5. Thermal insulation materials, technical characteristics and selection criteria

5.1 HEAT TRANSMISSION MODES AND TECHNICAL TERMS

5.1.1 Heat transmission modes

It is important to know how heat is transferred in fish holds. Heat is transferred by conduction, convection or radiation, or by a combination of all three. Heat always moves from warmer to colder areas; it seeks a balance. If the interior of an insulated fish hold is colder than the outside air, the fish hold draws heat from the outside. The greater the temperature difference, the faster the heat flows to the colder area.

Conduction. By this mode, heat energy is passed through a solid, liquid or gas from molecule to molecule in a material. In order for the heat to be conducted, there should be physical contact between particles and some temperature difference. Therefore, thermal conductivity is the measure of the speed of heat flow passed from particle to particle. The rate of heat flow through a specific material will be influenced by the difference of temperature and by its thermal conductivity.

Convection. By this mode, heat is transferred when a heated air/gas or liquid moves from one place to another, carrying its heat with it. The rate of heat flow will depend on the temperature of the moving gas or liquid and on its rate of flow.

Radiation. Heat energy is transmitted in the form of light, as infrared radiation or another form of electromagnetic waves. This energy emanates from a hot body and can travel freely only through completely transparent media. The atmosphere, glass and translucent materials pass a significant amount of radiant heat, which can be absorbed when it falls on a surface (e.g. the ship's deck surface on a sunny day absorbs radiant heat and becomes hot). It is a well known fact that light-coloured or shiny surfaces reflect more radiant heat than black or dark surfaces, therefore the former will be heated more slowly.

In practice, the entry of heat into fish holds/fish containers is the result of a mixture of the three modes mentioned above, but the most significant mode is by conduction through walls and flooring.

5.1.2 Definitions

The thermal properties of insulating materials and other common fishing vessel construction materials are known or can be accurately measured. The amount of heat transmission (flow) through any combination of materials can be calculated. However, it is necessary to know and understand certain technical terms to be able to calculate heat losses and understand the factors that are involved.

By convention, the ending -ity means the property of a material, regardless of its thickness and the ending -ance refers to the property of a specific body of given thickness.

Heat energy

One kilocalorie (1 kcal or 1 000 calories) is the amount of heat (energy) needed to raise the temperature of one kg of water by one degree Celsius (°C). The SI standard unit for energy is Joule (J). One kcal is approximately 4.18 kJ (this varies slightly with temperature). Another unit is the Btu (British thermal unit). One Btu corresponds roughly to 1 kJ.

Thermal conductivity

In simple terms this is a measure of the capacity of a material to conduct heat through its mass. Different insulating materials and other types of material have specific thermal conductivity values that can be used to measure their insulating effectiveness. It can be defined as the amount of heat/energy (expressed in kcal, Btu or J) that can be conducted in unit time through unit area of unit thickness of material, when there is a unit temperature difference. Thermal conductivity can be expressed in kcal m^{-1} $°C^{-1}$, Btu ft^{-1} $°F^{-1}$ and in the SI system in watt (W) m^{-1} $°C^{-1}$. Thermal conductivity is also known as the k-value.

Coefficient of thermal conductance "λ" (kcal m^{-2} h^{-1} $°C^{-1}$)

This is designated as λ (the Greek letter lambda) and defined as the amount of heat (in kcal) conducted in one hour through 1 m^2 of material, with a thickness of 1 m, when the temperature drop through the material under conditions of steady heat flow is 1 °C. The thermal conductance is established by tests and is the basic rating for any material. λ can also be expressed in Btu ft^{-2} h^{-1} $°F^{-1}$ (British thermal unit per square foot, hour, and degree Fahrenheit) or in SI units in W m^{-2} Kelvin $(K)^{-1}$.

Thermal resistivity

The thermal resistivity is the reciprocal of the k-value (1/k).

Thermal resistance (R-value)

The thermal resistance (R-value) is the reciprocal of λ (1/λ) and is used for calculating the thermal resistance of any material or composite material. The R-value can be defined in simple terms as the resistance that any specific material offers to the heat flow. A good insulation material will have a high R-value. For thicknesses other than 1 m, the R-value increases in direct proportion to the increase in thickness of the insulation material. This is x/λ, where x stands for the thickness of the material in metres.

Coefficient of heat transmission (U) (kcal m^{-2} h^{-1} °C^{-1})

The symbol U designates the overall coefficient of heat transmission for any section of a material or a composite of materials. The SI units for U are kcal per square metre of section per hour per degree Celsius, the difference between inside air temperature and outside air temperature. It can also be expressed in other unit systems. The U coefficient includes the thermal resistances of both surfaces of walls or flooring, as well as the thermal resistance of individual layers and air spaces that may be contained within the wall or flooring itself.

Permeance to water vapour (pv)

This is defined as the quantity of water vapour that passes through the unit of area of a material of unit thickness, when the difference of water pressure between both faces of the material is the unit. It can be expressed as g cm $mmHg^{-1}$ m^{-2} day^{-1} or in the SI system as g m MN^{-1} s^{-1} (grams metre per mega Newton per second).

Resistance to water vapour (rv)

This is the reciprocal of the permeance to water vapour and is defined as rv = 1/pv.

5.2 WHY INSULATION IS NECESSARY

The primary function of thermal insulation materials used in small fishing vessels using ice is to reduce the transmission of heat through fish hold walls, hatches, pipes or stanchions into the place where chilled fish or ice is being stored. By reducing the amount of heat leak, the amount of ice that melts can be reduced and so the efficiency of the icing process can be increased. As has already been discussed, ice is used up because it removes heat energy from the fish but also from heat energy leaking through the walls of the storage container. Insulation in the walls of the container can reduce the amount of heat that enters the container and so reduce the amount of ice needed to keep the contents chilled.

The main advantages of insulating the fish hold with adequate materials are:

- to prevent heat transmission entering from the surrounding warm air, the engine room and heat leaks (fish hold walls, hatches, pipes and stanchions);
- to optimize the useful capacity of the fish hold and fish-chilling operating costs;
- to help reduce energy requirements for refrigeration systems if these are used.

5.2.1 Insulating materials

Because hold space is often at a premium on small vessels and the costs of insulation can amount to a significant proportion of the costs involved in construction, the choice of insulation material can be very important.

Several thermal insulation materials are used commercially for fishing vessels, but few are completely satisfactory for this purpose. The main problems are lack of sufficient mechanical strength and moisture absorption. The latter is a particularly significant problem in fishing vessels, where melting ice is used as a chilling medium. Thermal insulators work by trapping bubbles or pockets of gas inside a foam structure. When these cells of gas are filled with moisture, there are significant losses in insulating efficiency.

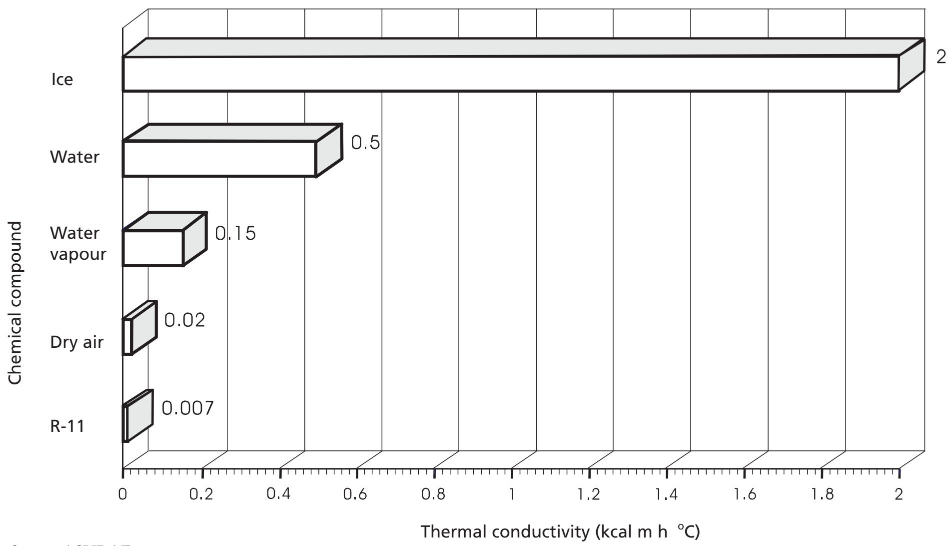
The thermal conductivity of water (at 10 °C) is 0.5 kcal m^{-1} h^{-1} $°C^{-1}$ and that of ice (at 0 °C) is 2 kcal m^{-1} h^{-1} $°C^{-1}$ (about four times the value of water). In comparison, dry stagnant air is about 0.02 kcal m^{-1} h^{-1} $°C^{-1}$. Figure 5.1 shows the thermal conductivities of R-11, dry air, water vapour and ice within an insulation material and illustrates the significant increase in thermal conductivity that can occur if air/gas is replaced by water vapour in the insulation.

Absorption of moisture by the insulating materials can take place not only by direct contact with water leaking into the hold walls, but also by condensation of water vapour in the walls where the dew point is reached in the temperature gradient through the walls.

The proper design of water vapour barriers is therefore of utmost importance for protecting the insulation from gaining moisture. In most climates the transmission of water vapour will tend to be from the outside to the inside of the hold walls, as the external temperature is likely to be higher than the internal temperature. This requires an impervious moisture-proof layer on the outside of the insulation, as well as a waterproof barrier on the lining to prevent liquid melt water entering the insulation. The vapour barrier can be achieved either through watertight surfaces of prefabricated insulation panels (sandwich-type panels, with one face being the vapour barrier of light-gauge galvanized steel sheets and the other face being the internal finish of plastic-coated aluminium or galvanized iron sheets), reinforced

FIGURE 5.1

Comparison of thermal conductivities of R-11, dry air, water vapour, water and ice within an insulation material



Source: ASHRAE, 1981.

BOX 5.1
Desirable characteristics for insulation materials for fish holds

Thermal conductivity
Best insulation materials should have the lowest thermal conductivity, in order to reduce the total coefficient of heat transmission. Thus, less insulating material will be required. Dry stagnant gas is one of the best insulating materials. The insulating properties of commercially available insulating materials are determined by the amount of gas held inside the material and the number of gas pockets. Therefore, the higher the number of cells (which can maintain the gas stagnant) and the smaller their size, the lower the thermal conductivity of such insulating material. These cells should not be interlinked, as this will allow convection of heat.

Moisture-vapour permeability
Best insulation materials should have very low moisture-vapour permeability. Thus, water absorption becomes negligible. Condensation and corrosion are minimized.

Resistance/installation features
The insulation material should be resistant to water, solvents and chemicals. It should be durable, and not lose its insulating efficiency quickly. It should allow a wide choice of adhesives for its installation. It should be easy to install, of light weight and easy to handle. Ordinary tools can be used for its installation. It should be economical, with significant savings on initial cost as well as savings on long-term performance. It should not generate or absorb odours. It should be unaffected by fungus or mildew and should not attract vermin. It should be dimensionally stable, so it will not crumble or pack down.

Safety features
The insulation material should be rated as non-flammable and non-explosive. In the event that the insulation material burns, the products of combustion should not introduce toxic hazards.

plastic materials, polythene sheets, plastic films of minimum thickness of 0.2 mm or aluminium foil of minimum thickness of 0.02 mm, laminated with a bitumen membrane. The minimum thickness of aluminium or galvanized sheets should be 0.3 mm.

Box 5.1 shows the main characteristics that a suitable insulation material should have.

5.3 THERMAL INSULATION MATERIALS

A wide range of insulation materials is available; however, few meet the requirements of modern fish hold construction. Selection of insulation material should be based on initial cost, effectiveness, durability, the adaptation of its form/shape to that of the fish hold and the installation methods available in each particular area. From an economic point of view, it may be better to choose an

TABLE 5.1
Density values and thermal conductivity at 20–25 °C of polyurethane insulation

Type	Density *(kg/m³)*	Thermal conductivity *(W m^{-1} °C^{-1}) / (kcal h^{-1} m^{-1} °C^{-1})*
Foam	30	0.026/0.0224
Rigid expanded board	30	0.02–0.025/0.0172–0.0215 average: 0.0225/0.0193
Rigid expanded board	40	0.023/0.02
Rigid expanded board	80	0.04/0.34
Foamed in place	24-40	0.023–0.026/0.0198–0.0224 average: 0.0245/0.0211

Source: FAO, 1989.

insulating material with a lower thermal conductivity rather than increase the thickness of the insulation in the hold walls. By reducing the thermal conductivity, less insulation will be required for a given amount of refrigeration and more usable volume will be available in the fish hold. The space occupied by the insulation materials in fishing vessels can represent, in many instances, about 10 to 15 percent of the gross capacity of the fish hold.

5.3.1 Polyurethane foam

One of the best commercially available choices of insulation material for fishing vessels is polyurethane foam. It has good thermal insulating properties, low moisture-vapour permeability, high resistance to water absorption, relatively high mechanical strength and low density. In addition, it is relatively easy and economical to install. The main features of polyurethane foams are shown in Table 5.1.

Polyurethane foam is effective as an insulator because it has a high proportion (90 percent minimum) of non-connected closed microcells, filled with inert gas. Until recently, the inert gas most commonly used in polyurethane foams was R-11 (trichlorofluoromethane). However, the Montreal Protocol on Substances that Deplete the Ozone Layer has called for the phasing out of the use of CFCs such as R-11. Replacement foaming agents are being investigated at the present time, with hydrocarbons, hydrofluorocarbons and inert gases such as carbon dioxide being developed as substitutes.

The main ways polyurethane foams can be applied and used are as rigid boards/ slabs and pre-formed pipes, which can be manufactured in various shapes and sizes. The main applications of these types of foam are in chill rooms, ice stores and cold stores. Structural sandwich panels incorporating slabs of foam can be produced for prefabricated refrigerated stores.

Foam can also be produced *in situ* by a variety of means, as follows:

- It can be poured in place. This involves mixing the chemicals either manually or by mechanical means and pouring in open moulds or spaces where insulation is required. The mixture creates a foam and solidifies. If necessary, the solidified foam can be cut to the required size or shape.
- It can be sprayed directly onto a solid surface using guns that mix and atomize the foam as it is being applied. For example, fish holds or tanks

BOX 5.2

Precautions against fire during the application of rigid polyurethane foam in ships

Storage on site

Urethane chemicals do not constitute a fire hazard.

Naked flames and sources of high radiant heat should be prohibited in areas where board or slabstock are stored. Inflammable solvents and adhesives should be stored under conditions where the usual precautions applicable to such materials are observed.

Site application

General – Whenever possible all welding and other operations involving naked flames or high temperatures in the proposed insulated area, or on external surfaces of it, should be completed before the foam is applied. All these operations, and smoking, must be prohibited while the application of the foam is in progress to prevent ignition of exposed foam, solvents or adhesives.

Dispensing in situ – The foaming takes place in cavities protected by cladding. There is no extra fire hazard associated with this operation, or with this type of insulation, other than the hazard of any inflammable solvent used for cleaning the equipment. The type of cladding must be approved by the Board of Trade (or the competent authority).

Spraying – Immediately after spraying, the foam is left exposed. In this condition, it constitutes a hazard if subjected to sources of heat or ignition. All welding or other operations involving naked flames or high temperatures in the area must be prohibited until the foam is suitably protected. Also, before the foam is protected, naked flames or high temperatures must not be allowed to penetrate the foam area from outside, e.g. by welding or cutting the plates behind the insulation. Dust arising from sanding or buffing operations, which may be carried out to produce a flat foam surface, may, in common with other dusts, constitute a fire hazard. Suitable precautions should be taken by removing the dust as soon as possible. The sprayed foam surface must be covered as soon as practicable, by cladding approved by the competent authority.

Board or slabstock – Particular attention must be paid to the fire hazards arising from the use of inflammable adhesives. Immediately after application the insulation is exposed and therefore constitutes a fire hazard similar to that of unprotected sprayed foam. The precautions detailed above for sprayed foam must be taken before the foam is protected by cladding approved by the competent authority.

Repair work

It may be found necessary to remove the cladding from the foam. If any welding or other operation involving naked flames or high temperatures is to be carried out, the foam must be cut back to at least 1 ft (0.33 m) from the site of operation. All exposed foam must be protected (e.g. with an asbestos blanket) from the naked flames or high temperatures.

Toxic hazards arising from burning foam

In common with wood, wool, feathers, etc. the products of combustion of urethane foam and other plastics are hazardous. In the case of fire, the normal dangers such as lack of oxygen, dense smoke and hot gases are present and normal fire-fighting drill should be observed.

Note: these guidelines only refer to those rigid polyurethane foams which incorporate a fire-retardant additive and which are made from methane diisocyanate.

Source: Doherty and Wilson, 1969.

can be sprayed directly on the outside surface and inaccessible areas may be sprayed on and built up without the need of moulds. The foam will adhere to itself and most metals, wood and other materials. It can also be injected into a cavity (e.g. it can be used for moulded insulated boxes). Spray and injection techniques are becoming the most widely used for the installation of rigid polyurethane foam in ships and fishing vessels.

- In frothing, the mixture of chemicals is dispensed partially pre-expanded, like an aerosol cream. Appropriate equipment, including an extra blowing agent, is required for immediate pre-expansion. The final phase of expansion takes place as the chemical reaction reaches completion. This technique is used when rigid foams/panels with a high strength–weight ratio are required.

Fire regulations require that fire-retarding agents should be incorporated into polyurethane insulation foam. In addition, a protective lining should be incorporated so as to make the foam more difficult to ignite from a small source of flame. Laboratory tests indicate that unprotected (rigid) polyurethane foam containing a fire-retardant will not ignite from small flame sources such as matches, but will burn rapidly when exposed to large sources of flame and heat. However, when the polyurethane foam is protected from direct contact with flames and air is excluded, the burning of the foam is eliminated. Also the type of resin and isocyanate used in the production of the foam can influence its performance against fire. Foams produced with toluene diisocyanate show a tendency to soften and melt more readily under the influence of heat than those foams made from methane diisocyanate. The precautions against fire during the application of polyurethane foam in ships listed in Box 5.2 should be taken into consideration.

Several grades of polyurethane foams are available, including grades that are particularly fire-resistant. These foams, which contain isocyanurate, can survive for 10–25 minutes before burn-through occurs, when exposed to a flame from a propane torch at 1 200 °C (standard polyurethane foams under the same test conditions are penetrated in about 10 seconds), therefore offering high resistance to actual penetration by fire. Commercially available isocyanurate foams have an average density of 35 kg/m^3, thermal conductivity of 0.022 kcal h^{-1} m^{-1} $°C^{-1}$ and permeance to water vapour of 16.7 g cm m^{-2} day^{-1} $mmHg^{-1}$. Figure 5.2 shows the relationship between the R-value and thickness of commercial isocyanurate foams.

Other grades of polyurethane are particularly strong, having quite high densities. For example, standard rigid foam used as insulation in chill rooms can have densities of around 30–40 kg/m^3 in comparison with other grades of foam used as a structural core in boats with a density of 100 kg/m^3 up to 300 kg/m^3. Its resistance to compression varies according to the density of the foam, with 2–3 kg/cm^2 for foams with densities of 35–40 kg/m^3 and higher resistance for higher densities. Table 5.2 gives the main physical properties of some commercial grades of polyurethane foam. These foams do not react with solvents used in the installation of fibreglass-reinforced plastic (such as styrene formulated polyesters or acetone). Therefore, expanded polyurethane foams are widely used as insulation in fish holds/fish containers together with a lining of fibreglass-reinforced plastic, despite the fact that they are significantly more expensive than

FIGURE 5.2

Relationship between thermal resistance (R-value) and thickness of commercial isocyanurate foam sheathing (data obtained from a Canadian manufacturer)

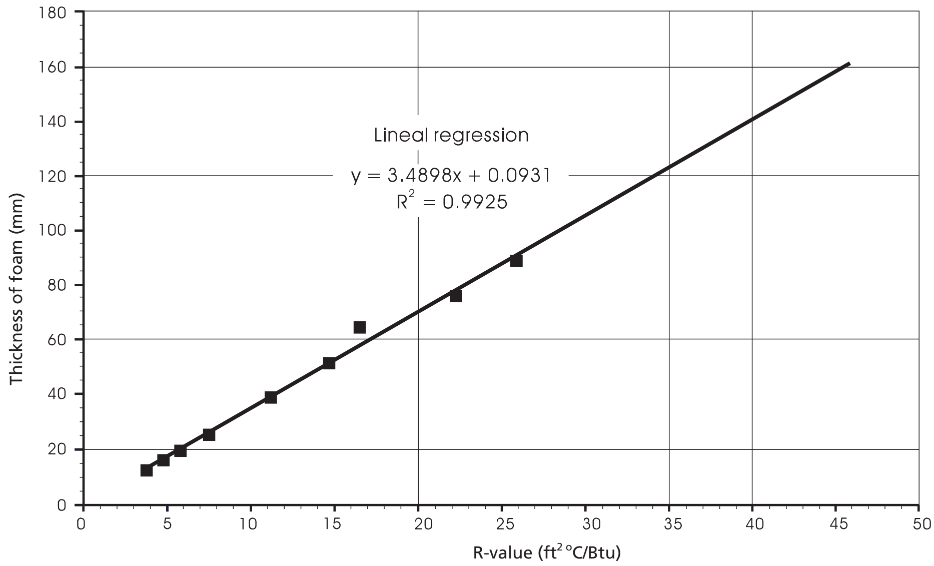
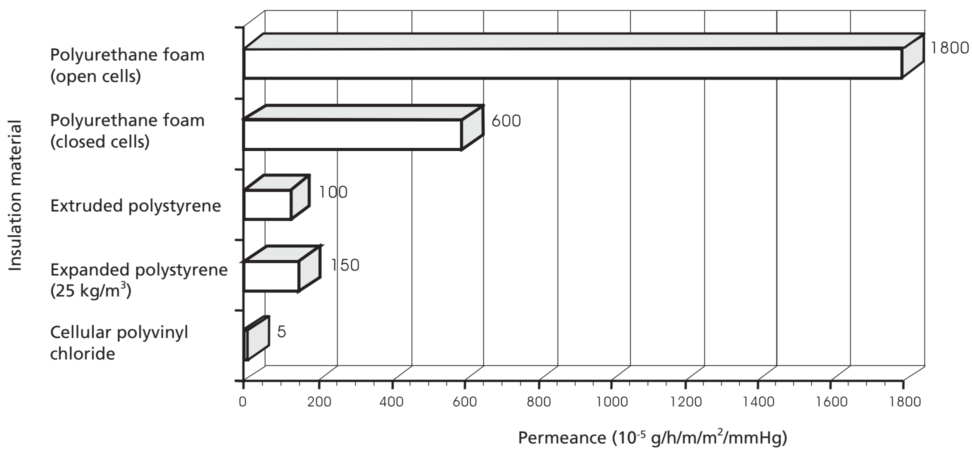


FIGURE 5.3

Comparison of permeability of different insulation materials to water and water vapour at 20 °C and 65 percent relative humidity



Source: Prepared by authors based on data from ASHRAE, 1981 and Melgarejo, 1995.

expanded polystyrene. Their main technical limitation is the fact that they are more likely to absorb water than expanded polystyrene, and can burn and produce toxic substances during ignition. Figure 5.3 shows the permeability of different insulation materials to water and water vapour.

TABLE 5.2
Physical properties of some grades of polyurethane foams

Physical properties	Test units	Test temp. (°F/°C)	American Society for Testing and Materials (ASTM) method	Grades of polyurethane foam				
				9002-2B	9002-3B	9002-4B	9005-2	9006-4
Nominal density	lb/ft (kg/m^3)	74/23.3	D1622	2 (32)	3(48)	4(64)	2(32)	4(64)
Type [1]				I	I	I	III	III
Class [1]				2	-	-	2	3
Compressive strength:								
a) Parallel	PSI[2]	74/23.3	D1621	38	70	100	25	75
b) Perpendicular	PSI	74/23.3	D1621	18	36	68	20	48
Compressive modulus:								
a) Parallel	PSI	74/23.3	D1621	1 050	1750	2 500	600	2 000
b) Perpendicular	PSI	74/23.3	D1621	450	950	1 500	500	900
Tensile strength:								
a) Parallel	PSI	74/23.3	D1623	56	84	112	40	90
b) Perpendicular	PSI	74/23.3	D1623	40	65	90	35	77
Shear strength:								
Perpendicular	PSI	74/23.3	C273	33	50	65	26	50
Flame resistance	NA	74/23.3	D1692	none	none	none	non-burning	non-burning
Thermal conductivity, also called K factor	$Btu/ft^2.h°F/in$	74/23.3	C177	0.11 to 0.16				
Water absorption (2 days under 2" head):								
a) By volume	%	74/23.3	D2127					
b) By weight	lb/ft^2	74/23.3	D2127	0.04	0.025	0.02	0.04	0.04
Dimensional stability:				1.6	1	0.8	1.7	1.7
a) Net change in volume:								
1 day	%	160/71.1	D2126 Prac. E	1.5				
7 days	%	160/71.1	D2126 Prac. E	2	1	1	1.2	1.3
28 days	%	160/71.1	D2126 Prac. E	2.5	1.5	1.5	1.7	2.7
b) Average linear change					2	2	2.7	3.6
1 day	%	160/71.1	D2126 Prac. E	0.7	0.5	0.5	0.6	0.6
7 days	%	160/71.1	D2126 Prac. E	1	0.7	0.7	0.8	1.4
28 days	%	160/71.1	D2126 Prac. E	1.2	1	1	1.4	1.8

[1] As specified by US Federal Specification HHI-I-00530.
[2] 1 PSI (pound/square inch) = 0.070307 kg/cm^2.
Source: American Society for Testing and Materials (ASTM) Book of Standards and CPR Division. The Upjohn Co., USA.

TABLE 5.3
Thermal conductivity and density values at 0 °C of polystyrene insulation

Type	Density *(kg/m³)*	Thermal conductivity *(W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)*
Expanded foam Type I	10	0.057/0.049
Expanded foam Type II	12	0.044/0.038
Expanded foam Type III	15	0.037/0.032
Expanded foam Type IV	20	0.034/0.029
Expanded foam Type V	25	0.033/0.028
Rigid extruded foam	33	0.033/0.028

5.3.2 Expanded polystyrene

Through polymerization styrene can be made into white pearls/beads of polystyrene plastic. These beads can then be expanded to form a foam known as expanded polystyrene. There are two main ways of making of expanded polystyrene: by extrusion and by moulding of slabs.

Extruded foams are made by mixing the polystyrene with a solvent, adding a gas under pressure and finally extruding the mixture to the required thickness. The extrusion process improves the characteristics of the final foam, such as its mechanical resistance, producing non-interconnecting pores and a more homogeneous material. The mechanical resistance of expanded polystyrene foams can vary from 0.4 to 1.1 kg/cm^2. There are several grades of foams available with densities from 10 to 33 kg/m^3, with thermal conductivities that are lower with the increase in density, as shown in Table 5.3.

Expanded polystyrene foams have a number of technical limitations:

- they are flammable, although fire-retardant grades are available;
- they break down gradually when exposed to direct sunlight;
- they react with solvents used in the installation of fibreglass-reinforced plastic (such as styrene-formulated polyesters) as well as with other organic solvents (petrol, kerosene, acetone, etc.).

This last characteristic makes them unsuitable for use in fish holds/fish containers that have a lining of fibreglass-reinforced plastic where the fibreglass is applied *in situ* directly onto the insulation material.

Rigid board panels can be made with expanded polystyrene of different densities, various thicknesses and sizes.

5.3.3 Expanded perlite

Perlite is a volcanic rock containing from 2 to 5 percent bonded water. It is a chemically inert substance composed basically of silica and aluminium, but some impurities, such as Na_2O, CaO, MgO and K_2O, which are hygroscopic, can absorb moisture easily. Therefore, depending on the storage conditions and the quality of the perlite, moisture absorption can be minimized. The average density of expanded perlite is about 130 kg/m^3 and its thermal conductivity is about 0.04 kcal m^{-1} h^{-1} °C^{-1} (0.047 W m^{-1} °C^{-1}). The perlite is expanded by means of rapid heating at a temperature between 800 and 1 200 °C. The vaporization of the bonded water and the formation of natural glass results in the expansion of the perlite particles, which have a granular shape. Therefore, the main parameters that define the characteristics of expanded perlite are:

- the origin of the mineral perlite;
- the granulometric characteristics of the mineral before the expansion process;
- the temperature of expansion.

However, despite its good insulating efficiency, this is only effective when it is dry or in a loose granular state. As these granules tend to absorb moisture and settle after installation, it becomes less effective as an insulation material with time. The most common way of applying perlite is pouring the granules and spreading them manually. It can fill small spaces more completely than fibrous insulation materials. Loose-fill insulation, such as expanded perlite, may be used in combination with other types of insulation material (e.g. slabs of cellular plastics) for filling awkwardly shaped areas of the fish hold where cutting of slabs to the desired shape would be time-consuming and incomplete.

Caution is needed during handling and installation of expanded perlite, as perlite dust can cause chronic poisoning.

5.3.4 Fibreglass

Fibreglass matting is also used as insulating material and offers the following advantages:

- high resistance to fire;
- high resistance to microbiological attack;
- good resistance to most chemicals;
- high heat resistance;
- available in a variety of presentations (e.g. blankets, mats, loose fill and boards);
- low thermal conductivity (see Table 5.4).

Fibreglass insulation is available in rolls of different thickness, also called blankets and mats. The width of the blankets and mats will depend on the way they are to be installed and some come faced on one side with foil or Kraft paper, which serve as vapour barriers.

However, the main technical limitations of fibreglass matting as insulation are:

- poor structural strength or compression resistance;
- a tendency to settle after installation if not properly installed;
- its permeability to moisture.

Rigid board panels can be made with compressed fibreglass. These lightweight insulation boards have relatively high R-values for their thickness.

5.3.5 Cork

Cork is probably one of the oldest insulation materials used commercially, and in the past it was the most widely used insulation material in the refrigeration industry. At present, due to the scarcity of cork-producing trees, its price is relatively high in comparison with other insulating materials. Therefore, its use is very limited, with the exception of some machine foundations to reduce the transmission of

TABLE 5.4
Thermal conductivity and density values at 0 °C of fibreglass insulation

Type	Density (kg/m³)	Thermal conductivity (W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)
Type I	10–18	0.044/0.038
Type II	19–30	0.037/0.032
Type III	31–45	0.034/0.029
Type IV	46–65	0.033/0.028
Type V	66–90	0.033/0.028
Type VI	91	0.036/0.031
Glass fibre, resin bonded	64–144	0.036/0.031

Source: Prepared by authors based on data from Melgarejo, 1995.

TABLE 5.5
Thermal conductivity and density values at 20–25 °C of cork insulation

Type	Density (kg/m³)	Thermal conductivity (W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)
Granulated loose, dry	115	0.052/0.0447
Granulated	86	0.048/0.041
Expanded cork slab	130	0.04/0.344
Expanded cork board	150	0.043/0.037
Expanded bonded with resins/bitumen	100–150	0.043/0.037
Expanded bonded with resins/bitumen	150–250	0.048/0.041

Source: Prepared by authors based on data from Melgarejo, 1995.

vibrations. It is available as expanded slabs or boards as well as in granular form, its density varies from 110 to 130 kg/m^3 and it has an average mechanical resistance of 2.2 kg/m^2. It can only be used up to temperatures of 65 °C. It has good thermal insulating effectiveness, is fairly resistant to compression and is difficult to burn. Its main technical limitation is the tendency to absorb moisture with an average permeance to water vapour of 12.5 g cm m^{-2} day^{-1} mmHg^{-1}. Table 5.5 gives some typical characteristics of cork.

5.3.6 Comparison of the various insulants

Some of the more common materials used for insulation are compared in Table 5.6 with their relative insulating values and the advantages and disadvantages of particular types. In general, the more expensive materials, such as the polyurethane foams are more efficient insulators for given thicknesses. Using the "R" system of grading (see definitions in paragraph 5.1.2), it is possible to arrive at equivalent "R values" for a variety of insulating material types.

Figure 5.4 shows the comparison of typical thicknesses of different insulation materials used for chill rooms and ice stores, operating on shore, in temperate and tropical areas, at average ambient air temperatures of 20, 30 and 40 °C. Some designers indicate that the thermal conductance coefficient (λ) for shore-based chill and ice stores should not exceed 0.26 kcal m^{-2} h^{-1} °C^{-1} (equivalent to an R-value =

TABLE 5.6
Common insulating materials, "R" values, advantages and disadvantages

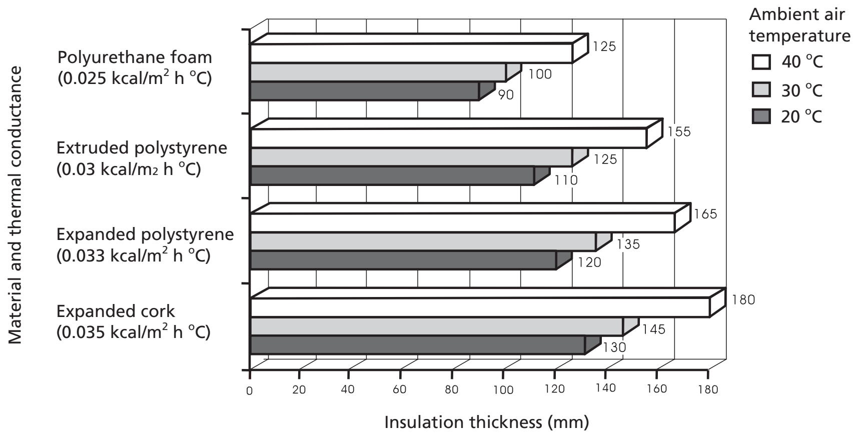
Insulating material	"R" value per inch (2.54 cm)	Advantages	Disadvantages
Polyurethane, board	6.25	Very good R-value, can be used with fibreglass resins	Not always easily available, relatively expensive
Polyurethane, spray on	7.0	Very good R-value, can be used with fibreglass resins, easy application with spray equipment	Not always easily available, expensive, requires special spray equipment
Polyurethane, poured (two-part chemical)	7.0	Very good R-value, can be used with fibreglass resins, relative ease of application	Not always easily available, expensive, requires very careful volume calculations
Polystyrene, sheets (smooth) Trade name "Styrofoam"	5.0	Readily available, low cost, reasonable R-value	Cannot be used with fibreglass resins unless protected, easily damaged
Polystyrene, foamed in place and expanded moulded beads. Known as Isopor, Polypor, etc.	3.75 to 4.0	Reasonable R-values, lower cost than smooth surfaced sheets	Cannot be used with fibreglass resins unless protected, easily damaged
Cork board	3.33	Availability in many markets, reasonable cost, can be covered with fibreglass	Lower R-values than polyurethane for styrene foams
Fibreglass wool batts	3.3	Low cost, ease of installation	Readily absorbs water or other fluids, loses insulating value when wet
Rock wool batts	3.7	As above	As above
Wood shavings	2.2	Readily available, low cost	Absorbs moisture and loses R-values when wet, decays
Sawdust	2.44	Readily available, low cost	Absorbs moisture and loses R-value when wet, packs down under vibration
Straw		Readily available, low cost	Absorbs moisture and loses R-value when wet, host to insects, etc.
Air space	1.0 approx.	No cost	Has to be completely sealed to prevent air circulation causing heat infiltration

18.8 ft^2 h °F Btu^{-1}). However, the setting of this value depends basically on the energy costs, therefore it may be reduced if, in the future, energy costs increase.

The selection of the optimum insulation thickness for fish holds will depend on factors such as the insulation costs (materials and installation), ice costs (or power and equipment costs according to the refrigeration requirements), annual cost savings in refrigeration due to improved insulation efficiency, and local conditions (type of fishing operations and vessel, species caught, fish prices, borrowing costs). Therefore, the optimum thickness of insulation should be selected on an individual basis. However, taking into account the local environmental conditions in which the fishing vessel is likely to operate, which do not depend on economic calculations, a minimum recommended thickness of insulation should be determined. In practice, a compromise should be reached between the optimum economic insulation thickness and the ice/refrigeration costs.

It is also important, for planning purposes, to take into consideration the heat gains from radiation and conduction, to select the optimum insulation thickness.

FIGURE 5.4
Comparison of typical insulation thickness for shore-based chilled and ice stores operating at average ambient air temperatures of 20 °C, 30 °C and 40 °C (thickness rounded up to nearest 5 mm)



5.4 TYPES OF PROTECTIVE LINING FOR FISH HOLDS AND SELECTION OF INSULATION MATERIALS

Certain aspects of the selection of insulation materials and protective lining for fish holds require careful consideration. For example, perlite, cork and other highly hygroscopic insulation materials should not be used on the sidewalls or flooring of the fish hold (due to the extremely wet conditions in these areas), unless suitable protective watertight linings are placed over them. Types of lining such as wood planking and plywood sheets alone are not suitable for protecting insulation materials for wet walls or flooring in fish holds. Protective metal linings that can be welded or soldered are a suitable alternative, provided that joints and seams are strong and complete watertightness can be ensured. The most suitable commercially available metal linings for fish holds are extruded aluminium alloy boards and mild steel plates. However, as welding of aluminium alloys is difficult and expensive, the aluminium alloy lining should be prepared before the application of the insulation, in order to prevent fire risks of some cellular insulation materials. Otherwise, strict fire precautions should be taken during installation of the lining or when repairs are needed. With the application of foam in-place insulation materials, fish holds or CSW/RSW tanks can be easily insulated by applying the foam in between the hull and the steel plate of the tank or fish hold walls, thus avoiding fire risks caused by welding operations.

A commonly used lining material for fish holds, in particular for wooden hull vessels, is fibreglass-reinforced plastic (FRP), which can be applied directly to some expanded cellular plastic insulation materials (such as polyurethane foams). In commercial practice, two or three layers of fibreglass (450 g/m^2 density mat) and resin, or two layers of 450 g/m^2 mat and a finishing layer of 300 g/m^2 mat and resin, are applied over the insulation material; the polyester resins are applied (with a roller) until a lining about 4–5 mm thick is obtained. An alternative method for the use of expanded polystyrene foam in conjunction with an FRP lining is to protect the insulation with marine plywood sheets not less than 8 mm thick and a layer of tar, then cover the marine plywood with a layer of FRP no less than 4 mm thick. Adequate provisions should be made to ensure proper ventilation between the marine plywood and the hull planking, to prevent fungal rot in the wooden hull and moisture absorption by the insulation material.