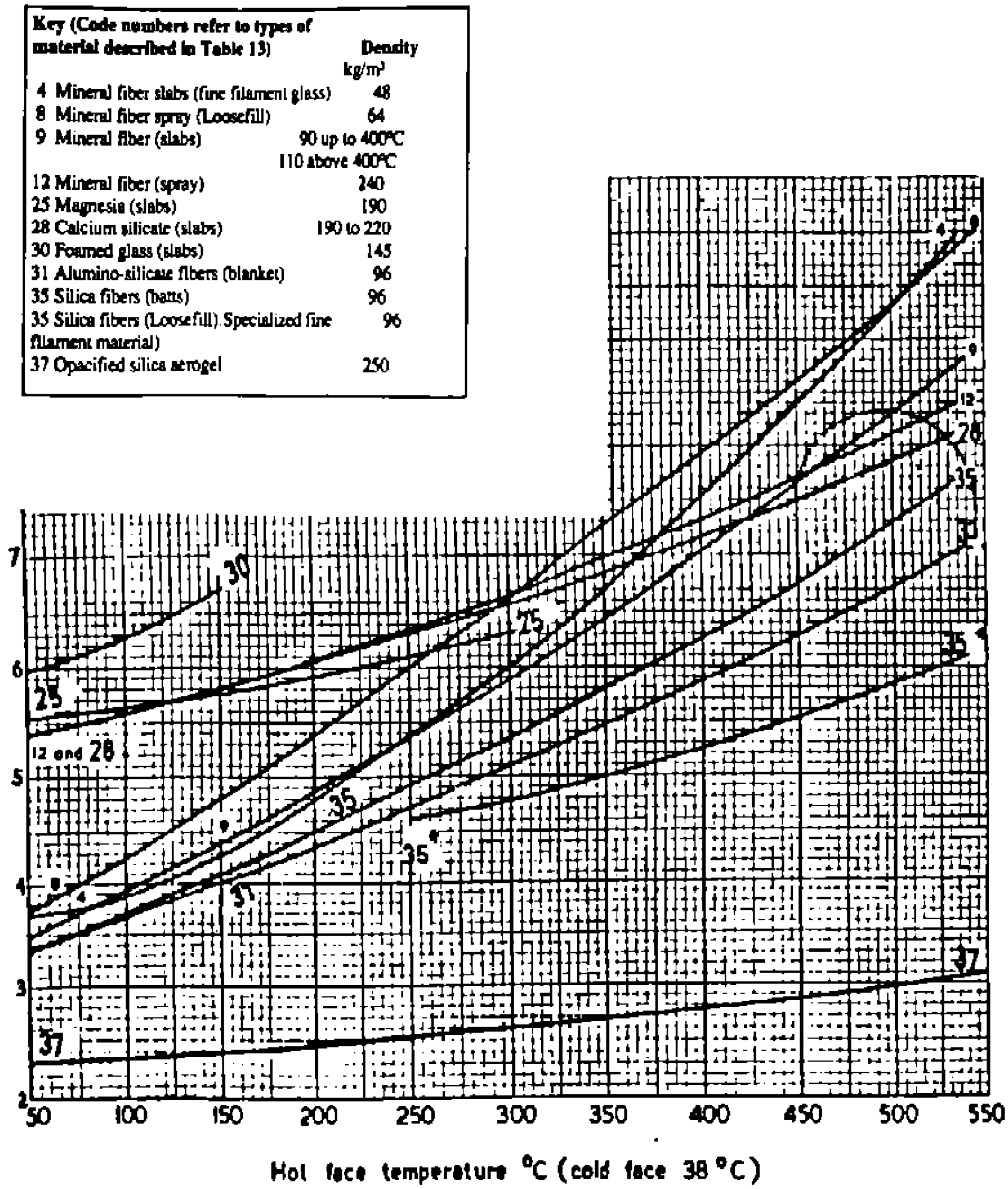
1) Evaluation criteria: Highly superior , superior O, inferior x
2) Thermal conductivities have been evaluated in steps of under 0.029, 0.029-0.040 and over 0.04 W/mK.
3) While combustible, self extinguishable.
4) Dust.
5) May cause irritation to the skin.
6) Poisonous gas will form when subject to fire.



a) Materials for use at relatively high temperatures

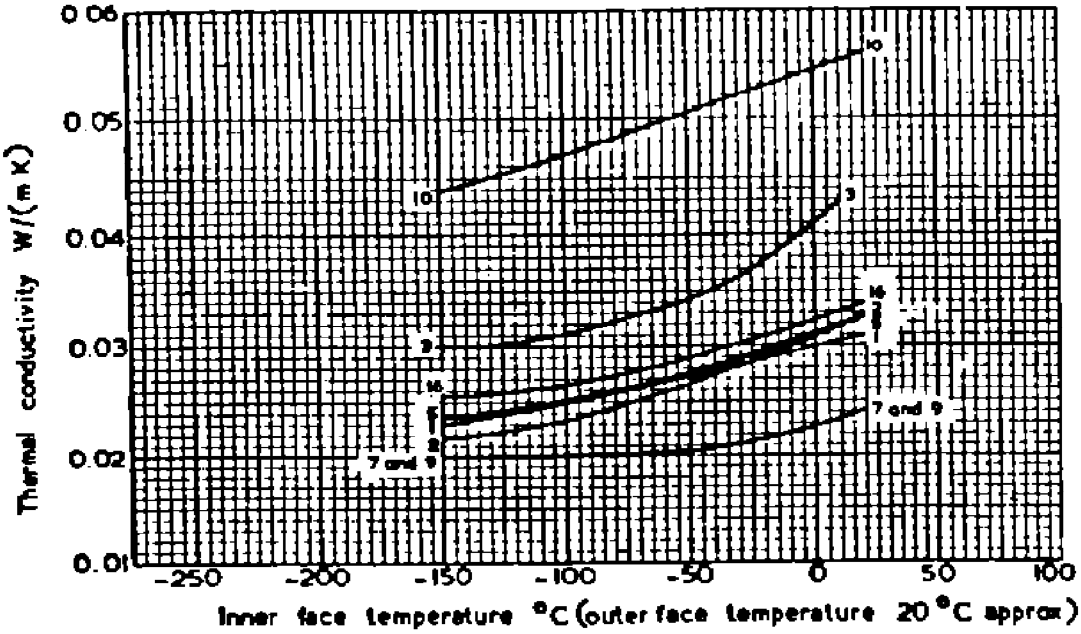
TYPICAL CONDUCTIVITY VALUES FOR INSULATING MATERIALS
Fig. 2

Note: See Table 13.



b) Materials for use at intermediate temperatures
Fig. 2

Key (Code numbers refer to types of material described in Table 15)	Density kg/m³
1 Phenolic foam	30
2 Expanded polystyrene	31
3 Crock	112 to 192
5 Expanded PVC	80
7 Polyurethane (rigid foam)	32
9 Isocyanurate (rigid foam)	48
10 Foam glass	145
16 Expanded perlite	48



c) Materials for 'Cold Insulation'
Fig. 2

8.3 Fastening Materials

8.3.1 Banding

8.3.1.1 Bands where used under cleading (Jacketing) for securing rigid preformed insulation on pipe, vessels and tanks shall be hot dip galvanized mild steel.

8.3.1.2 Bands for securing metal jacket on pipe, vessels and tanks shall be stainless steel 18-8 Cr-Ni AISI type 302 or 304.

8.3.1.3 Tape for securing pipe foam insulation used in low temperature services shall be glass filament rein- forced pressure sensitive type.

8.3.1.4 Type for sealing contraction joint in cold insulation system shall be foil-to-Kraft tape.

8.3.2 Miscellaneous fastening materials

8.3.2.1 Seals for bands shall be 18-8 Cr-Ni stainless steel AISI type 302 or 304.

8.3.2.2 Wire to secure insulation shall be soft annealed galvanized mild steel for hot insulation and stainless steel 18-8 Cr-Ni AISI type 302 or 304 for cold insulation.

8.3.2.3 Breather spring shall be 18-8 Cr-Ni stainless steel AISI type 302 or 304.

8.3.2.4 Sheet metal screw shall be hard aluminum alloy for aluminum jackets and 18-8 Cr-Ni stainless steel AISI type 302 or 304 for steel jacket.

8.3.2.5 Wire mesh poultry netting shall be galvanized carbon steel.

8.3.2.6 "S" clips shall be aluminum in the case of aluminum sheet and 18-8 Cr-Ni stainless steel AISI type 302 or 304 in the case of steel sheet.

8.3.2.7 Clips and quick release toggles shall be 18-8 Cr-Ni stainless steel AISI type 302 or 304 or hard aluminum.

8.3.2.8 Support ring shall be carbon steel.

8.3.2.9 Expanded metal as reinforcement shall be bitumen coated or galvanized mild steel or 18-8 Cr-Ni stainless steel AISI type 302 or 304.

8.4 Jacketing Materials

8.4.1 Jacketing materials shall be one of the following recommended metallic alloys, the application of which depends on condition:

a) Aluminum;
b) aluminized steel;
c) galvanized steel;
d) coated steel;
e) stainless steel.

Note that melting point of aluminum is considerably lower than other recommended jacketing materials.

8.4.2 The combination of jacketing and fastening materials for an insulation system shall be according to Table 17.

TABLE 17 - COMBINATION OF JACKETING AND FASTENING MATERIALS

FASTENER / JACKETING MATERIAL	BANDS	SELF-TAPPING SCREWS	RIVETS	CLIPS AND QUICK-RELEASE TOGGLES
Aluminum	Stainless steel	Hard aluminum or stainless steel	Hard aluminum	Stainless steel or aluminum
Aluminized steel galvanized steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel

8.5 Finishing Material

8.5.1 Joint sealer shall be non-setting, non-shrinking permanently flexible compound.

8.5.2 Flashing compound shall be high temperature asphalt mastic with non-asbestos fiber or filler for weather proofing application.

8.5.3 Weather proofing mastic for high temperature insulation system shall be emulsion type polymeric protective coating: Acrylic or polyvinyl acetate or combination of both.

8.5.4 Vapor barrier or weatherproofing mastic for low temperature insulation shall be non-asphaltic elastomeric mastic suitable for application over polyurethane or foamglass or other cold insulation.

8.5.5 Adhesive for cellular glass to sphere shall be a two part adhesive compound of latex rubber/hydraulic cement. (See 7.2.3.2.)

8.5.6 Properties for some insulation outer (jacketing and finishing) material are indicated in Table 18.

TABLE 18 - INSULATION OUTER (COVERTURE) MATERIAL SELECTION CRITERIA

Classification	Characteristics Type	Fire Resistivity	Chemical Resistivity	Required Mechanical Strength	Heat Resistivity	Water Resistivity	Moisture Resistivity	Physical Safety	Corrosion Resistivity	Adaptability for use with insulation material	Ease of Repair	Limitation
Weather-proofing and Indoor Use Outer Covering	Galvanized steel sheet	●	O	●	● (Approx. [illegible]°C)	●	X	●	X	●	X	Usable for both cold and hot insulation in outdoor and indoor areas
	Pre-painted galvanized steel sheet	●	●	●	O (Approx. [illegible]°C)	●	X	●	O	●	X	
	Stainless steel sheet	●	●	●	● (Approx. [illegible]°C)	●	X	●	●	●	X	
	Aluminium sheet	X	X	●	● (Approx. [illegible]°C)	●	X	●	X	Note 3 O	X	
Weather-proofing	Asphalt emulsion type mastic	X	O	O	X (Approx. [illegible]°C)	●	O	O	O	Note 4 O	●	Hot insulation outdoor use
	Resin (or rubber) emulsion type mastic	O	O	O	X (Approx. [illegible]°C)	●	O	O	O	O	●	
Indoor Outer Covering	Hard cement	●	O	●	● (Approx. 500°C)	O	X	X	O	O	●	Hot insulation indoor use
	Asbestos cloth	O	X	X	O Note 2	O	X	X	●	Note 5 O	O	Both hot and cold insulation. Dust prevention measures required for cold insulation indoor use
	Glass cloth	●	X	X	● (Approx. 100°C)	O	X	●	●	Note 6 O	●	
	Canvas	X	X	X	X (Approx. [illegible]°C)	O	X	●	●	O	●	
	Vinyl tape Adhesive tape	X	X	X	X (Approx. 60°C)	●	X	●	●	O	●	

Notes:

1) Evaluation criteria: Highly superior , superior O, interior X.

2) Heat resistivity depends on asbestos content: Be careful of this.

3) May be corroded by alkaline matter in insulation: Be careful of this point.

4) Water migrates from these hydrous materials to the insulation, impairing the insulation characteristics. Fiber-state insulation is easily affected and cracked by pressure.

5) Surface irregularities will easily occur when fibrous insulation is wrapped with cloth or tape.

6) Must be patched with cardboard or other material to provide good form.

APPENDICES

APPENDIX A
CALCULATION OF ECONOMIC THICKNESS

A.1 Introduction

The required thickness of insulation for any specific application depends upon the characteristics of the insulating material and the purpose of the equipment. Where the sole object is to achieve the minimum total cost, the appropriate thickness is known as the economic thickness.

The costs to be considered are as follows[1]:

a) The cost of heat lost from the insulated surfaces during the evaluation period;
b) the cost of the insulation system during the evaluation period.

Any increase in the amount of insulation applied raises the cost of the insulation but decreases the cost of heat lost. The sum of the two costs may be shown to lie on a curve with a rather flat region on either side of a minimum value representing the economic thickness.

Alternative systems should therefore be derived and compared. It should be noted that methods used for calculating economic thicknesses refer primarily to application over uniform types of surface, e.g., straight lengths of pipework. Thus they do not take account of insulating valves and bends, nor do they necessarily include the cost of providing for staggered joints or multiple layers. Also the method of algebraic solution requires the assumption that the incremental cost of insulation can be related to the volume of insulating material, i.e., per cubic meter or per liner meter for given diameters of pipe.

Methods of obtaining economic thickness are given in A.2 to A.4.

A.2 Economic Thickness by Tabulation (see Table A.1)

The cost of insulation (including application and any normal finish) and of the heat lost are tabulated for a range of thickness of insulation. These costs are added for each thickness and the minimum total becomes apparent. For the purpose of calculating the cost of heat lost, the surface coefficient can be taken to be 10.0 W/(m.K), since likely variations from this figure do not significantly affect the result. The insulating effect of finishing materials is ignored. The cost of heat lost is as follows:

a) Cost of heat lost from flat surface = 5400 Hq Y 10^{-6} cent/m^2;
b) cost of heat lost from cylindrical surfaces = 5400 Hq_1 Y 10^{-6} cent/m

Where:

$$q_1 = 10^{-3}\ \pi\ d_o\ q$$

This method is of advantage if the cost of increasing thickness of insulating material does not follow a uniform pattern, e.g., if there is a transition from a single layer to a double layer system.

1) It is recognized that in particular instances allowances may be necessary for the capital or operating costs of the installation as a whole, but these are not considered in this Standard.

A.3 Economic Thickness by Algebraic Solution

A.3.1 Incremental cost derivation

In the derivation of an algebraic expression for economic thickness, a term arises which is a function of the insulation cost, and for the equation given in A.3.2, the term is represented by the symbol C which is defined as the incremental cost of insulation.

It is important to realize that this is not the simple difference in applied cost between one thickness and the next higher one, but is more strictly interpreted as the derivative of the applied cost with respect to the volume of insulation. It should be noted that the additional cost of the finish and accessories resulting from the increasing thickness of insulation, is included.

Within the context of this method of economic thickness calculation, therefore, the value of C should be obtained from a measurement or deduction of the slope of the curve for the plot of insulation cost against insulation thickness. However, in practice, such a graph is unlikely to exhibit a curve (unless forced smoothing of the plotted points is carried out) and the alternative approach, [see (a) and (b) in this clause] is commonly adopted in these circumstances. By this method, any one value of C can be estimated from the costs of two correspondingly successive thicknesses, with the understanding that the value applies to neither one, but may relate to a thickness about midway between them. Sequential values obtained in this manner can still be very erratic and should be subsequently smoothed where the situation calls for an orderly progression of C values.

The equations for deriving the incremental cost in accordance with the two methods described in the previous paragraph are as follows:

a) From the slope of the cost curve:

1) Cylindrical surfaces:

$$C = \frac{S}{\pi\, d_n} \times 10^6$$

2) Flat surfaces:

$$C = S \times 10^3$$

b) From the cost of two successive thicknesses

This is determined from the change in cost divided by the corresponding change in volume on insulation:

1) Cylindrical surfaces:

$$C = \frac{(P_b - P_a)\, 10^6}{\pi\, (d_o + L_b + L_a)(L_b - L_a)}$$

2) Flat surfaces:

$$C = \frac{(P_b - P_a)\, 10^3}{(L_b - L_a)}$$

Where:

S is the slope of the curve of P against L;
d_n is the outermost diameter of the insulation (in mm);
P is the installed cost of insulation (in S/m or S/m²);

L is the insulation thickness (in mm);
d_o is the outside diameter of pipe (in mm);
C is the incremental cost (in S/m³).

Subscript a refers to one thickness and subscript b refers to the next higher thickness.

A.3.2 Methods of calculation

If it is assumed that the cost per cubic meter of each increment through the insulation thickness is constant, it is possible to give a simple algebraic expression relating the total cost of the insulation, plus that of the heat loss in an arbitrary period of time, to the thickness of insulation. This expression can then be used to find the thickness of insulation that gives the minimum total cost. The economic thickness obtained in this way is given by the following equation:

$$L = 5.76\left[\frac{HY\lambda(\theta_1 - \theta_m)}{C}\right]^{0.5}$$

The equation makes only an approximate allowance for the temperature difference between the atmosphere and the insulation surface, but this approximation has little effect on the calculated economic thicknesses and the method is applicable to all normal insulation systems. Appreciable inaccuracies occur when considering high cost insulation having a high thermal conductivity and in this case the method given A.2 has to be used.

In practice it may be found that the incremental cost of the insulation is not constant. The expression for economic thickness is given in the first paragraph of this clause; however; Table A.1 can still be used provided that the value of C taken is appropriate to the economic thickness. When making a calculation it is first necessary to take an approximate value for C which is used to calculate a value for the economic thickness. If the value of C taken is found not to be appropriate to the economic thickness obtained, a more appropriate value of C should be taken and the calculation repeated.

A.4 Examples of Calculation of Economic Thickness

A.4.1 General

To illustrate the application of the methods in A.3.2 the economic thickness for a typical case is deduced by each method in A.4.2 and A.4.3.

A.4.2 Economic thickness by tabulation

Cost of heat, Y	= 1.14 cent/useful MJ
Evaluation period, H	= 40000 h
Hot face temperature, θ_1	= +500°C
Ambient air temperature, θ_m	= +20°C
Thermal conductivity of the insulation, λ	= 0.09 W/(m.K)
Pipe diameter (outside), d_o	= 210 mm

In this example the least total cost tabulated occurs at a thickness of 100 mm; this is the economic thickness for the conditions indicated.

A.4.3 Economic thickness by algebraic solution

Cost of heat, Y	= 1.14 cent/useful MJ
Evaluation period, H	= 40000 h

Hot face temperature, θ_1 = +500°C
Ambient air temperature, θ_m = +20°C
Thermal conductivity of the insulation, λ = 0.09 W/(m.K)
Pipe diameter (outside), d_o = 219.1 mm

Symbols:

H = Evaluation period in hour (working);
Y = Cost of heat in cent/useful MJ;
q = Rate of heat loss through the insulating material per unit area of hot surface per second in W/m^2;
λ = Thermal conductivity of insulation material in W/mK;
θ_1 = Hot face temperature in °C;
θ_m = Ambient air temperature in °C;
χ = Economic thickness in mm.

For the purpose of the calculation, the incremental cost C varies from 891 S/m³ (see Table A.2). As an initial approximation, C is taken as the average of 698 \$/m³.

Step 1:

From the equation given in A.3.2.

$$\chi = 5.76 \left[\frac{40000 \times 0.76 \times 0.09 \times (500 - 20)}{465} \right]^{0.5} = 306.1\ mm$$

Therefore the economic thickness for a flat surface using insulation for which C = 698 \$/m³ is 306.1 mm.

Step 2:

The equation $\chi = 0.5\,(d_o + 2L)\ \ln\,(1 + 2L/d_o)$ is used to find the corresponding thickness L for a pipe of 219.1 mm outside diameter.

$$306.1 = 0.5\,(219.1 + 2L)\, ln \left[1 + \frac{2L}{219.1} \right]$$

The value of L can not be obtained directly from this equation. It can however be obtained either by trial and error or graphically (see Fig. A.2). The result is L = 192.4 mm (approximately).

Step 3:

If incremental costs are checked, it is found that for such a thickness the value of C is about 675 \$/m^3. Recalculation with C = 450 gives χ = 311.7 and L = 194.9 mm (approximately).

Checking incremental costs again gives a further value of 675 \$m^3 (approximately) for C, the same as the value previously taken. Further calculation is unnecessary. The economic thickness is therefore 195 mm.

A.5 Economic Thickness by Chart

In order to simplify the calculation outlined in A.3.2, Figs. A.1 and A.2 have been prepared from which the required information can be obtained.

TABLE A.1 - ECONOMIC THICKNESS : TYPICAL METHOD BY TABULATION

THICKNESS OF INSULATION IN mm	RATE OF HEAT LOSS PER LINEAR METER PER SECOND q_1 (IN W/M)	COST (IN cent)		
		HEAT LOSS, 3600 Hq_1 $Y \times 10^{-6}$	INSULATION + LABOUR + ANCILLARY MATERIALS	TOTAL
0	15018	2465335	0	2465335
50	624	102437	5139	107576
100	388	63695	9491	73186
160	288	47279	14850	62129
170	278	45636	15372	61008
180	269	44159	16506	60665
190	260	42681	17660	60341
200	252	41369	18444	59813
210	245	40220	19539	59759
220	239	39234	20633	59867
230	235	38250	21644	59894
240	228	37428	22532	59960
250	223	36608	23469	60077

TABLE A.2 - INCREMENTAL COST OF INSULATION - DOUBLE THICKNESS

Outside diameter of steel pipe (in mm)	THICKNESS (in mm)									
	120 to 140	140 to 160	160 to 180	180 to 200	200 to 220	220 to 240	240 to 260	260 to 280	280 to 300	Average cost (in g/m³)
	Incremental cost of insulation (in m³):									
17.2	632	—	—	—	—	—	—	—	—	632
21.3	631	—	—	—	—	—	—	—	—	631
26.9	618	—	—	—	—	—	—	—	—	618
33.7	652	451	—	—	—	—	—	—	—	552
42.4	573	570	283	—	—	—	—	—	—	475
48.3	553	557	416	—	—	—	—	—	—	509
60.3	517	514	512	202	—	—	—	—	—	436
76.1	358	523	523	101	—	—	—	—	—	376
88.9	362	510	511	508	—	—	—	—	—	473
101.6	496	510	507	507	415	—	—	—	—	487
114.3	422	513	513	514	499	—	—	—	—	492
139.7	404	489	490	493	491	—	—	—	—	473
168.3	410	456	458	459	459	455	—	—	—	450
219.1	594	445	447	450	449	449	—	—	—	465
244.5	382	439	439	439	433	442	439	—	—	430
273.0	581	432	428	429	431	429	431	—	—	452
323.9	300	428	436	438	445	439	444	445	—	422
355.6	599	407	426	436	439	431	416	436	—	449
406.4	562	408	440	433	431	400	436	434	—	443
457.0	637	401	425	420	419	423	420	422	421	443
508.0	548	405	424	410	420	416	415	418	418	430
Over 508	552	—	—	—	—	—	—	—	—	552

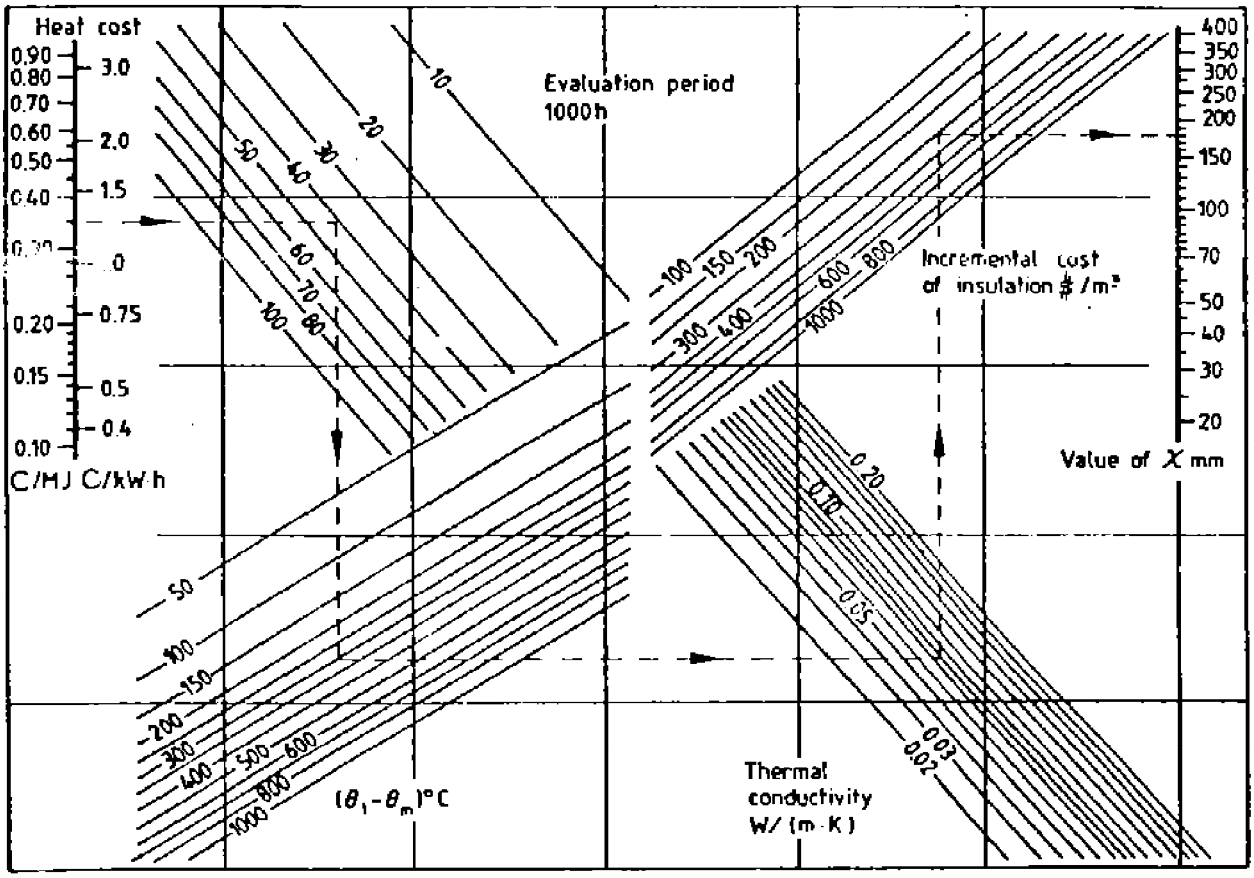


CHART FOR ECONOMIC THICKNESS OF THERMAL INSULATING MATERIAL (SEE A.5)
Fig. A.1

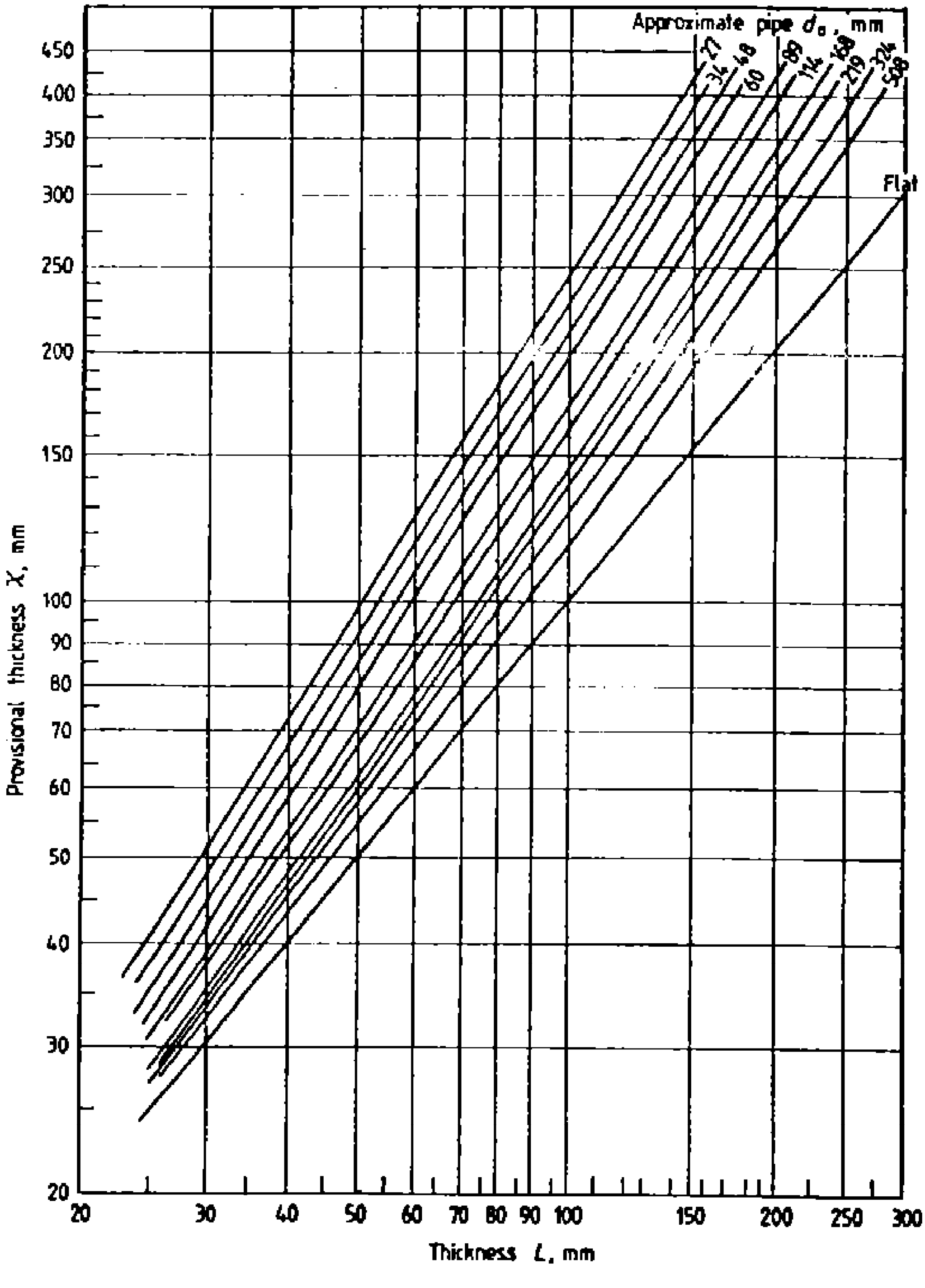


CHART SOLUTION FOR THE EQUATION

Fig. A.2

APPENDIX B
EQUATIONS FOR HEAT TRANSFER THROUGH THICKNESS OF INSULATION (THE CALCULATION BASED ON ENERGY SAVING)

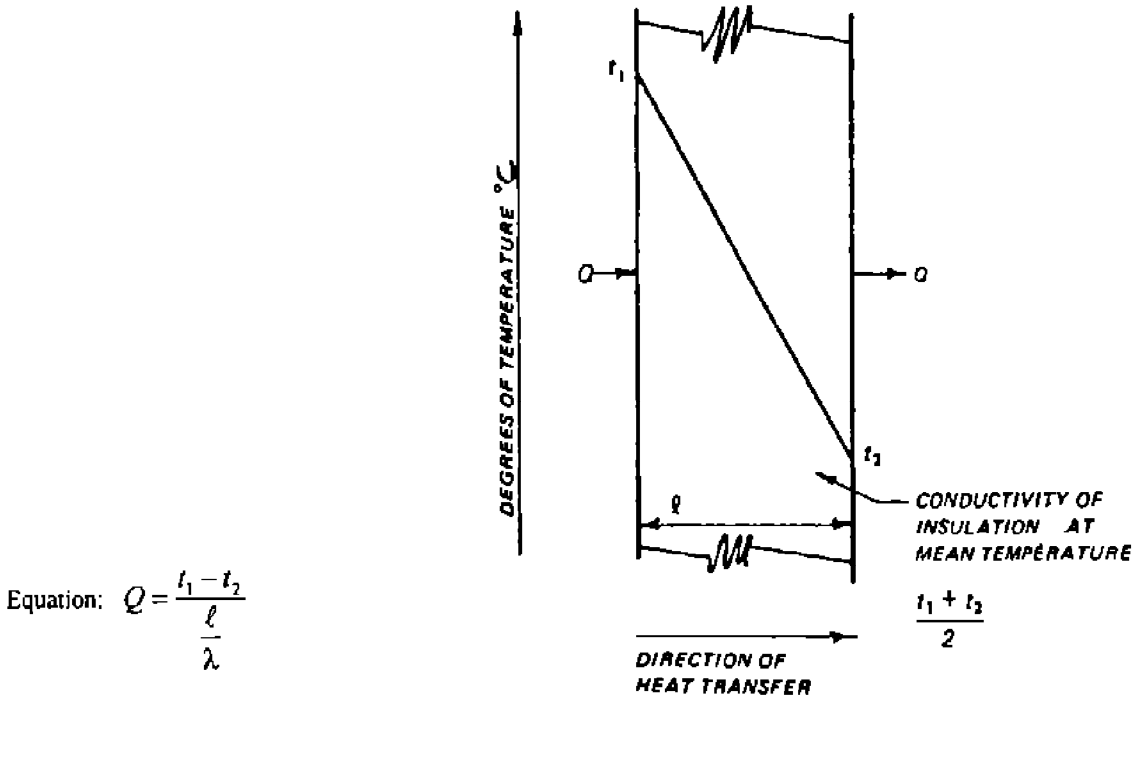
In this Appendix the heat transfer equations which relate the heat flow through the insulation to the insulation thickness and to the thermal conductivity of insulation materials for flat and cylindrical insulation are presented.

The symbols and units:

Q = heat flow in W/m;
$\mathbf{t_1}$ = temperature of hot surface in °C;
$\mathbf{t_2}$ = temperature of cold surface in °C;
l = thickness of insulation in meter;
λ = conductivity in W/mK

a) Equation for heat transfer for one thickness of flat insulation: $Q = \frac{t_1 \quad t_2}{\frac{l}{\mu}}$

In Fig. B1 these factors are shown schematically:



SCHEMATIC DIAGRAM OF HEAT TRANSFER THROUGH A SINGLE FLAT MATERIAL
Fig. B.1

Example 1:

If the temperature of insulation is 148.89°C on one surface and 21.1°C on the other surface and heat conductivity at 85°C is 0.062 W/mk and heat transfer is not to be over 94.577 W/m², what thickness of insulation is required.

As stated:

$\mathbf{t_1}$ = 148.89°C
$\mathbf{t_2}$ = 21.1°C
λ = 0.062 W/mk
$\mathbf{Q}$ = 94.577 W/m^2

$$l = \mu \frac{t_1 - t_2}{Q} = 0.062 \frac{148.89 - 21.1}{94.577} = 0.0838\, m$$

b) Equation for heat transfer for two or more thicknesses of flat insulation:

$$Q = \frac{t_1 - t_s}{\frac{l_1}{\mu_1} + \frac{l_2}{\mu_2} + \frac{l_3}{\mu_3}}$$

In which l_1, l_2, l_3 are thicknesses of first, second and third insulation material in meter and λ_1, λ_2, λ_3 are conductivities of first, second and third insulation materials in W/mk respectively. t_s is lower temperature surface. In figure B.2 the factors are shown schematically:

Example 2:

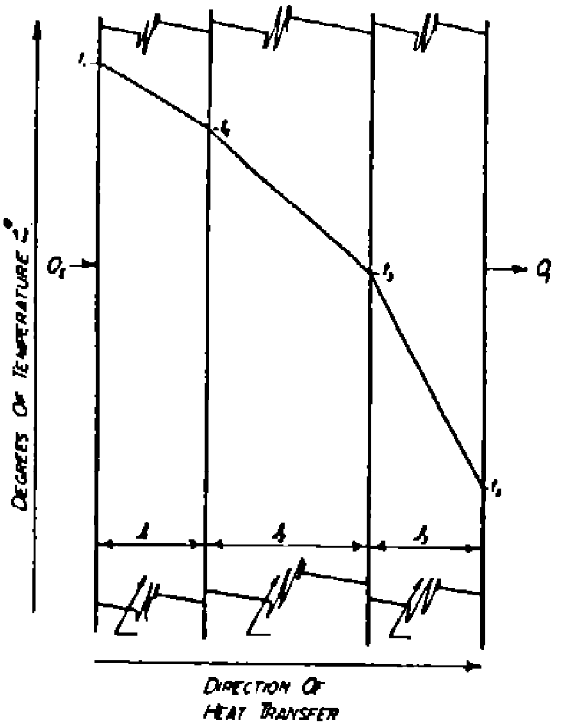
Find the thickness of two different insulation so that the heat transfer will be less than 315.26 W/m² when the temperature on one side is 760°C (t_1) and temperature on the other side is 0°C (t_s). Conductivity of one insulation is 0.108 W/mk and that of the other is 0.072 W/mk. Maximum temperature of the insulation with the lower conductivity is 649°C (t_2).

$$Q = \frac{t_1 - t_s}{\frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2}} \Rightarrow \frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} = \frac{t_1 - t_s}{Q} = \frac{760 - 0}{315.26} = 2.41$$

As it is stated that $t_1 - t_2$ = 760-649 = 111Δ°C or less and Q is stated to be no more than 315.26 W/m²:

$$l_1 = \left(\frac{t_1 - t_2}{Q}\right)\lambda_1 = + \left(\frac{760 - 649}{315.26}\right) 0.108 = 0.038 \text{ m}$$

$$l_2 = \left(\frac{t_2 - t_s}{Q}\right)\lambda_2 = \left(\frac{649 - 0}{315.26}\right) 0.072 = 2.058 \times 0.072 = 0.148$$



Note:

Conductivity:

λ_1 At Mean Temp. $\dfrac{t_1 + t_2}{2}$

λ_2 At Mean Temp. $\dfrac{t_2 + t_3}{2}$

λ_3 At Mean Temp. $\dfrac{t_3 + t_4}{2}$

Equation: $$Q_t = \frac{t_1 - t_4}{\dfrac{\ell_1}{\lambda_1} + \dfrac{\ell_2}{\lambda_2} + \dfrac{\ell_3}{\lambda_3}}$$

SCHEMATIC DIAGRAM OF HEAT TRANSFER THROUGH THREE FLAT MATERIALS
Fig. B.2

c) Equation for heat transfer through one thickness of cylindrical insulation:

$$Q = \frac{t_1 - t_2}{\left[\dfrac{r_2 \log_e\left(\dfrac{r_2}{r_1}\right)}{\lambda}\right]}$$

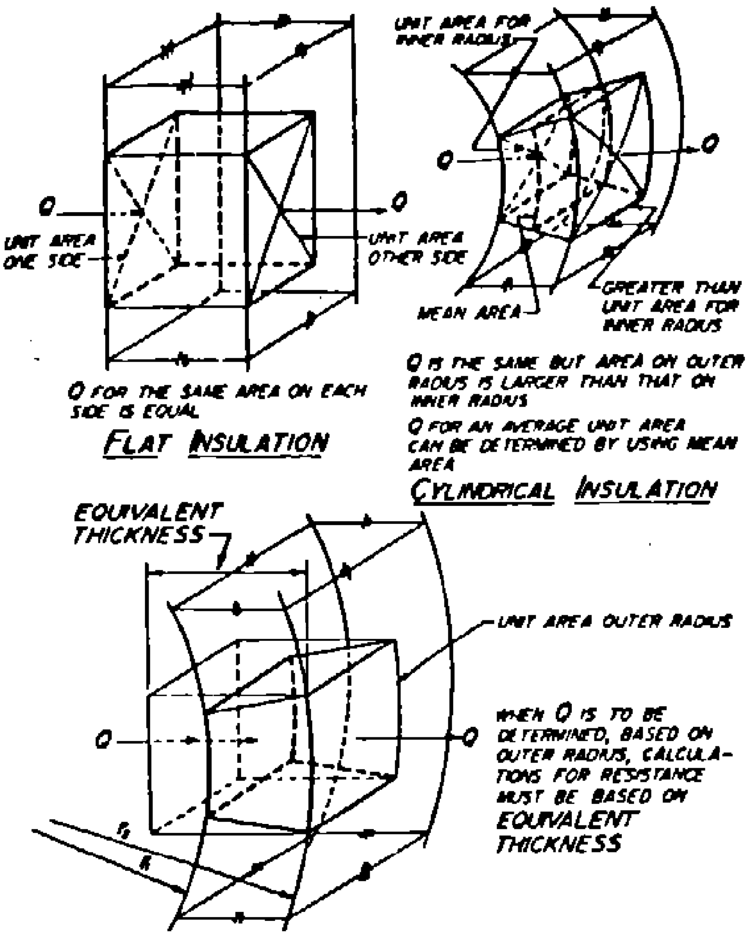
in which:

r_1 = inner radius of a single layer of cylindrical insulation in meter;

r_2 = outer radius of a single layer of cylindrical insulation in meter;

$r_2 \log_e \dfrac{r_2}{r_1}$ = equivalent thickness

This is a more common method of calculating heat transfer in which all heat transfer is based on outer area of the insulation and equivalent thickness has been used in the formula. The schematic diagram is shown in Fig. B.3.



EQUIVALENT THICKNESS OF CYLINDRICAL INSULATION
Fig. B.3

Example 3:

If : The temperature of the higher temperature side (inner) $t_1 = 232.2°C$;
The temperature of the lower (outer) side $t_2 = 37.7°C$;
The conductivity of the insulation $\lambda = 0.0577$ W/mK;
The inner radius $r_1 = 0.0381$ m.

Determine " ℓ " the thickness and r_2 outer radius of insulation:

$$Q = \frac{t_1 - t_2}{\dfrac{r_2 \log_e \dfrac{r_2}{r_1}}{\lambda}}$$

$$r_2 \log_e \frac{r_2}{r_1} = \left(\frac{t_1 - t_2}{Q}\right)\lambda = \left(\frac{232.2 - 37.7}{220.7}\right) 0.0577 = 0.051$$

As r_2 is the unknown and appears twice in the remaining factor, it is difficult to compute directly.

However by looking in Table B.1 for the values of $r_2 \ \log_e \frac{r_2}{r_1}$ it can be determined that the r_2 = 0.0762 m and insulation thickness will be:

$r_2 - r_1$ = 0.0762 - 0.0381 = 0.0381 m

d) Equation for heat transfer through two or more thicknesses of cylindrical insulation.

The same form of equation presented to calculate the heat flow through one thickness of cylindrical insulation should also be used where the total thickness is composed of two or more thicknesses of different λ values. In all cases, however, the multiplier for $\log_e$ is the outermost radius:

r_1 = inner radius of innermost insulation in meters;
r_2 = outer radius of innermost insulation and inner radius of outermost insulation in meters;
r_s = outer radius of outermost insulation in meters
t_1 = temperature of innermost surface in °C;
t_2 = temperature of radius between inner and outermost insulation in °C;
t_s = temperature of outer surface in °C;
λ_1 = conductivity of innermost insulation in W/mk;
λ_2 = conductivity of outermost insulation in W/mk;

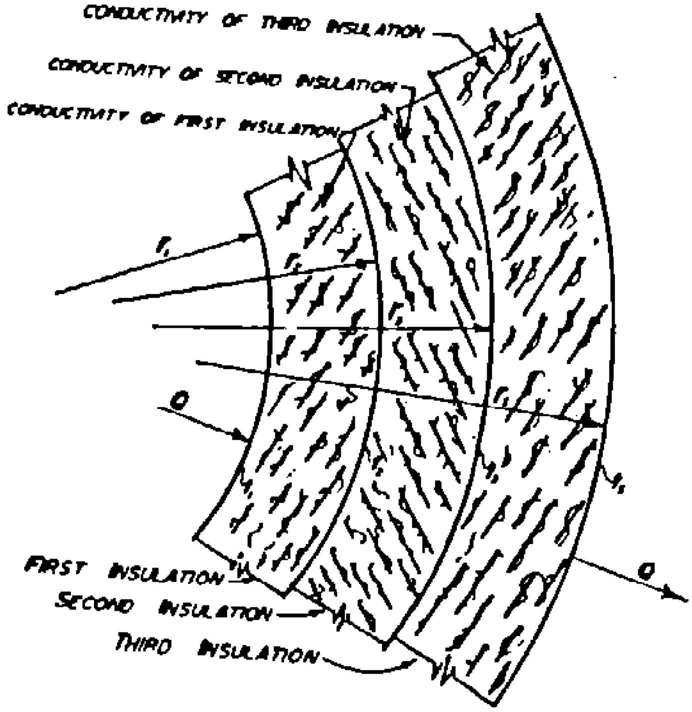
Heat transfer through two different types of cylindrical insulation in W/m² is:

$$Q = \frac{t_1 - t_s}{\left[\dfrac{r_s \log_e \dfrac{r_2}{r_1}}{\lambda_1}\right] + \left[\dfrac{r_s \log_e \dfrac{r_s}{r_2}}{\lambda_2}\right]}$$

Heat transfer Q through two different types of cylindrical insulation in W/m^2 is:

$$Q = \frac{t_1 - t_s}{\left[\dfrac{r_s \log_e \dfrac{r_2}{r_1}}{\lambda_1}\right] + \left[\dfrac{r_s \log_e \dfrac{r_3}{r_2}}{\lambda_2}\right] + \left[\dfrac{r_s \log_e \dfrac{r_s}{r_3}}{\lambda_2}\right]}$$

A schematic diagram is shown in Fig. B.4:



Equation:

$$Q = \frac{t_1 - t_a}{\dfrac{r_a \log_e \dfrac{r_2}{r_1}}{\lambda_1} + \dfrac{r_a \log_e \dfrac{r_3}{r_2}}{\lambda_2} + \dfrac{r_a \log_e \dfrac{r_4}{r_3}}{\lambda_3}}$$

SCHEMATIC DIAGRAM OF HEAT TRANSFER THROUGH THREE DIFFERENT TYPES OF CYLINDRICAL INSULATION MATERIALS

Fig. B.4

TABLE B.1 - EQUIVALENT THICKNESS - METERS

Tube Size	NOMINAL INSULATION THICKNESS – mm																			
Dia. mm	13	25	38	51	64	76	89	102	114	127	140	152	165	178	190	203	318	229	241	254
6.4	0.078	0.063	0.100	0.160	0.202	0.256	0.335	0.376	0.424	0.477	0.544	0.606	0.657	0.731	0.798	0.881	0.901	0.984	1.035	1.130
12.7	0.021	0.051	0.088	0.175	0.167	0.211	0.248	0.308	0.356	0.406	0.458	0.511	0.565	0.620	0.675	0.733	0.791	0.848	0.906	0.967
25.4	0.017	0.042	0.070	0.102	0.135	0.172	0.211	0.251	0.292	0.334	0.378	0.423	0.474	0.516	0.532	0.612	0.681	0.710	0.762	0.812
50.8	0.015	0.035	0.058	0.084	0.111	0.141	0.172	0.204	0.238	0.273	0.309	0.346	0.388	0.422	0.462	0.502	0.543	0.585	0.627	0.670
76.2	0.014	0.032	0.053	0.075	0.099	0.125	0.153	0.187	0.211	0.242	0.274	0.306	0.339	0.374	0.412	0.444	0.482	0.519	0.558	0.592
101.6	0.014	0.031	0.050	0.070	0.092	0.116	0.141	0.167	0.195	0.222	0.252	0.282	0.312	0.344	0.376	0.408	0.440	0.476	0.511	0.546
127.0	0.014	0.030	0.048	0.067	0.088	0.110	0.133	0.158	0.183	0.209	0.236	0.264	0.293	0.322	0.353	0.383	0.413	0.446	0.478	0.511
152.4	0.014	0.029	0.046	0.065	0.084	0.105	0.128	0.150	0.174	0.199	0.224	0.251	0.278	0.306	0.333	0.363	0.391	0.422	0.454	0.484
177.8	0.013	0.029	0.045	0.063	0.082	0.102	0.123	0.145	0.168	0.191	0.216	0.241	0.267	0.293	0.318	0.341	0.375	0.404	0.432	0.463
203.2	0.013	0.028	0.044	0.062	0.080	0.098	0.120	0.141	0.163	0.185	0.209	0.233	0.257	0.282	0.307	0.335	0.362	0.389	0.416	0.445
228.6	0.013	0.028	0.044	0.061	0.079	0.097	0.117	0.137	0.158	0.180	0.203	0.226	0.250	0.274	0.298	0.324	0.350	0.377	0.401	0.431
254.0	0.013	0.028	0.043	0.060	0.077	0.095	0.115	0.134	0.155	0.176	0.198	0.220	0.243	0.268	0.292	0.315	0.340	0.364	0.390	0.418
304.8	0.013	0.027	0.042	0.058	0.075	0.093	0.111	0.130	0.152	0.169	0.190	0.211	0.233	0.255	0.277	0.298	0.324	0.348	0.374	0.411
355.6	0.013	0.027	0.042	0.057	0.073	0.090	0.108	0.126	0.145	0.164	0.184	0.204	0.225	0.246	0.261	0.290	0.311	0.338	0.360	0.382
406.4	0.013	0.027	0.041	0.056	0.072	0.089	0.106	0.123	0.141	0.160	0.179	0.199	0.218	0.239	0.260	0.281	0.308	0.325	0.347	0.370
457.2	0.013	0.027	0.041	0.056	0.071	0.087	0.104	0.121	0.139	0.157	0.175	0.194	0.214	0.234	0.251	0.274	0.293	0.317	0.338	0.360
508.0	0.013	0.027	0.041	0.055	0.071	0.086	0.100	0.119	0.138	0.159	0.172	0.191	0.207	0.229	0.248	0.269	0.291	0.310	0.332	0.352
609.6	0.013	0.028	0.040	0.054	0.069	0.085	0.100	0.116	0.133	0.150	0.167	0.185	0.203	0.221	0.242	0.259	0.281	0.298	0.317	0.337
711.2	0.013	0.028	0.040	0.054	0.068	0.084	0.099	0.118	0.131	0.197	0.164	0.180	0.198	0.218	0.235	0.257	0.279	0.297	0.310	0.328
812.8	0.013	0.028	0.040	0.054	0.068	0.083	0.097	0.113	0.128	0.145	0.161	0.178	0.194	0.212	0.233	0.247	0.268	0.283	0.304	0.320
914.4	0.013	0.026	0.039	0.053	0.067	0.082	0.096	0.112	0.127	0.143	0.158	0.175	0.191	0.206	0.226	0.243	0.262	0.278	0.300	0.314
1016.0	0.013	0.026	0.039	0.053	0.067	0.081	0.096	0.111	0.126	0.141	0.157	0.173	0.189	0.205	0.223	0.239	0.260	0.274	0.299	0.309
1219.2	0.012	0.026	0.039	0.053	0.066	0.080	0.095	0.110	0.124	0.139	0.154	0.170	0.185	0.201	0.216	0.234	0.248	0.268	0.280	0.301
1422.4	0.012	0.028	0.038	0.052	0.066	0.080	0.094	0.108	0.122	0.138	0.152	0.168	0.182	0.198	0.214	0.230	0.245	0.262	0.276	0.295
1625.6	0.012	0.028	0.039	0.052	0.068	0.080	0.093	0.108	0.121	0.136	0.151	0.165	0.180	0.196	0.210	0.226	0.243	0.259	0.274	0.289
1828.8	0.012	0.026	0.039	0.052	0.065	0.079	0.093	0.107	0.121	0.135	0.150	0.164	0.179	0.194	0.209	0.224	0.239	0.256	0.270	0.286

Note:

Tabular values are those of the Equivalent Thickness $L_m = r_{2m} \log_e \frac{r_{2m}}{r_{1m}}$ for the Nominal Insulation Thickness given:

r_{1m} = Inside radius of insulation in meters;

$r_{1m} - r_{2m}$ = Actual thickness (ℓ_m) in meters;

r_{2m} = Outside radius of insulation in meters;

L_m = Equivalent thickness in meters.

APPENDIX C
CALCULATION OF THICKNESS OF INSULATING MATERIAL REQUIRED TO PREVENT CONDENSATION

C.1 Equations

The limiting condition for the formation of condensation on the surface of an insulating material occurs when the surface temperature equals the dew point temperature θ_d, i.e., when $\theta_2 = \theta_d$.

From the heat transfer equation: $\mathbf{Q} = \dfrac{\theta_1 - \theta_2}{R} = \dfrac{\theta_1 - \theta_m}{R + R_s}$

Also: $\mathbf{Q} = \dfrac{\theta_2 - \theta_m}{R_s}$

Therefore: $\dfrac{\theta_1 - \theta_2}{R} = \dfrac{\theta_{d2} - \theta_m}{R_s}$

or in the limiting case: $\dfrac{\theta_1 - \theta_d}{R} = \dfrac{\theta_d - \theta_m}{R_s}$

When surface condensation is a problem, the insulated surface is below the ambient air temperature, i.e., $\theta_m > \theta_d > \theta_1$ and the latter equation is written more conveniently as follows:

$$\frac{\theta_d - \theta_1}{R} = \frac{\theta_m - \theta_d}{R_s} \quad \text{or} \quad \frac{R}{R_s} = \frac{\theta_d - \theta_1}{\theta_m - \theta_d}$$

The ratio R/R_s can be expanded using the resistance equations and the result are as follows:

a) Cylindrical surface:

$$\text{Where: } R = 10^{-3} \frac{d_o}{2\lambda} \ln\left(\frac{d_i}{d_o}\right) \text{ and } R_s = \frac{d_o}{hd_i}$$

$$\text{Then: } \frac{R}{R_s} = 10^{-3} \frac{hd_i}{2\lambda} \ln\left(\frac{d_i}{d_o}\right)$$

b) Flat surface:

$$\text{Where: } R = 10^{-3} \frac{L}{\lambda} \text{ and } R_s = \frac{1}{h}$$

$$\text{Then: } \frac{R}{R_s} = 10^{-3} \frac{h}{\lambda} L$$

The equations can be expressed as follows:

$$\frac{R}{R_s} = 10^{-3} \frac{h}{\lambda} \chi$$

The final equation therefore becomes:

$$10^{-3}\,\frac{h}{\lambda}\chi = \frac{\theta_d - \theta_1}{\theta_m - \theta_d} \text{ or } \chi = 10^{-3}\,\frac{\lambda}{h}\left(\frac{\theta_d - \theta_1}{\theta_m - \theta_d}\right)$$

Given an appropriate value for λ and assigning a value to h (from C.3), the minimum value of χ can be calculated from which the least overall thickness is derived by using either Fig. A.2 or other appropriate means.

C.2 Dew Point Temperatures for Air

Some typical figures are shown in Table C.1.

C.3 Outer Surface Heat Transfer Coefficient

A comprehensive survey of values is not possible here but those given in Table C.2 are typical.

The symbols and units:

Q	= Rate of heat loss through the insulating material per unit area of hot surface per second in W/m²;
θ_1	= Temperature of hot surface in °C;
θ_2	= Temperature of the exterior (surface temperature of the insulating material) in °C;
θ_m	= Temperature of the ambient still air in °C;
θ_d	= Dew point temperature in °C;
R	= Thermal resistance of the insulation per square meter of hot surface in m²K/W;
R_s	= Thermal resistance of the insulation surface to air boundary in m²K/W;
λ	= Thermal conductivity of insulating material in W/mK;
d_o	= Outside diameter of pipe or tube in mm;
d_1	= Outside diameter of the layer of insulating material in contact with the hot surface in mm;
h	= Heat transfer surface coefficient per square meter of external surface of insulation in W/m²K;
L	= Overall thickness of insulation in mm;
χ	= Provisional thickness adopted for calculation purposes in mm.

TABLE C.1 - DEW POINT FOR RELATIVE HUMIDITIES FOR AMBIENT STILL AIR TEMPERATURES FROM -20°C TO +50°C WITH STANDARD BAROMETRIC PRESSURE

AMBIENT TEMPERATURE (in °C)	RELATIVE HUMIDITY (in %)									
	50	55	60	65	70	75	80	85	90	95
	Dew point temperature (in °C):									
-20	-27.0	–26.0	–25.2	–24.5	–23.7	-22.9	-22.3	-21.7	-21.1	-20.5
-15	-22.3	–21.3	–20.4	–19.6	–18.8	-18.0	-17.5	-16.7	-16.2	-15.6
-10	-17.6	–16.6	–15.7	–14.7	–13.9	-13.2	-12.5	-11.8	-11.2	-10.6
-8	-15.7	–14.7	–13.7	–12.8	–12.0	-11.3	-10.5	-9.8	-9.2	-8.6
-6	-13.9	–12.8	–11.8	–10.9	–10.1	-9.9	-8.6	-7.9	-7.2	-6.6
-4	-12.0	–10.9	–9.9	–9.0	–8.1	-7.4	-6.6	-5.9	-5.3	-4.6
-2	-10.1	–9.0	–8.0	–7.1	–6.2	-5.4	-4.6	-3.9	-3.3	-2.6
0	-8.1	–7.1	–6.0	–5.1	–4.2	-3.4	-2.7	-1.9	-1.3	-0.6
2	-6.5	–5.4	–4.4	–3.4	–2.6	-1.7	-1.0	-0.2	0.5	1.3
4	-4.9	–3.8	–2.7	–1.5	–0.9	0	0.9	1.7	2.5	3.3
6	-3.2	–2.1	–1.0	0.1	0.9	2.0	2.8	3.7	4.5	5.3
8	-1.5	–0.5	0.7	1.8	2.9	3.9	4.8	5.7	6.5	7.3
10	0.1	1.4	2.6	3.7	4.8	5.8	6.7	7.6	8.4	9.2
12	1.9	3.4	4.5	5.7	6.7	7.7	8.7	9.6	10.4	11.2
14	3.7	5.1	6.4	7.5	8.6	9.7	10.5	11.5	12.4	13.2
16	5.6	6.9	8.2	9.4	10.5	11.6	12.5	13.4	14.3	15.2
18	7.4	8.8	10.1	11.3	12.4	13.5	14.5	15.5	16.3	17.2
20	9.2	10.7	12.0	13.2	14.4	15.4	16.4	17.4	18.3	19.2
22	11.0	12.6	13.9	15.1	16.3	17.4	18.4	19.4	20.3	21.2
24	12.9	14.4	15.8	17.0	18.2	19.3	20.3	21.3	22.2	23.1
26	14.8	16.2	17.6	18.9	20.1	21.2	22.3	23.3	24.2	25.1
28	16.6	18.1	19.5	20.8	22.0	23.1	24.2	25.3	26.2	27.1
30	18.4	19.9	21.4	22.7	23.9	25.1	26.2	27.2	28.1	29.1
35	23.0	24.5	26.0	27.4	28.7	29.9	31.0	32.1	33.1	34.1
40	27.6	29.3	30.7	32.2	33.5	34.7	35.9	37.0	38.0	39.0
45	32.2	33.8	35.4	37.0	38.2	39.5	40.7	42.0	42.9	44.0
50	36.7	38.5	40.1	41.6	43.0	44.7	45.5	46.8	47.9	49.0

TABLE C.2 - VARIATION OF OUTER SURFACE COEFFICIENT WITH TEMPERATURE DIFFERENCE BETWEEN SURFACE AND AIR FOR VARIOUS OUTER DIMENSIONS OF INSULATION

Outer diameter insulation (in mm)	High emissivity surface				Low emissivity surface			
	Temperature difference (θ_m - θ_2) (in K)							
	1	2	5	10	1	2	5	10
	Outer surface coefficient, k (in W/(m^2.K)):							
40	8.0	8.4	9.1	9.7	3.4	3.9	4.7	5.4
60	7.6	8.0	8.7	9.3	3.1	3.5	4.2	4.9
100	7.3	7.7	8.3	8.8	2.7	3.1	3.8	4.4
200	7.0	7.4	7.9	8.4	2.4	2.8	3.4	4.0
Vertical flat surface	6.6	7.0	7.5	8.0	2.0	2.4	3.0	3.6

Note:

The above figures refer to the outer surface of the insulation.

The values given in Table C.2 are typical for heat gain situations under conditions of natural convection.

C.4 Examples

C.4.1 Example 1: To calculate the minimum thickness to prevent condensation using the equation in C.1.

A pipe of 60.3 mm outside diameter containing fluid at 0°C is insulated with material of thermal conductivity 0.039 W/(m.K), to prevent condensation when in air at +22°C and 85% relative humidity. Calculate the minimum insulation thickness needed for finishes of high emissivity.

From Table C.1 the dew point temperature θ_d = +19.4°C

Then from C.1: $$\chi = \frac{19.4 - 0}{22 - 19.4} \times \frac{0.039 \times 10^3}{h} = \frac{291}{h}$$

An approximate value for the surface coefficient is now taken to an initial assessment of the thickness.

Assume h = 7.0, then $\chi = \frac{291}{7.0} = 41.5\ m$

From Fig. A.2, L = 30 mm

An approximate outer insulation diameter can now be determined, i.e., 120 mm, from which a better surface coefficient is selected.

Thus a second approximation for h is 7.7 W (m².K) and $\chi = \frac{291}{7.7} = 37.8\ m$

From which L = 28 mm (approximately).

Further approximations to the surface coefficient do not affect this result significantly and therefore the required thickness is not less than 28 mm.

C.4.2 Example 2: To check the outer surface temperature of a given thickness of insulation for comparison with the dew point temperature using the heat loss equations

The user is frequently faced with a limited choice of insulation thicknesses. It is necessary to compare the outer surface temperature of a selected thickness with the dew point temperature, to determine whether or not condensation is likely to occur.

The calculation can be made using the value of χ obtained from Fig. A.2 and the equation from C.1 or using an equation for the surface temperature.

A pipe of 168.3 mm outside diameter carrying fluid at 0°C and located in air at +26°C and 85% relative humidity is to be insulated with material of thermal conductivity 0.035 W/(m.K). Calculate the surface temperatures of insulation thicknesses of 30 mm and 40 mm for finishes of high emissivity and compare them with the dew point temperature.

From the heat transfer equation:

$$Q = \frac{\theta_i - \theta_m}{R + R_s} \quad R = 10^{-3} \frac{d_o}{2\lambda} \ln\left(\frac{d_i}{d_o}\right) \quad R_s = \frac{d_o}{h d_i}$$

Also: $\theta_s = \frac{q d_o}{h d_i} + \theta_m$

By substitution:

$$\theta_2 = \frac{\theta_1 - \theta_m}{10^{-3}\frac{hd_1}{2\lambda}\ln\left(\frac{d_1}{d_o}\right) + 1} + \theta_m$$

The outer surface temperature of a 30 mm and a 40 mm insulation thickness is calculated as follows:

a) For 30 mm insulation thickness

Insulation outside diameter, d_1 = 168.3 + 60 = 228.3 mm. From Table 32 an approximate value of 7.2 is taken for h.

$$\text{Therefor: } \theta_2 = \frac{0.26}{10^{-3}\frac{7.2\times228.3}{2\times0.035}\ln\left(\frac{228.3}{168.3}\right)+1} + 26 = +22.8°C$$

$\theta_m - \theta_2$ = 26°C - 22.8°C = +3.2°C. Thus, a second, closer approximation of 7.5 is taken for h, from which θ_2 = +22.9°C.

From Table C.1, the dew point θ_d = +23.2°C and therefore condensation would occur.

b) For 40 mm insulation thickness

Insulation outside diameter, d_1 = 168.3 + 80 = 248.3 mm.

From Table C.2, and approximate value of 7.2 is taken for h.

$$\text{Therefore: } \theta_2 = \frac{0.26}{10^{-3}\left(\frac{7.2\times248.3}{2\times0.035}\right)\ln\left(\frac{248.3}{168.3}\right) + 1} + 26 = +23.6°C$$

$\theta_m - \theta_2$ = +2.4°C. Thus, a closer approximation of 7.4 is taken for h, from which θ_2 = +23.7°C.

The dew point θ_d = +23.3°C and therefore condensation is unlikely to occur.

APPENDIX D
WATER-VAPOR PERMEANCE FOR SOME VAPOR-BARRIERS AND THE CONVERSION FACTORS

TABLE D.1 - WATER-VAPOR PERMEANCE CONVERSION FACTORS

	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^{-8}	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^{9}	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	2.338×10^{2}	2.747×10^{3}	6.898×10^{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

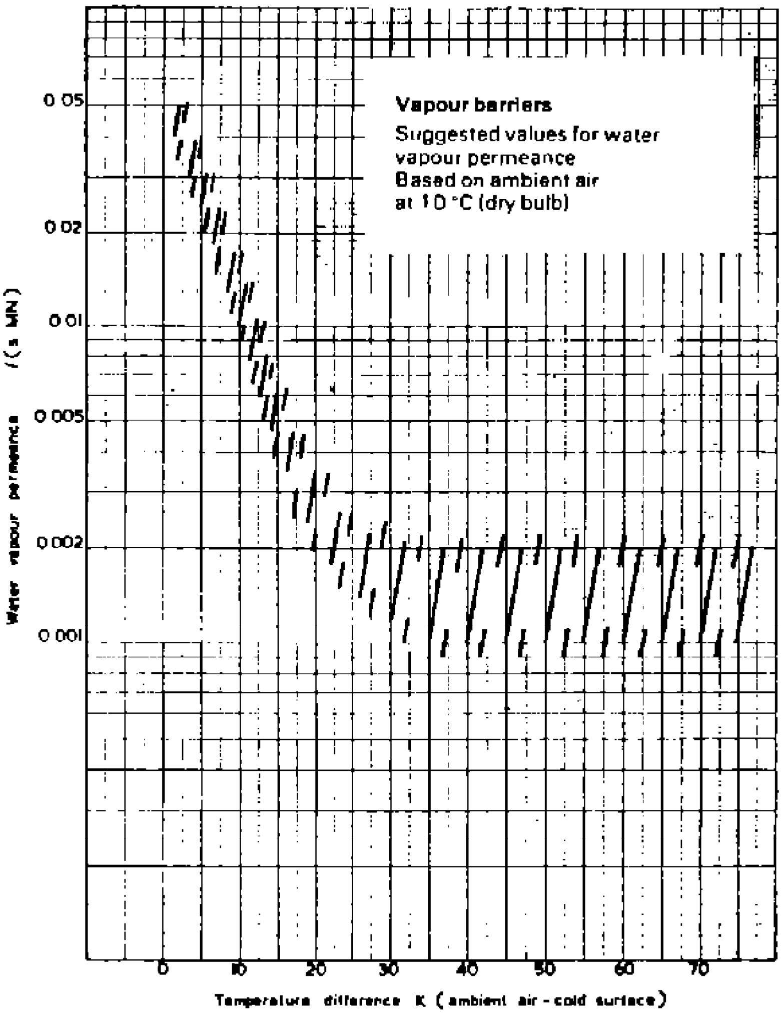
Notes:

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.

2)This was the term used by the building industry.

3) No conversion from temperate to tropical is shown for the reasons given in Clause 46 of BS 2972:1975.

4) The symbol 'gr' refers to grains.



VAPOR BARRIERS: SUGGESTED VALUES FOR WATER VAPOR PERMEANCE
Fig. D.1