The use of ice on small fishing vessels
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by
Michael Shawyer
and
Avilio F. Medina Pizzali

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The fisheries sector plays an important role in many developing countries, contributing towards food security, generation of employment and procurement of foreign exchange. It is becoming increasingly clear that many fish resources are being subjected to exploitation at or above their capacity to remain sustainable. At the same time, there is a very large wastage of fishery resources as a result of discarding unwanted catches at sea, and failure, particularly in smaller vessels, to preserve effectively those fish that are marketable. Under these circumstances, the need for improved handling, care and preservation of the catch is clear.

This publication deals with the use of ice, improved fish storage and preservation on small fishing vessels, including the technology aspects of making and handling ice – both on shore and on board fishing boats, the construction of fish boxes and fish holds, and fish handling. It is aimed at personnel, primarily in developing countries, with varying degrees of knowledge on the subject, including students, government technical and training officers, boatyard staff, refrigeration engineers and mechanics, and boat owners.
ABSTRACT

The use of ice on board smaller fishing vessels is increasing. One reason for this is the decrease in near-shore fish resources that is forcing the fishermen to make longer fishing trips and to conserve the catch on board during the trip. Another reason is the increasing demand for good quality fresh fish and the globalization of the markets for these products with increased quality control.

This publication describes the requirements for the use of ice (and chilled seawater) on board fishing vessels, from small insulated containers in dugout canoes, to refrigerated tanks on bigger vessels. It also gives an overview of the different types of ice plants and the ice produced in them.

Chapter 1 describes the physical changes in fish exposed to heat, and how chilling the product delays these processes.

Chapter 2 gives an overview of the different types of ice and chilled seawater and how they are produced.

Chapter 3 describes the installation requirements for shore-based ice plants and how the ice is stored and handled.

Chapter 4 describes the on-board handling of ice and fish, including the advantages and drawbacks of the different types of ice and chilling systems.

Chapters 5 and 6 give a description of the materials used for insulation and the design of insulated containers and fish holds.

Finally, in Chapter 7 some calculations are given that can be used to estimate the quantity of ice needed for a fishing trip, and the volume of the fish hold.

The publication is aimed both at fishermen who want more information about the different techniques used, and at boat owners and economic agents who want to invest in the use of ice to preserve the catches.

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Department of Fisheries and Oceans Canada, St John’s, Newfoundland, Canada.

Department of Fisheries of Newfoundland and Labrador, St. John’s, Newfoundland, Canada.

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1. Introduction

All species of fish, when properly chilled, will stay fresh for longer periods than those that are not preserved in any way. The use of chilling techniques such as ice, therefore, effectively prolongs the length of time available for fishing trips and makes it possible to increase the catch with economic benefits for the vessel and crew. Products brought to market in a well-preserved condition will generally command higher prices, both at wholesale and retail levels, and thus give better returns to the fishing operation.

Given the above, it might be assumed that all types and sizes of fishing vessels would benefit from the use of ice for catch preservation. However, in practice there are limitations. On the smallest types of vessels, such as small rafts and the smallest dugout canoes, there is no space to keep ice until it is needed. However, this may not be a problem as the fishery undertaken by these very small craft usually only lasts a few hours and fish is consumed or sold on a daily basis. In some of these very small fishing craft, owners are aware of the problems of catch deterioration and often use wet sacking or palm leaves to cover the catch, lower the temperature and so reduce spoilage.

Many larger vessels capable of spending a day or more in fishing operations will benefit from the use of some form of on-board preservation, such as ice or chilled seawater (CSW). This category might include artisanal fishing vessels, such as larger dugout canoes, outboard-motor-powered launches and larger inboard-engine-powered vessels up to 20 m long.

With increasing demand for good-quality fresh fish, globalization of the market for these products and increasing awareness of fishermen, the use of ice on board boats is growing. Increase in the use of ice creates a need to ensure that it is used efficiently. Ice production consumes a lot of energy, so unnecessary waste is to be avoided. The most economic way of reducing this waste on board fishing vessels is by using proper storage, such as adequately insulated ice boxes, containers and fish holds where ice is stored and used to preserve the catch.

On small boats portable insulated boxes made of various materials are often used to carry ice to the fishing grounds. Ice is then transferred to the catch in suitable ratios until either all the ice is used, or there is no more space aboard for more fish. Larger boats are able to carry more ice, which allows them to make longer fishing trips, generally with better economic returns for the vessel and crew.

With advances in refrigeration, in particular the advent of compact and relatively lightweight ice-making machines suitable for on-board installation, it is now possible to install ice machines of various types on quite small vessels. This gives a certain measure of independence in fishing operations where trip length is no longer limited by the quantity of ice loaded in port or by how long it will last in the ice hold.
The beneficial effects of using ice can be apparent for a wide range of fishery activities, both small and large scale, and for virtually all species. Ice raises both the quality, and thus the value, of practically all species of fish. This promotes sustainable use of these renewable resources because the harvesting sector is able to preserve catches for longer periods and therefore reduce post-harvest losses.

1.1 CHILLING VERSUS FREEZING OF FISH
This publication is particularly concerned with chilling in fishing operations. However, there are other means of preserving fish that enable it to be stored for periods of time before marketing. One of the methods closely allied to chilling is freezing. There are many factors to be taken into account when considering the differences between chilling and freezing of fish products for various markets. Both chilling and freezing operations can produce stable products and the choice of one or the other depends on many factors.

Table 1.1 lists some of the advantages and disadvantages of the two methods. It can be used to help decide whether freezing or chilling is the option most appropriate to a particular situation.

1.2 THE PRESERVATIVE EFFECTS OF CHILLING FISH
The use of temperature reduction as a means of preserving fish and fishery products is very important worldwide both for local and export markets. This publication specifically examines the preservative effects and use of ice on board small fishing vessels.

For the purpose of this publication, the definition of chilling is as follows:

Chilling is the process of cooling fish or fish products to a temperature approaching that of melting ice.

The purpose of chilling is to prolong the shelf-life of fish, which it does by slowing the action of enzymes and bacteria, and the chemical and physical processes that can affect quality. Fresh fish is an extremely perishable food and deteriorates very rapidly at normal temperatures. Reducing the temperature at which the fish is kept lowers the rate of deterioration. During chilling the temperature is reduced to that of melting ice, 0 °C/32 °F.

<table>
<thead>
<tr>
<th>TABLE 1.1</th>
<th>Advantages and disadvantages of chilling and freezing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chilling</strong></td>
<td><strong>Freezing</strong></td>
</tr>
<tr>
<td>Short-term storage (up to one month maximum for some species, only a few days for others)</td>
<td>Long-term storage (a year or more for some species)</td>
</tr>
<tr>
<td>Storage temperature 0 °C</td>
<td>Storage temperature well below zero, e.g. -30 °C</td>
</tr>
<tr>
<td>Relatively cheap</td>
<td>Relatively costly</td>
</tr>
<tr>
<td>Product resembles fresh fish</td>
<td>If poorly done can badly affect quality</td>
</tr>
<tr>
<td>Relatively low-tech</td>
<td>Relatively high tech</td>
</tr>
<tr>
<td>Low skills required</td>
<td>High skills required</td>
</tr>
<tr>
<td>Portable refrigeration</td>
<td>Generally static operations</td>
</tr>
</tbody>
</table>
The most common means of chilling is by the use of ice. Other means are chilled water, ice slurries (of both seawater and freshwater), and refrigerated seawater (RSW). For the full benefits of chilling to be realized, it is essential to maintain chill temperatures throughout the different fish-handling operations.

Although ice can preserve fish for some time, it is still a relatively short-term means of preservation when compared to freezing, canning, salting or drying, for instance. When used properly it can keep fish fresh so that it is attractive in the market place.

The use of ice for preserving fish and fishery products has proved to be an effective handling method on board fishing vessels for the following reasons:

• Ice is available in many fishing areas or ports.
• Purchasing patterns can be varied according to need (e.g. block ice of different sizes is frequently manufactured, and crushed, small or fragmentary ice ready for use is sold by weight).
• Ice has a very high cooling capacity.
• Ice is harmless, and in general relatively cheap.
• Ice can maintain a very definite temperature.
• Ice can keep fish moist and as it melts it can wash surface bacteria from the fish.
• Ice can be moved from place to place and its refrigeration effect can be taken to wherever it is needed.
• Ice can be made on shore and used at sea.

However, packing fish in ice on board small fishing vessels, whether in boxes, shelves or pounds, is a labour-intensive task and other methods have been introduced to reduce the time and labour required. Among these, the most widely used are RSW and CSW. RSW is labour saving and an acceptable chilling method, but requires on-board mechanical refrigeration, pumping and filtering systems. It is also a relatively costly system. In CSW systems, sufficient ice is carried on a fishing voyage and mixed first with seawater before fish are added to the ice and water slurry.

Both these systems offer the advantages of quick chilling, reduced physical damage to the fish and quicker handling with less labour. However, they require more specialized installations on board and have usually only been found suitable where large volumes of fish need to be handled in a short time period, for instance when handling small pelagics on board purse seine vessels.

A typical comparison of temperature profiles for a medium-size round fish chilled in crushed ice, RSW and ice slurry is shown in Figure 1.1. According to these data, the fastest and most efficient chilling medium is ice slurry followed by RSW. The ice chilling rate is the lowest due to reduced contact of ice with the fish (an air layer surrounding the fish was created during ice meltage). To ensure maximum contact of ice with the fish, proper selection of the size of ice particles and good stowage practices are needed. The rate of chilling is governed by:

• the size, shape and thickness of fish;
• the method of stowage;
• adequate mixing of ice, water and fish (in ice slurries);
The use of ice on small fishing vessels

1.3 FACTORS AFFECTING THE RATE OF SPOILAGE IN FISH

The main factors that affect the rate of spoilage in chilled fish are:

- temperature
- physical damage
- intrinsic factors

1.3.1 Temperature

It is well known that high temperatures increase the rate of fish spoilage and low temperatures slow it down. Therefore, if the temperature of fresh fish is low, then quality is lost slowly. The faster a lower temperature is attained during fish chilling, the more effectively the spoilage activity is inhibited. Generally, the rate at which fish loses quality when stored in ice (0 °C) is used as the baseline when comparisons are made regarding shelf-life at different storage temperatures. The relationship between the shelf-life of fish at 0 °C and at t °C is known as the relative rate of spoilage at t °C (RRS) and is defined below:

\[
\text{Relative rate of spoilage at } t \, ^\circ\text{C} = \frac{\text{keeping time at 0 } ^\circ\text{C}}{\text{keeping time at } t \, ^\circ\text{C}}
\]

Further information on spoilage rates can be found in FAO Fisheries Technical Paper No. 348, *Quality and quality changes in fresh fish* (FAO, 1995a).
1.3.2 Physical damage
Fish is soft and easily damaged, therefore rough handling and bruising result in contamination of fish flesh with bacteria and allow releases of enzymes, speeding up the rate of spoilage. In addition, careless handling can burst the guts and spread the contents into the fish flesh.

1.3.3 Intrinsic factors
The intrinsic factors affecting the spoilage rate of chilled fish are shown in Table 1.2.

1.4 SHELF-LIFE OF FISH IN ICE
Chilling of fish can slow down the spoilage process, but it cannot stop it. Therefore, it is a race against time and fish should be moved as quickly as possible.

The main question for fishermen, traders and consumers is how long fish will keep in ice. As discussed previously, shelf-life will depend on several factors. However, the fish spoilage pattern is similar for all species, with four phases of spoilage as outlined in Table 1.3.

There have been many research studies regarding the shelf-life of fish stored in ice. Based on these studies, it is generally accepted that some tropical fish species can keep for longer periods in comparison to fish from temperate or colder waters. This can be attributed to differences in the bacterial growth rates, with a 1–2 week slow growth phase (or period of adaptation to chilled temperatures) in tropical

<table>
<thead>
<tr>
<th>Intrinsic factors</th>
<th>Relative spoilage rate of fish stored in ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow rate</td>
<td>Fast rate</td>
</tr>
<tr>
<td>Shape</td>
<td>Flat fish Round fish</td>
</tr>
<tr>
<td>Size</td>
<td>Large fish Small fish</td>
</tr>
<tr>
<td>Fat content in the flesh</td>
<td>Lean species Fatty species</td>
</tr>
<tr>
<td>Skin characteristics</td>
<td>Thick skin Thin skin</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Fish just caught is very fresh and has a sweet, seaweedly and delicate taste. There is very little deterioration, with slight loss of the characteristic odour and flavour. In some tropical species this period can last for about 1 to 2 days or more after catching.</td>
</tr>
<tr>
<td>Phase II</td>
<td>There is a significant loss of the natural flavour and odour of fish. The flesh becomes neutral but has no off-flavours, the texture is still pleasant.</td>
</tr>
<tr>
<td>Phase III</td>
<td>The fish begins to show signs of spoilage. There are strong off-flavours and stale to unpleasant smells. Texture changes are significant, flesh becoming either soft and watery or tough and dry.</td>
</tr>
<tr>
<td>Phase IV</td>
<td>Fish is spoiled and putrid, becoming inedible.</td>
</tr>
</tbody>
</table>
TABLE 1.4
Shelf-life of some marine and freshwater fish species stored in ice

<table>
<thead>
<tr>
<th>Species</th>
<th>Shelf-life (days in ice)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperate waters</td>
<td>Tropical waters</td>
</tr>
<tr>
<td><strong>Marine species</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cod, Haddock</td>
<td>9–15</td>
<td>White-fleshed lean</td>
</tr>
<tr>
<td>Whiting</td>
<td>7–9</td>
<td>White-fleshed lean</td>
</tr>
<tr>
<td>Hake</td>
<td>7–15</td>
<td>White-fleshed lean</td>
</tr>
<tr>
<td>Bream</td>
<td>10–31</td>
<td>Lean/low fat</td>
</tr>
<tr>
<td>Croaker</td>
<td>8–22</td>
<td>Lean</td>
</tr>
<tr>
<td>Snapper</td>
<td>10–28</td>
<td>Lean</td>
</tr>
<tr>
<td>Grouper</td>
<td>6–28</td>
<td>Lean</td>
</tr>
<tr>
<td>Catfish</td>
<td>16–19</td>
<td>Lean</td>
</tr>
<tr>
<td>Pandora</td>
<td>8–21</td>
<td>Lean</td>
</tr>
<tr>
<td>Jobfish</td>
<td>16–35</td>
<td>Lean</td>
</tr>
<tr>
<td>Spadefish</td>
<td>21–26</td>
<td>Lean/low fat</td>
</tr>
<tr>
<td>Batfish</td>
<td>21–24</td>
<td>Lean</td>
</tr>
<tr>
<td>Sole, Plaice</td>
<td>7–21</td>
<td>Flat fish</td>
</tr>
<tr>
<td>Flounder</td>
<td>7–18</td>
<td>Flat fish</td>
</tr>
<tr>
<td>Halibut</td>
<td>21–24</td>
<td>Flat fish</td>
</tr>
<tr>
<td>Mackere11</td>
<td>4–19</td>
<td>Pelagic fish; high/low fat</td>
</tr>
<tr>
<td>Summer herring</td>
<td>2–6</td>
<td>Pelagic fish; high fat</td>
</tr>
<tr>
<td>Winter herring</td>
<td>7–12</td>
<td>Pelagic fish; low fat</td>
</tr>
<tr>
<td>Sardine</td>
<td>3–8</td>
<td>Pelagic fish; high fat</td>
</tr>
<tr>
<td><strong>Freshwater species</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catfish</td>
<td>12–13</td>
<td>Lean</td>
</tr>
<tr>
<td>Trout</td>
<td>9–11</td>
<td>Low fat</td>
</tr>
<tr>
<td>Perch</td>
<td>8–17</td>
<td>Lean/low fat</td>
</tr>
<tr>
<td>Tilapia</td>
<td>10–27</td>
<td>Lean</td>
</tr>
<tr>
<td>Mullet</td>
<td>12–26</td>
<td>Lean</td>
</tr>
<tr>
<td>Carp</td>
<td>16–21</td>
<td>Lean/low fat</td>
</tr>
<tr>
<td>Lungfish</td>
<td>11–25</td>
<td>Lean/low fat</td>
</tr>
<tr>
<td>Shad</td>
<td>25</td>
<td>Medium fat</td>
</tr>
<tr>
<td>Corvina</td>
<td>30</td>
<td>Medium fat</td>
</tr>
<tr>
<td>Pacu</td>
<td>40</td>
<td>Fatty</td>
</tr>
<tr>
<td>Bagre (type of catfish)</td>
<td>25</td>
<td>Medium fat</td>
</tr>
<tr>
<td>Chincuna</td>
<td>40</td>
<td>Fatty</td>
</tr>
</tbody>
</table>

1 Fat content and shelf-life are subject to seasonal variations.
fish stored in ice. However, due to differences in the criteria used to define the limit of shelf-life, and methodologies used, comparison between shelf-life of fish from tropical and temperate waters is still difficult. Tables 1.4 and 1.5 show shelf-life of several fish species stored in ice and RSW.

<table>
<thead>
<tr>
<th>Species</th>
<th>Shelf-life (days in the chilling medium)</th>
<th>Storage temperature in RSW (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ice (0 °C)</td>
<td>RSW</td>
</tr>
<tr>
<td>Pacific cod</td>
<td>6–9</td>
<td>-</td>
</tr>
<tr>
<td>Pink shrimp</td>
<td>-</td>
<td>4–5</td>
</tr>
<tr>
<td>Herring</td>
<td>-</td>
<td>8–8.5</td>
</tr>
<tr>
<td>Walleye pollock</td>
<td>6–8</td>
<td>4–6</td>
</tr>
<tr>
<td>Rockfish</td>
<td>-</td>
<td>7–10</td>
</tr>
<tr>
<td>Chum salmon</td>
<td>-</td>
<td>7–11</td>
</tr>
<tr>
<td>Silver hake</td>
<td>4–5</td>
<td>4–5</td>
</tr>
<tr>
<td>Capelin</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

2. The manufacture of ice

2.1 SEA OR FRESHWATER

When considering the manufacture of ice on board fishing vessels, seawater will be the natural choice of raw material. When considering whether to use fresh or seawater in land-based plants, the decision will depend on several factors, such as the availability of regular supplies, the location of the ice plant and the intended use of the ice (e.g. for use on board fishing vessels or on shore). Whatever type of water is used, it must be remembered that the resultant ice will come into direct contact with food. For this reason it is essential that the water used is free from contamination that could cause risks to human health or tainting of the fish so that it becomes unacceptable. This implies that the water must be of drinking-water quality and comply with the safety standards laid down by such bodies as the World Health Organization.

The use of seawater ice for chilling fish has been studied for several years and, with the development of suitable small ice machines that can be installed on board fishing vessels, this alternative is becoming more feasible for fishermen. The main advantages of the use of seawater ice are:

• It can be produced at sea or on shore where shortages of freshwater are a serious problem or where freshwater is expensive.

• Since space on fishing vessels is limited, the ability to produce ice when and if it is needed, rather than having to predict needs before a fishing trip begins, can have practical advantages.

• Slightly lower storage temperatures can be obtained with seawater ice; therefore the shelf-life of fish can be prolonged. Commercially available flake/scale ice machines can manufacture seawater ice with a temperature from $-9 \, ^\circ C$ to $-20 \, ^\circ C$ and a variable percentage of salt content.

However, there are some major disadvantages, such as:

• Seawater ice is not homogenous and when stored it can become a mixture of ice crystals and chilled salt solution, which is semi-fluid in consistency and leaches out the brine solution as the ice rises in temperature. Therefore, seawater ice has no fixed melting point ($-1.5 \, ^\circ C$ to $-2 \, ^\circ C$ for seawater ice having a salt content between 3 and 3.6 percent) and losses through melting and leaching of the brine solution will depend on the storage temperature.

• Because of its variable temperature, there is a risk of partially freezing fish and salt absorption (particularly with thin-skinned fish) when using seawater ice.

• Machines specifically designed for seawater ice production are needed to obtain the best-quality ice. These tend to be more expensive to purchase and run than ice machines designed for freshwater ice manufacture.
The following design factors for on-board seawater ice machines should be considered:

- The plant needs to be capable of operating and producing ice under extreme pitching and rolling conditions of fishing vessels.
- The plant needs to be made from non-corrosive materials (such as high-quality stainless steel, aluminium, plastics, rubber and fibreglass) to resist the marine environment.

### TABLE 2.1

Typical characteristics of flake seawater ice-maker units suitable for small and medium fishing vessels

<table>
<thead>
<tr>
<th>Capacity (kg of ice/24 h)</th>
<th>Cooling requirements (kcal/h)</th>
<th>Refrigerant</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>550</td>
<td>4 000</td>
<td>R-22</td>
<td>The ice-making unit is equipped with a stainless steel revolving drum evaporator. This unit can be installed on deck or inside the fish hold. Condensing unit and compressor are located in the engine room. Ice production capacity is based on a water supply temperature of 10 °C and evaporator temperature of –30 °C. It is estimated that a one-day ice production will require a refrigerated storage space of about 1.24 m³.</td>
</tr>
<tr>
<td>1 350</td>
<td>7 100</td>
<td>R-22</td>
<td>As above. It is estimated that a one-day ice production will require a refrigerated storage space of about 3.05 m³.</td>
</tr>
<tr>
<td>1 950</td>
<td>11 000</td>
<td>R-22</td>
<td>As above. It is estimated that a one-day ice production will require a refrigerated storage space of about 4.4 m³.</td>
</tr>
<tr>
<td>4 500</td>
<td>21 434</td>
<td>R-22, or any ozone-friendly refrigerant</td>
<td>The self-contained unit has a pressurized water feed system and a stainless steel evaporator disc for producing subcooled flake ice. Ice production capacity is based on a water supply temperature of 16 °C and –23 °C evaporator temperature. An optional remote water-cooled condensing unit suitable for use with seawater can be installed (40–80 litres per minute of water consumption at 16 °C). It is estimated that a one-day ice production will require a refrigerated storage space of about 10.2 m³.</td>
</tr>
<tr>
<td>8 000</td>
<td>36 290</td>
<td>As above</td>
<td>The flake ice-maker can be installed on board as a self-contained unit or as a remote unit with a refrigeration plant that can be driven electrically, by diesel or hydraulics. All ice contact surfaces of the unit are stainless steel or corrosion resistant to seawater materials. Seawater supply for ice-making is delivered to the freezing surface in a pressurized system. The evaporator suction temperature is –32 °C and seawater supply temperature is 21 °C. The manufacturer recommends the use of pressurized water delivery and variable speed for on-board installed ice-makers.</td>
</tr>
<tr>
<td>10 000</td>
<td>45 363</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td>12 000</td>
<td>54 435</td>
<td>As above</td>
<td>As above</td>
</tr>
</tbody>
</table>

1 Ice production capacities can vary with evaporator and water temperatures, type of refrigerant and ice thickness. Therefore, the above data are the average output of seawater ice leaving the ice-maker at a temperature of –20 °C, under the conditions listed above.
The manufacture of ice

- The equipment needs to operate at a lower temperature than freshwater ice machines – usually between –18 and –21 °C because seawater freezes at a lower temperature than freshwater.

The advantages of having on-board ice machines, especially for fishermen dedicated to the production of fresh fish, can be summarized as follows:
- They allow flexibility in catch volume and trip length.
- After the initial purchase costs of the machine, ice production can be less costly and only involves keeping the ice machine properly maintained and in good repair.
- The fisherman is no longer dependent on shore-based plants for ice supplies for fishing trips; ice can be generated as and when required.
- Being able to produce ice on board can overcome the problems that occur when a boat that has been loaded with shoreside ice returns with little or no catch. Ice costs can amount to a considerable percentage of operational costs in many countries.

The principal disadvantages are:
- Costs of purchase and installation of machine and any ancillary equipment that may also be required, such as auxiliary power, conveyors, etc.
- The ice produced is usually from saltwater, which can affect some fish species by salt absorption into the product.
- Ice and consequently catch can be contaminated if care is not taken to use only clean seawater.
- Machine maintenance will require some specialized technical expertise.
- Additional power is needed.
- Skilled labour and maintenance services are required (possibly on board the vessel).

The most common type of ice-maker to be installed on board a small fishing vessel would be a flake ice-maker. Table 2.1 gives some characteristics of flake ice-makers capable of producing seawater ice suitable for use on board small- and medium-size fishing vessels.

Table 2.2 gives some typical dimensions for various types of “package” ice machines that, according to manufacturers, are suitable for installation on board fishing vessels. All machines shown are water-cooled models, except for the Coldisc model. Some examples of other machines are given to show how changes in dimensions affect production capacities.

However, in order to use ice at sea it is not necessary to take ice-makers to sea. As has already been indicated, ice can be moved from place to place and is a form of portable refrigeration. This allows ice made in shore-based plants to be taken to sea and used as and when required.

2.2 TYPES OF ICE AND HOW THEY ARE MADE

2.2.1 Block ice

Block ice was first manufactured commercially in 1869. It is made by filling metal cans with water and lowering them into a bath of brine (usually sodium or calcium chloride) refrigerated to well below the freezing point of water. The water freezes...
in the cans and the ice blocks are removed from the cans after several hours of freezing. The cans are immersed in freshwater to release the ice blocks, which are then stored.

The production of block ice is a batch operation and, once emptied, the cans are refilled with water and replaced in the brine tank for a further freezing period. Whatever the capacity of the ice-maker for block ice production, a continuous labour force is required to manage all operations, particularly ice harvesting and handling. The main advantages of block ice in comparison with other types of ice are:

- simple and easy storage, handling and transportation;
- relatively slow melting rate, and therefore losses during storage and distribution are minimal;
- the ice is compact and therefore less storage space is required;
- the ice can be reduced to any particle size as required through crushing before use;
- the plant is robust engineering and relatively simple to maintain by a competent mechanical engineer;
- the ice can be handled easily and sold by the block.

The main disadvantages of block ice production are:

- the long time period required (8–36 h) to complete the freezing of water in cans (block size from 12 to 140 kg);
- high labour costs and continuous attention to operations;

### TABLE 2.2
Capacities and principal dimensions of various ice-making machines suitable for use on fishing vessels

<table>
<thead>
<tr>
<th>Type of machine</th>
<th>Capacity (tons US &amp; kg/24 h)</th>
<th>Depth (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flake ice “Coldisc” front discharge</td>
<td>1.0 t 909 kg</td>
<td>660</td>
<td>520</td>
<td>510</td>
<td>45 kg only</td>
</tr>
<tr>
<td>Flake ice, drum type</td>
<td>1.0–2.5 t 909–2 272 kg</td>
<td>965</td>
<td>635</td>
<td>1 118</td>
<td>250</td>
</tr>
<tr>
<td>Flake ice, drum type</td>
<td>6.0 t 4 272 kg</td>
<td>1 219</td>
<td>813</td>
<td>1 143</td>
<td>614</td>
</tr>
<tr>
<td>Shell ice, tube type, hot gas cycle</td>
<td>1.5 t 1 363 kg</td>
<td>1 372</td>
<td>762</td>
<td>1 555</td>
<td>771</td>
</tr>
<tr>
<td>Shell ice, tube type, hot gas cycle</td>
<td>3.0 t 2 727 kg</td>
<td>2 444</td>
<td>762</td>
<td>1 555</td>
<td>1 315</td>
</tr>
<tr>
<td>Slush ice</td>
<td>3.3 t 3 000 kg</td>
<td>1 000</td>
<td>650</td>
<td>800</td>
<td>260</td>
</tr>
<tr>
<td>Slush ice</td>
<td>3.5 t 3 181 kg</td>
<td>630</td>
<td>580</td>
<td>1 700</td>
<td>390</td>
</tr>
<tr>
<td>Slush ice</td>
<td>5.5 t 4 992 kg</td>
<td>1 000</td>
<td>800</td>
<td>1 900</td>
<td>500</td>
</tr>
<tr>
<td>Slush ice</td>
<td>7.0 t 6 363 kg</td>
<td>660</td>
<td>1 010</td>
<td>1 700</td>
<td>800</td>
</tr>
</tbody>
</table>

1 Outputs based on ambient of 90 °F (32 °C).
2 Outputs based on ambient of 50 °F (10 °C).
3 Output based on 0 to 1 °C feedwater, prechiller unit recommended.
• it is not a continuous automatic process and it takes a long time to produce ice from first start-up;
• space requirements for the ice plant itself are greater than for modern automatic ice-makers;
• adequately treated brines are necessary to minimize equipment corrosion; ice must be crushed before use.

Containerized block ice plants are available that house the ice plant, ice store and complete refrigeration and electrical systems inside standard containers. This allows portability, ease of transport by sea and land, better reliability and significantly shorter installation and break-in periods than traditional non-containerized types. These advantages are important, particularly in remote areas where there is limited refrigeration and maintenance expertise. These units are fitted into standard 40 ft containers, and are easy to install. They only require a levelled foundation and to be under cover for protection against the weather, and they can be built in tropical climates and coastal conditions. Units are available that produce blocks of various sizes from 12.5 to 25 kg. Table 2.3 gives some information on containerized block ice plants.

Figure 2.1 shows the relationship between the thickness of ice produced and the time it takes to freeze in typical block ice production. In general, the thicker the ice block, the longer the freezing time. For example, a 136 kg block will require on average about 36 h of freezing time, in comparison to a 25 kg block that will require on average about 12 h.

<table>
<thead>
<tr>
<th>Ice capacity (kg/24 h)</th>
<th>Ice storage capacity (kg)</th>
<th>Space requirements (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 000</td>
<td>6 000</td>
<td>30 (for the container)</td>
</tr>
<tr>
<td>5 000</td>
<td>5 000</td>
<td>30 (for the container)</td>
</tr>
<tr>
<td>7 500</td>
<td>3 000</td>
<td>30 (for the container)</td>
</tr>
<tr>
<td>10 000</td>
<td>none</td>
<td>30 (for the container)</td>
</tr>
</tbody>
</table>

1 Rated capacity at continuous harvest operation. Ice storage temperature is about –5 °C, with an eight-hour freezing cycle.

2.2.2 Rapid block ice
The long time periods required to produce blocks of ice have led to the development of what are known as rapid block ice plants. The aim of these plants is to produce blocks of ice in a few hours. Instead of ice cans being immersed in a brine tank, the water in the can is frozen by a refrigerant which is circulated through the outer jacket of each can, as well as through a piping system located inside the cans. Ice is formed simultaneously on all refrigerated surfaces in contact with the water. After completion of the freezing cycle, the blocks are quickly removed from the can by means of a hot gas defrost and released by gravity. The main advantages of rapid block ice-makers are their reduced space requirements in comparison with traditional block ice-makers.
The use of ice on small fishing vessels

2.2.3 Flake ice

Flake ice can be defined as dry and subcooled small ice in flat pieces having an irregular wafer shape.

This type of small ice is manufactured by spraying or pouring water onto a refrigerated surface, often in the form of a cylinder or drum. The water freezes on the surface and forms thin layers of ice (2–3 mm thick). A scraper removes the subcooled ice, which breaks into small pieces resembling splinters of glass. These pieces of ice usually fall from the drum directly into a refrigerated compartment for storage. The cooled cylinder can rotate either in a vertical or horizontal plane.

A second type of flake ice-maker of particularly compact size, specifically designed for on-board ice-making is illustrated in Figure 2.2. Produced by North Star Ice Equipment Corporation, it departs from the normal drum style configuration and instead produces flake ice on a rotating subcooled evaporator disc. Ice is then harvested from both sides of the disc by adjustable ice scrapers. It would appear that this machine could be used in fish holds of boats 12 to 16 m long in some artisanal fleets considering its compact size and light weight. On smaller vessels it is likely to be installed on deck. The technical characteristics of this type of ice-maker are shown in Table 2.4.
A variation on flake ice is known as chip ice. Chip ice is manufactured by flowing water inside the ice-making cylinder, which is surrounded by an evaporating coil. The water is frozen inside the cylinder at an evaporator temperature of −12 to −30 °C and removed with an auger revolving inside the cylinder and pushing the ice upwards. In the upper part of the cylinder the ice is pressed, frozen further and ejected through the top of the cylinder. Chip ice has a temperature of −0.5 °C and an average thickness of 7–8 mm.

When installed on board fishing vessels, flake ice machines are often mounted on the deck so that the ice produced is discharged directly into the fish hold via a small hatch provided for this purpose. Most drum-type ice-makers designed for fishing vessels have an ice discharge port directly below the drum centre, making installation over a dedicated hatch possible. Depending on the machine, its location on deck and manufacturers’ recommendations, some form of shielding or cabinet may be necessary to protect control panels or other parts of the unit from the environment.

The below-deck installation is generally more problematic as most machines rely on gravity after removal of ice from the drum to put ice in the storage bins. This would require a fairly large fish hold with sufficient height to the deckhead to provide room for the machinery installation and enough height to allow gravity feed to a collection area or storage pens. Flake or shell ice machines may require the installation of conveyors or augers in larger vessels, though in the majority
The use of ice on small fishing vessels

of instances, crew with shovels will transfer the ice produced to storage pens as needed.

The main advantages of flake ice are as follows:

- Flake ice has a larger heat-exchange surface than most other types of ice, therefore heat transfer between fish and ice occurs faster and more efficiently.
- Due to the fact that flake ice is slightly subcooled (−5 to −7 °C), it can give off 83 kcal per kg when melting from ice to water; therefore slightly more heat can be extracted than with other types of ice at a temperature of 0 °C (80 kcal per kg).
- It is easy to store and handle when adequately designed subcooled (−5 °C) insulated storage is provided.
- The plant is small and compact, using less space than block ice plants.

### TABLE 2.4
Typical characteristics of some flake ice-makers

<table>
<thead>
<tr>
<th>Ice capacity(^1) (kg/24 h)</th>
<th>Cooling requirements (kcal/h)</th>
<th>Refrigerant</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 000</td>
<td>4 760</td>
<td>R-22 or any suitable ozone-friendly refrigerant</td>
<td>Water supply: 42 litres per hour at 16 °C and −23 °C evaporator temperature. Ice thickness: 1.5 mm. Size of the unit without ice storage: H (510 mm) × W (520 mm) × L (660 mm). Unit weight: 45 kg. (Disc unit)</td>
</tr>
<tr>
<td>2 250</td>
<td>10 590</td>
<td>As above</td>
<td>Water supply: 102 litres per hour at 16 °C and −23 °C evaporator temperature. Ice thickness: 1.5 mm. Size of the unit without ice storage: H (1 065 mm) × W (685 mm) × L (865 mm). Unit weight: 165 kg. An optional remote water-cooled condensing unit suitable for installation on board fishing vessels can be fitted, with a seawater supply at 16 °C of 1 200 litres per hour. Standard operating temperature of condenser: 35 °C</td>
</tr>
<tr>
<td>4 500</td>
<td>21 434</td>
<td>As above</td>
<td>Water supply: 204 litres per hour at 16 °C and −23 °C evaporator temperature. Ice thickness 1.5 mm. Size of the unit without ice storage: H (1 065 mm) × W (865 mm) × L (865 mm). Unit weight: 225 kg. An optional remote water-cooled condensing unit suitable for installation on board fishing vessels can be fitted, with a seawater supply at 16 °C of 2 400–4 800 litres per hour. Standard operating temperature of condenser: 35 °C</td>
</tr>
<tr>
<td>9 000</td>
<td>42 867</td>
<td>As above</td>
<td>Water supply: 420 litres per hour at 16 °C and −23 °C evaporator temperature. Ice thickness 1.5 mm. Size of the unit without ice storage: H (1 065 mm) × W (1 120 mm) × L (865 mm). Unit weight: 300 kg. An optional remote water-cooled condensing unit suitable for installation on board fishing vessels can be fitted, with a seawater supply at 16 °C of 4 800–9 600 litres per hour. Standard operating temperature of condenser: 35 °C</td>
</tr>
</tbody>
</table>

\(^1\) For large ice-makers it is recommended that in tropical areas, with water temperatures over 21 °C, feed water should be chilled in a separate chiller (to cool the water to a range of 4.4 to 7.2 °C) to avoid significantly lower ice outputs and higher energy consumption. See Figure 2.3 for details on the relationship between feed-water temperature and required tonnes of refrigeration (1 tonne of refrigeration = 3 024 kcal/h = 12 000 Btu/h).
• The manufacture of ice begins within a very short time of starting the machine, almost allowing "ice on demand".
• Ice is ready to use immediately after manufacture (does not need crushing). However, flake ice has a number of disadvantages in comparison to block ice. For example:
  • The plant is less robust and more complex and requires skilled engineers for maintenance.
  • Because of its higher surface area, the ice melts more quickly.
  • Weight for weight, flake ice requires more storage space.
  • The ice produced has to be weighed before sale rather than being sold by the unit.

As with block ice plants, flake ice plants can be containerized into 20 and 40 ft containers, depending on the capacity of the ice-makers and ice storage systems required. These units can be made so that they simply need to be connected to a power and water supply and with some modifications can be installed on board very large fishing vessels. However, these shipboard units are outside the size range of vessels examined in this publication. Large capacity models for freshwater flake ice production are also available for onshore installations, making between 10 and 100 tonnes of ice with multicontainer systems (these models have the complete ice-maker unit mounted on top of the insulated container which is used as an ice store). Technical specifications and characteristics of some typical containerized flake and chip ice plants are given in Table 2.5.
2.2.4 Compacted blocks of small ice

When there is a need for ice supplies to be transported over long distances, or there are preferences in certain fisheries for block ice, it is feasible to produce blocks from small or flake ice using block-compacting machines. These machines press small ice (flake or chip ice) into blocks of standard sizes and can be easily installed in shore-based small ice plants. These compacted blocks of small ice can be used on board fishing vessels giving the advantages of conventional block ice. They could be particularly suitable in tropical developing fisheries where ice-melt rates are high and fishermen are used to handling blocks of ice from older ice plants. The compacted blocks of small ice are easier to break into small pieces when needed.

### TABLE 2.5

**Typical technical features of containerized flake/chip ice plants**

<table>
<thead>
<tr>
<th>Ice capacity (kg/24 h)</th>
<th>Ice storage capacity</th>
<th>Container (m³)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 000</td>
<td>13 m³ / 5 000 kg</td>
<td>20 ft</td>
<td>Space requirements: 15.74 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 3 000 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>5 000</td>
<td>13 m³ / 5 000 kg</td>
<td>20 ft</td>
<td>Space requirements: 15.74 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 5 000 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>10 000</td>
<td>13 m³ / 5 000 kg</td>
<td>20 ft</td>
<td>Space requirements: 15.74 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 10,000 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>5 000</td>
<td>37 m³ / 15 000 kg</td>
<td>40 ft</td>
<td>Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 5,000 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>7 500</td>
<td>37 m³ / 15 000 kg</td>
<td>40 ft</td>
<td>Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 7,500 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>10 000</td>
<td>37 m³ / 15 000 kg</td>
<td>40 ft</td>
<td>Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and freshwater feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 10,000 litres/24 h. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>3 000</td>
<td>20 m³ / 8 000 kg</td>
<td>15 m³</td>
<td>Type of container: 10 ft. Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and water feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 10,000 litres/24 h. Water-cooled condensers for seawater can be installed. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>5 000</td>
<td>20 m³ / 8 000 kg</td>
<td>15 m³</td>
<td>Type of container: 40 ft. Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and water feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 10,000 litres/24 h. Water-cooled condensers for seawater can be installed. Refrigerant used: R-22 or R-717</td>
</tr>
<tr>
<td>10 000</td>
<td>20 m³ / 8 000 kg</td>
<td>15 m³</td>
<td>Type of container: 40 ft. Space requirements: 30 m³. Standard operating conditions: ambient temperature: 35 °C and water feed temperature: 25 °C; power: 380 volts/3 phase/50 or 60 Hz; water supply: 10,000 litres/24 h. Water-cooled condensers for seawater can be installed. Refrigerant used: R-22 or R-717</td>
</tr>
</tbody>
</table>
### 2.2.5 Slush ice

One type of ice plant well suited for use on board fishing vessels is the slush ice machine that produces subcooled ice crystals. When mixed with water, the crystals allow slurry to be pumped easily by flexible hoses to wherever it is required on the boat. This ice acts in a similar manner to CSW when in slurry form, and as such can be used in CSW tanks or fish holds. In slightly less liquid form it can also be used to bulk pack fish in tote boxes. Figure 2.5 shows in diagrammatic form how this type of installation may be installed in fishing vessels of appropriate size.

Slush ice is a mixture of ice crystals in water and water slurry. The ice is formed by freezing ice crystals out of a weak brine solution in a tube-in-tube heat exchanger, also called a scraped-surface heat exchanger. Water is frozen as tiny round/ellipsoid crystals (about 0.2 to 1.3 mm diameter) on the inner-tube surface and a rotary screw conveyor moves the ice crystals out of the heat exchanger into a storage tank with water. The resulting mixture of ice and water (slush ice) can be pumped from the storage tanks through piping or hoses to the fish-chilling area or directly to an insulated container. The density and fluidity of slush ice can be adjusted by regulating the amount of water added, so that they can be tailored to different applications.

The advantages claimed for slush ice for chilling fish are as follows (see also Table 2.6):

---

**FIGURE 2.4**

Typical plant installation (24 tonnes/day)

1. Ice storage tank
2. Ice discharge chute
3. Slurry delivery tank (optional)
4. Slurry delivery pump (optional)
5. Brine control system
6. Optional wall mount control panel
7. Pumping station
8. Ice generator

Source: Sunwell Engineering Co. Ltd, Woodbridge, Ontario, Canada.
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FIGURE 2.5
Schematic of slush ice use on fishing boats

- It ensures faster and even chilling of fish to or below 0 °C, due to improved heat transfer.
- It gives better contact with fish surface without bruises or pressure damage.
- It is claimed that ice contamination is significantly reduced due to the sealed system design of the ice-maker and storage.
- Ice can be pumped directly to where it is needed so there is not necessarily a need for storage.

TABLE 2.6
Typical specifications for a twin-tube slush ice-maker

<table>
<thead>
<tr>
<th>Capacity (kg/24 h)</th>
<th>Power requirements</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 000, based on feed water at 10 °C and 3% NaCl concentration</td>
<td>220 volts, AC, 3 phases, 50/60 Hz; 9.6 kW</td>
<td>Two ice-generator tubes, 316 stainless steel. R-22 as refrigerant. Two compressors of 8 610 kcal/h capacity and –11 °C at suction and 38 °C at condensing. Two seawater-cooled condensers of 1 380 litres per hour capacity each, with standard operating condensing temperature of 38 °C. Seawater supply temperature of 24 °C. Frame construction: stainless steel tube. Dimensions of unit: W: 100 mm; L: 660 mm; H: 1 700 mm</td>
</tr>
</tbody>
</table>

Note: currently, models of slush ice-makers from 2.5 to 24 tonnes per 24 h capacity are available, both as self-contained units or as remote units, with separated refrigeration systems for on board installation.

Source: Brontec USA Inc.
Since the “raw material” for ice production is a brine solution (3–5 percent NaCl), seawater can be used for slush ice manufacture. This allows units to be installed on board fishing vessels. The commercial application of slush ice on board industrial purse seiners has been tested for chilling small pelagics, with good results. The slush ice has been used to enhance the traditional RSW system on board purse seiners, and improve the chilling process by significantly shortening the cooling period, from 7–20 h on regular RSW to about one hour. As can be seen from Figure 2.6, the cooling time for fish in slush ice is considerably shorter than in flake ice and is comparable with cooling times encountered with CSW.

2.2.6 Chilled seawater

CSW as a cooling medium is becoming much more common in small fishing vessels. For instance, boats as small as 32 ft (9.75 m) length overall are using this system to preserve high-value catch in top condition after capture. Overall temperature control in the CSW tanks is achieved by the addition of ice to lower seawater temperature and that of the catch as it is added during the trip. To prevent temperature stratification in CSW tanks, two basic systems are used, one is compressed air, also known as the “champagne” system, and the other is CSW recirculation by pump. These are illustrated in Figure 2.7.

2.2.7 Refrigerated seawater

RSW systems have an on-board refrigeration plant to chill the seawater rather than using melting ice. In addition, they need pumps, piping and filters for circulation.
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Two basic systems are used for RSW cooling of products: one involves simply immersing the catch in filled RSW tanks; the second system does not use tanks but sprays chilled water over shelved catch.

When filling RSW tanks in the hold with clean water that is then refrigerated, some boats will load ice into the tanks prior to filling with water. This saves time and alleviates some of the load on the refrigeration system by pre-chilling the water. Figure 2.8 illustrates a typical RSW spray system as installed in vessels of
the Pacific northeast coast. Tanks for RSW are similar in arrangement to CSW tanks, the principal difference is in the installation of a refrigeration unit with its power supply and a much better filter system for the recirculated water.

Recent developments in hydraulic systems have now made it possible to run a refrigeration compressor using hydraulic power from a power take off (PTO)
from the boat’s main engine. This has been developed utilizing load-sensing pumps, which, when set, maintain a constant flow regardless of engine speed. This allows a refrigeration compressor to run at constant speed whether the engine is idle or running at full speed. These pumps go to standby mode when there is no demand for hydraulic flow, and only small amounts of power are consumed in this mode. However, if the main engine is idling when the compressor cuts in there is a considerable power demand. For this reason engineers recommend that the main engine should have very good power reserves at low or idle speeds.

### 2.3 REFRIGERANTS AND THEIR ENVIRONMENTAL IMPACT

Chemicals used as refrigerants, known as chlorofluorocarbons (CFCs), are known to have adverse effects on the earth’s stratospheric ozone layer. As a consequence, international efforts are being made to phase out most of the CFCs or halogenated hydrocarbons from commercial use (see Table 2.7). A number of more environmentally acceptable alternatives are being proposed, such as R-22, ammonia (R-717), HP-62 and hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), see Table 2.8. Examples of the new HFCs and HCFCs are as follows:

- HCF R-134a (CF3CFH2): which is a replacement for the CFC R-12 used in small chillers, domestic refrigeration and vehicle air-conditioning units.

#### TABLE 2.7

Montreal Protocol provisions regarding ozone-depleting chemicals

<table>
<thead>
<tr>
<th>Chemical compound</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group I – CFCs</strong></td>
<td>Gradual reduction over the 1990s. Full replacement by the year 2000 in developed countries and by the year 2010 in developing countries.</td>
</tr>
<tr>
<td>R-11; R-12; R-113; R-114, R-115, R-502</td>
<td></td>
</tr>
<tr>
<td><strong>Group II – Halons</strong></td>
<td>Gradual reduction over the 1990s. Full replacement by the year 2000 in developed countries. Developing countries have a ten-year grace period.</td>
</tr>
<tr>
<td>Halon 1211; halon 1301; halon 2402 and carbon tetrachloride</td>
<td></td>
</tr>
<tr>
<td><strong>Group III</strong></td>
<td>Gradual reduction over the 1990s. Full replacement by the year 2005 in developed countries. Developing countries have a ten-year grace period.</td>
</tr>
<tr>
<td>Methyl chloroform</td>
<td></td>
</tr>
</tbody>
</table>

Note: all Protocol provisions came into force on 1 January 1989 and were revised in 1990.

#### TABLE 2.8

Atmospheric lifetimes and ozone depletion potential of some halogenated hydrocarbons

<table>
<thead>
<tr>
<th>Chemical compound</th>
<th>Lifetime (years)</th>
<th>Ozone depletion potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC: R-32 (CHF₂)</td>
<td>6.7</td>
<td>0</td>
</tr>
<tr>
<td>HFC: R-125 (CF₂CF₃)</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>HFC: R-134a (CF₂CFH₂)</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>HCF: R-143a (CF₃CH₂)</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>HCF: R-22 (CF₂Cl)</td>
<td>14</td>
<td>0.047</td>
</tr>
<tr>
<td>CFC: R-11 (CF₂Cl₂)</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>CFC: R-12 (CF₂Cl₃)</td>
<td>105</td>
<td>0.95</td>
</tr>
</tbody>
</table>
• HCFC R-22 (CHF2CL): which is a replacement for CFC R-12 in industrial refrigeration units.

The main technical characteristics of HFCs and HCFCs are:
• Both types of refrigerants are volatile and insoluble in water.
• Following release into the environment, these refrigerants remain in the atmosphere where they are oxidized into a variety of degradable products, which are not considered to be toxic or noxious.
• Commercially available HCFs and HCFCs are classified as “ozone-friendly” refrigerants.
• HCFCs are considerably less harmful towards the ozone layer than CFCs, but HCFCs do transport chlorine into the ozone layer following release into the environment. Therefore, countries such as the United States of America have developed a schedule for a complete ban on the manufacture and importation of HCFCs by the year 2030.

With regard to the refrigerants most widely used in fisheries, R-12, R-22, R-502 and ammonia (R-717) are the leading products, see Table 2.9. However, with the ban on CFCs by the year 2000 in developed countries, most of the existing refrigeration plants using CFCs will be facing serious problems in the conversion from R-12 and R-502 to other refrigerants. From the engineering point of view, the conversion of refrigeration plants to use alternate refrigerants is possible in some cases. For example, a brief analysis for converting R-12 refrigeration plants into R-22 plants could show the following:
• There are significant differences between R-12 and R-22, such as boiling point temperatures at normal atmospheric pressure (–29.8 °C for R-12 and –40.8 °C for R-22) and higher gas discharge pressures for R-22.
• Due to the higher discharge temperatures of R-22, differently rated condensers will have to be installed in the converted refrigeration plant. In addition, as a general rule, a refrigerant with a lower boiling point will require a smaller compressor than a refrigerant with a higher boiling point for the same capacity. Also, in general, refrigerants with lower boiling points will require higher operating pressures.
• As a result of the higher gas pressures of R-22, the converted refrigeration plant will require other pipework suitable to resist the higher working pressures.
• An accurate costing should be done before retrofitting existing refrigeration plants, considering that in some cases the conversion may be too expensive.

### Table 2.9

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Evaporating pressure at –15 °C (lbs sq. in)</th>
<th>Condensing pressure at 30 °C (lbs sq. in)</th>
<th>Boiling point at 1.013 bar (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-12 (CCl₂F₂)</td>
<td>11.8</td>
<td>93.2</td>
<td>–29.8</td>
</tr>
<tr>
<td>R-22 (CHClF₂)</td>
<td>28.3</td>
<td>159.8</td>
<td>–40.8</td>
</tr>
<tr>
<td>R-717 (ammonia)</td>
<td>19.6</td>
<td>154.5</td>
<td>–33</td>
</tr>
</tbody>
</table>
Therefore, a detailed analysis of costs and benefits should be prepared before taking any decision, including a realistic assessment of the residual life span and economic value of the refrigeration plant.

2.4 SAFETY OBSERVATIONS
Currently R-717 (ammonia) is the main alternative refrigerant for CFCs used commercially for large-size ice plants, with the advantage that this chemical has no detrimental effect on the ozone layer. Although R-717 is considered toxic and corrosive, the sharp odour and irritating properties also serve as a warning when leaks develop. It is rated as being lethal, or capable of producing serious injuries to humans at concentrations of 0.5 to 1 percent for exposures of a few to 30 minutes. This is particularly true on board boats, where clouds of R-717 are produced by large gas leaks in enclosed areas, which in some cases could trap and cause serious injuries or death to personnel before they could evacuate the refrigeration section. In addition, R-717 can be subject to explosion and fire when combined with certain amounts of air or oxygen. The smallest percentage of gas/vapour that will make an ignitable air-vapour mixture for R-717 is 15.5 percent by volume in air. If there is less gas in the mixture, it is too lean to burn. However, on board, in some areas such as refrigerated process or storage areas, which can be considered as unusually tight locations, the release of R-717 in large quantities can result in an explosion. Therefore, there are health hazards associated with the use of R-717 and skilled labour is required to operate and maintain R-717 refrigeration plants.

On board large fishing vessels, R-717 refrigeration machinery should be located in a separate refrigeration section (vapour-proof type compartment equipped with leakage/fire alarms systems). The refrigeration section should have two exits, one of them with direct access to the open deck. The section should be provided with emergency ventilation with a capacity of 30 times the air volume per hour and be equipped with remote-controlled emergency water sprinklers. The exits from the refrigeration section should be equipped with emergency water curtains to prevent further leakage of ammonia outside the room. The primary function of the sprinkler systems is to limit the spread of gas, to protect personnel in these areas and maintain escape routes. Additionally, water sprinklers may extinguish fires in the refrigeration room and control the amount of heat produced. Suitable pressurized air breathing apparatus should be available at both exits from the refrigeration section and be located within easy reach.
3. Planning considerations for ice plants

3.1 Planning the requirements
This section outlines some of the points to be considered when planning for the installation of an ice-making facility. Further information can be found in specialized publications available from many different sources, including FAO papers and publications. Some of these are listed in the bibliography.

Prior to actually purchasing any ice-making equipment, it is necessary to assess the actual requirements. This will help prevent the costly mistake of purchasing an inappropriately sized unit. Purchase and installation of an undersized unit may necessitate purchase of more equipment or replacement to upgrade the system in the future. Undersized units may also require more maintenance and repairs, because the system has to operate more or less continuously. An oversized system, while initially costing more to purchase, is probably the better option in the long run. However, if a system is too oversized, it could cost more to operate than is economically feasible.

There are a number of basic facts and considerations to be kept in mind when planning for the installation of ice-making facilities. Some of these are listed below:

• the probable demand for ice (consumers);
• the ability of consumers to pay a fair price for ice;
• the availability of a clean uncontaminated water supply;
• air and feed water temperatures;
• the reliability of the electrical power supply;
• a convenient site for the installation of the plant;
• qualified personnel to maintain and operate the equipment;
• spare parts and service availability in the country;
• willing investor(s) to finance the costs of purchase and maintenance of the plant.

Initially, a thorough study of likely demand will need to be made, not only from the fishery itself, but also for possible domestic use for chilling other foods and drinks, for instance. It has been the authors’ experience that when an ice plant is opened, where previously none existed, there is an immediate increase in demand for domestic use and from shoreside businesses. This can sometimes lead to shortages for fishermen, post-harvest marketing facilities and traders who are dependent on steady supplies of ice for their operations. Also, in many situations, an allowance will be necessary for passing trade from fishermen from outside the immediate area who, when they find ice available, will take the opportunity to buy.
The use of ice on small fishing vessels

Calculation of ice requirements for the local fleet can be relatively simple. The number of boats in the fleet will generally be known more or less accurately and the hold capacity and amount of fish landed by the larger vessels can be estimated. The ice requirements of smaller boats using insulated boxes can also be calculated in a similar manner.

The figure obtained for the fleet will then need adjustment to allow for melt losses on board the boats, and variations in output due to variations in input water temperature and local ambient temperatures. For example, a small ice plant rated for an output of 5 tonnes in a 24-hour period under temperate conditions will not produce as much if operated at tropical ambient temperatures and humidity. Table 3.1 gives information on variations in ice production at different water temperatures. This is only one factor to be considered in ice plant efficiency; other factors such as refrigerant temperatures and the difference between condensing and evaporating temperatures also affect output capacity. When these factors combine, the efficiency and output of the plant can drop by more than 50 percent. The details of ice plant design and operation are covered in more detail in other FAO publications dealing specifically with the subject of ice plants (see Bibliography).

Estimating local, non-fishery shoreside ice consumption is perhaps a little more difficult. This will depend on the size of the community and its infrastructure, such as markets, shops, restaurants and bars. However, with careful research in the community and surrounding areas it is possible to make some fairly accurate estimates for non-fishery consumption. It may be that sales from the ice plant will be restricted to fishery needs only, so that domestic demand does not need to be considered. However, commercially run ice plants would not normally ignore commercial opportunities, and sales to domestic users may be made to subsidize them.

In addition to calculating the maximum production and storage capacity of the ice-making plant, the seasonal variations in demand need to be considered. There may be species that are abundant for only one or two months per year, placing high

<table>
<thead>
<tr>
<th>Feed water temperature (°C)</th>
<th>Ice plant capacity (tonne/24 h)</th>
<th>Relative output capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>43.0</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>41.8</td>
<td>97</td>
</tr>
<tr>
<td>10</td>
<td>40.4</td>
<td>94</td>
</tr>
<tr>
<td>15</td>
<td>39.2</td>
<td>91</td>
</tr>
<tr>
<td>20</td>
<td>38.0</td>
<td>88</td>
</tr>
<tr>
<td>25</td>
<td>36.8</td>
<td>85</td>
</tr>
<tr>
<td>30</td>
<td>35.7</td>
<td>83</td>
</tr>
<tr>
<td>35</td>
<td>34.5</td>
<td>80</td>
</tr>
</tbody>
</table>

pressure on ice needs for a short period only. One way of addressing this problem is by the use of multiple or modular ice-making machines. For normal operations, one machine is used to supply ice for normal demands. During peak periods, a second or third machine would be brought on line. Installing multiple ice-making machines also provides a backup system in case of breakdown or servicing requirements of the operating units. Figure 3.1 shows a fairly typical modular flake ice plant with ice machines, ice rake, storage bin and delivery system.

Having established that there is a demand/need for an ice plant or ice provision at a particular location, it is then necessary to establish the availability of some basic technical requirements. These include:

- **An adequate supply of clean water.** If water of adequate quality is not immediately available, then the costs of filtration and treatment will need to be taken into account when assessing the economic feasibility of the operation. If ice is to be made from seawater rather than freshwater, the potential markets for the ice will be much more limited. Ice made from seawater will not be suitable for hotel, domestic or catering use, for instance.

- **A reliable source of power for the refrigeration equipment.** In many situations this will be electrical power. Direct-drive diesel units have been produced, but these tend to be more expensive than purchasing power directly from a supplier. Despite this, it may still be advisable where the local electricity supply is unreliable, to install a stand-by or emergency diesel electric generator set.

For installation in remote regions where electricity supply is either non-existent or unreliable and constant hours of strong sunlight are normal, solar-powered absorption refrigeration systems may be suitable. These systems are usually for production of block ice and a standard unit can produce 200 kg of blocks in 24 hours. Blocks weigh approximately 20 kg each. For larger production volumes, extra units are added as required.

The exact location of the ice-making facility can often be crucial to the success and viability of the operation. The needs of the end users of the ice should be carefully considered in final site selection. Installations are often built in locations that were considered best from an engineering standpoint, or because the site was cheap or land was deemed suitable by planners with little local knowledge of the site. Many such sites, whilst they may be only a short distance from the central fish harbour, can go virtually unused by fishermen because it is not convenient for them or within their normal patterns of operation to visit the location. End users must be consulted in site selection.

Competent trained personnel will be needed to maintain and repair the plant, along with a reliable source of spare parts for the equipment installed. Even the best equipment available will break down eventually. Where spares are not readily available, there is always a risk of considerable down time whilst waiting for simple spare parts. In many countries spare parts have to be imported, signifying a requirement for foreign exchange, which may or may not be easily found. These are all matters to be considered when investment in ice-making machinery is being considered.
Because of the relatively high investment costs of ice plants, it is not unusual for these to be borne by more than one person, or by an organization such as a fishermen’s cooperative. Either way, the economics of the investment must be sound so that potential investors are not exposed to unnecessary financial loss due to poor planning; otherwise it can be extremely difficult to finance plant costs without willing investors.

In some instances, ice plant purchase and installation costs are paid for by international technical assistance projects, and then donated to local organizations when the project ends. Considerable numbers of these plants fail within short periods due to lack of sufficient funds for maintenance and repairs, and a lack of adequate training of local personnel, who are ultimately left to try and maintain the equipment. The root cause was probably an incomplete analysis of the requirements in the beginning, and the assumption that if an ice plant were available, even if poorly located, it would attract customers. Initial cost–benefit and capacity analysis of the potential market is therefore extremely important, along with an assessment of the availability of parts and technical expertise on site for ongoing maintenance and repair.

3.2 STORAGE OF ICE ON SHORE

It is usually impossible for ice to be produced only when needed, and some sort of storage facility is required within the ice-manufacturing plant. Many commercial ice-plant installations are actually supplied with insulated storage capacity as part of the package, such as that shown in Figure 3.1.

![FIGURE 3.1 Commercial ice plant with storage facility](source: North Star Ice Equipment Corp., Seattle, WA, USA.)
Figure 3.2 shows the storage space requirements for different types of commercially available ice, which vary according to their bulk density. In general, the storage space requirements for block ice are less than for any other type of ice. However, flake ice, despite its greater storage space requirements, can be stored to a greater depth in a silo. Therefore, in practice, flake ice floor space requirements would be much the same as for other types of ice.

### 3.3 HANDLING OF ICE

Methods of handling vary considerably between different types of ice.

Block ice, for instance, requires special handling equipment in the plant, especially for larger-sized blocks. Some form of mechanical hoist is normally used to lift blocks from their containers prior to shipment. Blocks can also be moved from place to place by sliding them along shoots or over the ground. Individual blocks can be carried manually from place to place without any special containers or facilities. One advantage of block ice is its comparative longevity in storage compared with other forms of ice. This factor makes it a favourite of many fishermen. Blocks must be crushed before use and on some fishing boats a mechanical block-grinding device is carried. This machine can be powered by electrical, hydraulic or small gasoline motors and in some cases it is manually operated by addition of a flywheel. A typical unit is shown in Figure 3.3.

A simple block-ice grinder of this type can be adapted from an animal feed mincer. The teeth should be made of hardened steel, welded onto the cylinder and kept sharp. The unit can be fabricated from steel plate and angle iron by most
local metal shops with welding equipment. The unit should be dimensioned to accommodate the biggest ice blocks supplied by the ice plant.

Flake ice can be transported using screw conveyors, gravity feed or pneumatic systems. The ice can be discharged directly into the fish hold or into insulated containers, which are then shipped to the boat. Where manpower is available or only small quantities are required, the ice can be shovelled into containers. Flake ice tends to pack in containers or the fish hold and become difficult to work over a period of several days. This can be somewhat alleviated if the ice is worked occasionally with shovels.

In large installations, flake ice is taken from the storage bin by a screw conveyor incorporated in the storage area, as can be seen in Figure 3.1. Sometimes it is necessary to transfer the ice over slightly longer distances, for example across a wharf apron or quayside that is also used as a roadway. In this case, an auxiliary screw-type conveyor unit can be used as shown in Figure 3.4.

Flake ice can also be loaded and transferred using pneumatic powered systems. An example of one such system is shown in Figure 3.5 using two methods of discharge for loading the ice, one by gravity feed via a cyclone hopper, the other
by direct high-velocity discharge. Both methods require an operator to be on hand to manage loading. The system cannot be left running without ice being drawn off as the delivery pipes and cyclone unit may clog and become inoperable. Ice is fed to the air pressurized pipes by means of a “conveying valve”, and held in a hopper prior to being fed into the system. This valve is designed to feed ice to the pressurized side of the system without allowing air out through a one-way valve arrangement.

The problem of subcooled ice such as flake ice becoming difficult to work or solidified after a period of storage is addressed in various ways. Larger plants will have rake systems, which are belt mounted to keep the ice continuously and evenly distributed in the store. The rake also feeds ice to the delivery system. Other systems, such as round “hopper-style” storage bins, use rotating paddles or chains to keep the ice from freezing into a solid mass in the storage and delivery hopper.
FIGURE 3.5
Pneumatic ice delivery system

Source: North Star Ice Equipment Corp., Seattle, WA, USA.
4. The use of ice and chilled seawater on fishing vessels

4.1 INITIAL CAPTURE AND IMMEDIATE HANDLING ON BOARD

In order for the best-quality fish to be available to the consumer, care must be taken to reduce spoilage at all stages. Spoilage begins as soon as the fish dies, so it may begin before the fishermen lift the fishing gear out of the water. For instance, the common practice in many countries of leaving gill nets to “soak” for long periods causes a high percentage of loss, over 25 percent according to some studies by the Bay of Bengal Programme (BOBP) (FAO, 1991). Fishing with hand lines, beach seines and other active gear tends to produce good-quality fish, as there is no “soaking” period of the gear. One way of combating initial spoilage in gill nets is to haul nets more frequently. However, these suggestions can be resisted by fishermen because they require more effort, may cost more and may take them away from other activities.

Hence, the use of ice in itself is no guarantee of a better product unless proper handling procedures are fully implemented before the fish are actually stowed in the hold on ice. Even when fish nets or other gear are hauled more frequently, rapid spoilage can take place, especially if the catch is left lying around on deck in the sun and heat for any length of time, thus negating any gain in quality from more frequent hauling periods.

The spoilage processes are continuous and cannot be reversed; no amount of icing will convert poor-quality fish back into a good-quality product.

In summary, the time between the capture or death of the fish to when they are properly iced must be as short as possible, with minimum exposure to high temperatures. In tropical conditions, this would also require that fish be kept in the shade and out of direct sunlight. Where it is not possible to ice fish immediately, wet sacking is sometimes spread over the fish awaiting storage. Also, on some fishing vessels it is common to have a fixed or temporary canopy over the working deck (see Figure 4.1) which serves as a sun shelter for the crew and for the catch waiting to be processed prior to stowage in the fish hold.

Without insulation in the fish hold, the rate of ice meltage and loss is likely to be high, particularly in tropical and subtropical regions. Heat infiltration and consequent spoilage of the catch caused by excessive ice melting is most pronounced near the vessel sides and deckhead, as illustrated in Figure 4.2. One way of combating this without insulating the hold is to place plenty of extra ice against the vessel sides before stowing the fish, and extra layers of ice on top of the last layers of fish near the deckhead, which should help compensate for heat penetration. Though insulation installation may appear costly initially, it may repay itself over a period of time by saving ice and bringing better prices for better-quality fish.
FIGURE 4.1
Protection of catch against heat from the sun

a) Poor practice
Fish left on deck in direct sun, no cover

b) Better practice
Fish on deck covered with wet sacking or tarpaulin while awaiting stowage

c) Best option, if mode of fishing permits.
Canopy may be fixed or temporary, painted white for maximum reflection of sunlight
For optimal use of ice, the following points should be taken into account:

- All ice used must be clean and of small particle size for maximum contact. Block ice must be finely crushed to prevent large particles from damaging the fish.
- The proper ratios of fish to ice must be observed. In temperate climates, one part fish to one part ice is common. In tropical conditions, one part fish to three parts ice is not unusual.
- Areas of heat penetration into the hold, such as the engine room bulkhead and hull sides, must be given extra layers of ice to compensate for rapid ice loss in these areas, particularly if insulation is poor.
- The last layers of fish near the deckhead should have extra layers of ice to fully cover the fish and allow for any extra melting from heat penetration through the deck.
Fish and ice must be carefully and evenly stowed to allow even distribution of both. Shelves and boxes must not be overfilled or crushing damage to the fish will result.

Fish temperatures at the dockside when discharging should be between 0 °C and 2 °C, and there should also be considerable amounts of ice still evenly distributed among the fish.

Ice must be layered under, around and on top of the fish.

Figure 4.3 illustrates common bulk fish stowage methods in a typical small fishing vessel hold.

4.2 FISH STORAGE CONSIDERING TYPE OF ICE USED

The type of ice used in any particular fishery will generally depend on what is available locally from shoreside ice plants. Ice plants that are built specifically for fishery operations will usually supply subcooled flake or shell ice, or block ice. In some countries with newer plant installations “slush ice” may also be available.

For efficient and rapid cooling, ice must be used correctly. It is important to completely surround the fish with ice so that it is in full contact with the product. For this, ice needs to be in very small pieces or in slush form, or perhaps made into an ice-water slurry as in CSW applications. A few large lumps of ice scattered over the fish do not have the same cooling effect as small particle ice packed around...
the fish. Whether in boxes or stowed in bulk in fish-hold pens, fish also need to be carefully layered in ice. Improperly and properly iced boxed fish are shown in Figure 4.4.

![Typical plastic fish box/tote (stackable)](image)

A) Poor practice

Fish stacked in box with no ice around them; only cooling is from small amount of melt water

Scattered lumps of ice over fish

B) Good practice

Fish properly layered in box with ice on bottom of box and packed all around and over layers of fish

Ice covers all fish for full cooling effect
In order to optimize the chilling power of ice, some small-decked fishing vessels operating in warm climates have insulated tubs installed on deck. The tubs are filled with ice and CSW and are used for the rapid cooling of freshly caught fish prior to stowage on ice in the hold. An advantage of this system, even though it uses ice to chill the seawater, is that less ice is required in the hold to chill the fish down to 0 °C so, where hold size is a limiting factor, more fish can be stored. Because fish can be chilled almost immediately on capture, this system is capable of producing better quality fish.

4.2.1 Block ice/crushed ice
Block-ice plants are still commonly found in many countries because they are relatively simple to operate and maintain. Often, these plants were built to supply local stores, bars, market places and domestic households as well as the fishing industry.

Block ice is preferred by fishermen in many parts of the world because it will last longer and takes up less space in the fish hold. However, as already mentioned, for block ice to be used effectively for stowage of fish, and to make full use of its cooling power, it first has to be crushed or ground into small pieces. Common practice in many countries is for the ice to be transported and stored as blocks, and ground into pieces as required. In order for the broken ice to make good contact with the fish it must be broken into small enough pieces. In many instances the ice is broken into smaller pieces by simply using an ice pick or hammer. Generally this does not break the ice sufficiently for it to make good contact with the fish and thus the fish can still be exposed to high ambient temperatures. A much more effective means of crushing block ice is to use a mechanical grinder or crusher that can reduce block ice to small pieces of 1 cm × 1 cm or smaller, as described in section 3.3.

4.2.2 Flake ice
Flake ice has the advantage over block ice of being relatively easy to use since it does not need crushing before use. Because it is slightly subcooled during manufacture and can be packed well around fish, it may be more efficient in cooling fish than crushed block ice. However, because it has a higher surface area and holds a lot of air, it takes up more room in storage and melts more quickly than uncrushed block ice.

4.2.3 Slush ice
Slush ice is an extremely efficient cooling agent for fish. It is capable of reducing fish temperatures to 0 °C very rapidly. This type of ice is mostly used to stow fish in closed containers such as boxes or insulated tubs. Its use for stowage of fish on shelving depends on the texture (liquidity) of the ice. Too much water in the mix will tend to run off the shelves leaving the fish exposed. This liquidity factor can be controlled by the operator if the vessel has an ice machine installed. Otherwise the ice has to be loaded in dry form and clean seawater added as required. This ice is finding acceptance with vessels engaged in fisheries for high-value species such as shrimp, where shrimp are loaded directly into large insulated tubs with slush...
ice at capture and delivered to markets or the processing plant with no further packing and therefore little or no damage to the product. In many ways this ice has similar characteristics to cooling with CSW.

4.2.4 Chilled seawater
CSW is very efficient in cooling because the fish are completely surrounded by the cooling medium. However, it requires watertight boxes or tanks installed in the hold that can incur extra costs, which cannot always be justified. This type of installation is mostly used for:

- fisheries dedicated to capture of high-value species;
- the preservation of fish where there is a relatively short time between capture and delivery to the processing plants, such as that for sardine and anchovy;
- the preservation of bulk catches of small pelagics (for example) where it is impractical to ice fish individually. In this case, fish can often be loaded directly from the purse seine into the CSW hold thus providing rapid and efficient chilling.

The use of tanks also produces a reduction of available hold space, in some cases by as much as 20 percent.

Typical ratios for mixing ice, water and fish in insulated tanks or tubs will vary depending on the climate. FAO Fisheries Circular No. 773 (FAO, 1984) gives the following figures for temperate and tropical climates:

- Temperate climate: 1 kg water : 1 kg ice : 4 kg fish
- Tropical climate: 1 kg water : 2 kg ice : 6 kg fish

According to the Circular, this is the necessary volume of ice to chill fish to 0 °C. If the fish have already been cooled down, the volume of ice can be reduced accordingly. All other factors being equal, it must be remembered that ice will be required for chilling the water in the system as well as the fish, so in theory more ice will be needed with a CSW system than with a plain ice system.

In its simplest form, CSW is made by adding fresh seawater to ice held in tubs or in subdivided waterproof compartments or in tanks in the fish hold. This system works for short periods, but suffers from the problem of temperature stratification. This is caused by the fact that warm water will rise in the tank and ice and fish will tend to float in the water. Unless the CSW and the fish are agitated, the temperature stratification can cause uneven cooling of fish. Conversely, damage can be caused to the fish if agitation is too violent, so methods have been devised that combine the need to circulate the water in the tank and the need to treat the fish with care. Two common methods used are:

- Compressed air introduced into the bottom of the CSW tank via perforated pipes. The air is usually supplied from an air pump located adjacent to the CSW tanks. The resulting streams of bubbles rising to the surface force colder water from the tank bottom to rise and mix with the upper layers. Due to the large amount of bubbles produced this is commonly known as the “champagne system”. This is a relatively simple and economical means of reducing temperature stratification and can be used successfully on small fishing vessels with limited space.
The use of ice on small fishing vessels

- CSW circulated by water pumps. For this system to be efficient, a filtration system is needed to ensure that there is no clogging of return pipes with fish, fish scales and other debris. For more information and details on this system refer to Chapter 2 of this document.

4.3 WORKABILITY OF ICE OVER TIME

During storage there is a tendency for pieces of ice to freeze together, making it difficult to handle and mix with fish efficiently. Research into this problem has been conducted by the Canadian Federal Department of Fisheries using the following parameters to measure the amount of coagulation:

- pressure necessary to break the ice surface;
- depth of gauge penetration;
- pressure necessary to move a shovel pushed into the ice;
- size of clumped fragments.

The research came to the following conclusions:

- Shell ice: remained completely workable through seven days of tests.
- Flake ice: workable for up to 48 hours, but only workable with difficulty after 96 hours.
- Crushed block ice: virtually unworkable after 24 hours.

In most cases when block ice is used on fishing vessels, it would be carried on board whole and only crushed for use as needed, thus the problem of pieces clumping together would not become apparent.

Table 4.1 gives some general visual physical workability observations regarding the ice types being tested.

<table>
<thead>
<tr>
<th>TABLE 4.1</th>
<th>Type of ice and visual observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>Shell</td>
</tr>
<tr>
<td>0</td>
<td>Ice shells vary in size (10–100 mm) and approx. 6 mm thick</td>
</tr>
<tr>
<td>24</td>
<td>Shrinkage 5 mm from sides Individual pieces retain shape</td>
</tr>
<tr>
<td>48</td>
<td>Shrinkage 10 mm from sides Individual pieces smaller with pitted surface appearance</td>
</tr>
<tr>
<td>96</td>
<td>Shrinkage 10 mm + Pieces noticeably smaller Ice tends to stick together but still breaks up and shovels easily</td>
</tr>
<tr>
<td>168</td>
<td>Shrinkage 20–40 mm Noticeably dirty No real clumping, breaks up easily</td>
</tr>
</tbody>
</table>

4.4 QUANTITIES OF ICE REQUIRED ON BOARD

The amount of storage space required for ice will depend on the size of the vessel, the length of the fishing trip, the quantity of fish likely to be caught and whether the vessel has on-board ice-making facilities.

4.4.1 Chilling the fish

Table 4.2 shows the weight of ice necessary to cool 10 kg of fish to 0 °C from various ambient temperatures. For larger volumes of fish, the amount of ice should be multiplied by the actual weight of fish to be stowed in the hold. For example, at an ambient temperature of 30 °C, a load of 1 000 kg of fish would require 340 kg of ice, or slightly over a ratio of 1:3 ice to fish just to cool the fish to 0 °C. This does not allow for losses due to heat infiltration or extra ice necessary to maintain the fish at 0 °C for the rest of the trip.

<table>
<thead>
<tr>
<th>Temperature of fish (°C)</th>
<th>Weight of ice needed (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3.4</td>
</tr>
<tr>
<td>25</td>
<td>2.8</td>
</tr>
<tr>
<td>20</td>
<td>2.3</td>
</tr>
<tr>
<td>15</td>
<td>1.7</td>
</tr>
<tr>
<td>10</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
</tr>
</tbody>
</table>


In practice, therefore, much greater quantities are required to ensure that the fish remains chilled once its temperature has been reduced to 0 °C, and that it can be stored at chill temperature for some time.

It is a generally accepted “rule of thumb minimum” to use an ice to fish ratio of 1:1 in the tropics. In many instances ratios of up to 3:1 ice to fish are used. The main influence on the ratio is the length of the fishing trip.

A more detailed presentation can be found in Chapter 7.

4.4.2 Trip duration and estimated volume and composition of catch

It is of little benefit if the amount of ice loaded prior to a fishing trip only lasts part way through the planned voyage. Therefore, careful consideration must be given to how much ice is actually necessary for the average trip. Several factors should be considered when trying to estimate an adequate quantity of ice per trip, such as:

- planned length of the trip;
- historic average catch per trip;
- type of fish being caught, i.e. large, medium, small or mixed;
- available carrying space, in hold and/or containers;
The use of ice on small fishing vessels

- anticipated ice losses to heat gain in hold or containers;
- local ambient temperatures.

The market for the fish being caught may also have a bearing on the quantities of ice to be used. For example, if high-value pelagics such as swordfish, yellowfin or bluefin tuna and mahi mahi for export markets are being landed, the requirements for icing may be more stringent than for fish destined for local consumption.

Ideally, there should still be some ice left in the hold after all fish have been discharged at the end of each trip. This will indicate that the weight of ice was correctly estimated. Old ice must never be left in the hold for reuse. It must be discarded and the hold washed down with clean water and sanitized with a chlorine-based or other commercial cleaning agent solution, and surfaces should be scrubbed with brushes to remove any hardened blood or fish slime. Only after the hold has been thoroughly cleaned should ice be loaded for the next trip.

The amount of ice that can be taken on board may be restricted by the space availability for initial stowage before commencement of fishing. A balance has to be struck between ice carried, anticipated catch and catch composition. The latter is important, as stowage rates per cubic metre of hold space vary, not only with stowage method used, i.e. shelving or boxing, but also with the size of fish captured. Tables 4.3 and 4.4 show this relationship. In practice, the ice carried could be expected to exceed the minimum estimated quantities by 30 percent or more, to compensate for heat losses. Uninsulated holds will require considerably more ice.

Example: A vessel with an insulated usable fish hold volume of 6 m$^3$ is departing on a fishing trip of three to four days, and expects to be catching average- to large-sized fish with a total weight of about 1 500 kg. The fish are to be stowed in bulk. The ice needed for the trip can be calculated as follows:

- $1500/10 \times 3.4 = 510$ kg of ice will be needed for chilling the fish to 0°C (see Table 4.2).
- To mix the fish with ice at a ratio of 1:2 (ice to fish) another $750$ kg are needed.
- Another 30 percent has to be added to compensate for heat losses: $30/100 \times (510 + 750) = 378$ kg.

The total amount of ice needed is thus calculated to be 1 638 kg. To be on the safe side, the skipper would load 2 000 kg of ice, which corresponds to an ice to fish ratio of 1.3:1, which is slightly above the “rule of thumb minimum”. This quantity of ice would occupy around 4 m$^3$ in the fish hold (see Table 4.3) when the vessel departs for fishing. When departing from the fishing ground, the fish hold would be filled with 1 500 kg of fish mixed with approximately 750 kg of ice. This would also occupy some 4 m$^3$ of the fish hold (see Tables 4.3 and 4.4).

The volume required for stowage of a tonne of fish stored under three methods of stowage with a 2:1 fish to ice ratio is given in Table 4.4.

The weight of volumes of ice varies according to the type of ice being used (see Table 4.3 and Figure 3.2). Cooling of the catch depends on the weight of ice used, not the volume, so for equivalent cooling capacity, equal weights of ice must be compared.
4.4.3 Storage considerations

There are various means of storage used on board fishing vessels, depending on the size and type of the vessel.

On larger boats using bulk stowage for ice and fish, the hold needs to be properly insulated and is usually subdivided into pens or pounds. The insulation retards excessive ice loss from heat penetration and helps maintain proper icing ratios. Subdivided pens are also necessary to keep unused ice separate from the fish and ice mixture and to allow sorting of catch by size and species as necessary. A typical subdivided fish hold is shown in Figure 4.5.

For decked boats without insulated fish holds, the use of insulated boxes of appropriate size to permit fitting through hatches and to allow manhandling in the hold is a viable alternative to retrofitting the hold with insulation. Tubs do, however, cut down on available stowage space for ice and catch. Again, with high-value species this is less of a problem.

For small open boats, ice is mostly carried in boxes or insulated containers that are used initially to carry the ice, then subsequently to store the catch in ice. Boxes and containers can also be used as shoreside shipping containers if required, thus reducing the need to rebox the fish at landing.

Some artisanal vessels, such as the large canoes of Senegal, require specially shaped boxes in order not to lose too much capacity. This tends to make them unsuitable for other purposes such as dockside storage or shipping containers. On the other hand, section shapes of the typical larger-size dugout canoes found
The use of ice on small fishing vessels

FIGURE 4.5
Typical subdivided fish hold on small fishing vessel

Longitudinal penboards can effectively reduce the danger of the "free surface effect" if loaded with small pelagics such as sardines.

New ice, penned

Engine room

Drainage sump to collect melt water and fish wastes, which can then be pumped overboard

Shelving

This hold can be used for:
- Bulk fish in pens (midship forward)
- Bulk shelved fish (aft)
- Boxes can also be used if and when required

in Central and South America and parts of Africa lend themselves quite well to standard box configurations, which are more suitable for the other uses, as mentioned above (see Figure 4.6).

Small fibreglass fishing vessels have become relatively common in many countries around the world. Mostly they are of the open style with only thwarts and floor area installed, having been produced as multipurpose vessels rather than specifically for fishing. In order to make these vessels more appropriate for fishing operations, some have been adapted to incorporate a small fish hold in the hull. A typical adaptation of this type is shown in Figure 4.7. Many conversions of this type have been made to boats of 25 to 29 ft in length in Central America and the
The use of ice and chilled seawater on fishing vessels

Caribbean, so they are already well tested. This type of installation was developed at the request of the fishermen.

Larger-decked vessels with fish holds generally carry their ice in the hold, where it is kept in hold pens below deck until required for icing the catch. However, some decked vessels in the size range from 35 ft to 55 ft Loa (10.6 m to 16.7 m) load insulated containers full of ice either directly into the fish hold or secure them on deck. These same containers are then used to store part of the catch on ice. By adding clean seawater to the ice in insulated tubs, fish can also be stowed in CSW, which helps prevent the problem of crushing lower layers of fish in the tubs, especially those of large capacity. Stability problems could arise if large heavy tubs are carried on the decks of small vessels, so care must be taken in this regard.

When discharging the catch into containers, the fish can be removed from the hold and transferred directly to the processing plant or market, eliminating handling steps and resulting in a better quality product. With larger boxes or tubs, mechanical equipment may be required for lifting the full boxes from the hold of the vessel and then moving them around on the quayside.

In cases where the ice plant facility is located at some distance from the fishing harbour, the insulated tubs may also be used to transport ice from the plant to the fishing vessels, thus preventing excessive melting losses.

There are several types of insulated boxes or tubs available commercially around the world. These boxes are generally manufactured to be easily stackable with provision for ease of handling, either manually or by slings and/or fork-lift machines. Large insulated tubs are manufactured by “roto-moulding” techniques or by “injection-moulding” processes. Roto-moulding is the most common at
The use of ice on small fishing vessels

Double hatches

Insulation: 3" (7.6 mm) styrofoam lined with 1/4" (6 mm) plywood and sheathed with fibreglass

Fish and ice Keep plenty of ice against side of hold when stowing fish

Drains to sump

FIGURE 4.7
26 ft fishing vessel with hold space added

Permanent fish hold in 26 ft fibreglass F/V
Note longitudinal removable pen boards

Note: Floors are covered by heavy expanded sheet metal, either aluminium or galvanized steel. The mesh is fine enough to prevent flake ice passing through easily, but allows melt water and fish juices to drain into bilges for pumping overboard.
FIGURE 4.8
Typical fishtub and plastic fish boxes

A) Typical insulated tub, capacity 666 litres, injection-moulded
Notes: The provisions for lifting hooks and pallet jacks or fork-lift trucks are moulded integrally.
Tubs are also provided with tight-fitting insulated lids and can be stacked.

Source: Saeplast, Iceland

Boxes of this type range in size from approximately 300 to 1,000 litre capacity

B) Plastic tote boxes for iced fish
Fish packed in ice in boxes usually maintain quality for longer periods than if kept on shelving or in bulk.
Plastic tote boxes are designed to be fully stackable and drain outside the lower boxes, if stacked directly on top of each other. In staggered stacking, this feature does not work properly.
The use of ice on small fishing vessels

present, as it is generally more economical to produce the shells; however, the manufacturing process does not lend itself easily to mass production methods. Insulation is generally of polyurethane foam, which is injected into the completed plastic shells.

Injection-moulding requires much more expensive tooling that can only be used for one size of tub. Other sizes or shapes require separate moulds. One advantage claimed for injection-moulding is that it is more readily adapted to mass production methods and tub shell thickness can be more accurately controlled.

The sizes of these tubs range from small units of about 60 litre capacity to large 1 000 litre units, with various intermediate sizes also available for different applications. Smaller units can be handled manually when partially loaded; larger tubs require mechanical means for handling such as simple pallet jacks, which can also be used on board, fork lift trucks and/or the vessel’s own cargo boom and winch. Some typical types of insulated plastic tubs are shown in Figure 4.8.

Rather than using insulated containers or tubs, it is also common practice to use non-insulated (often plastic) fish boxes stacked inside the insulated hold for storage of fish and ice. These enable fish to be carefully iced and the catch to be separated into different sizes and types of fish before icing. Once boxed, the fish can then be removed from the hold in the boxes and transported to processing plants or markets without further handling. Suitable boxes are made in a variety of shapes and sizes for different applications. Boxing in this way tends to be less economical on space than other means of stowage but this is often compensated for by the convenience of this type of storage.
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 \(\lambda\) (kcal m\(^{-2}\) h\(^{-1}\) °C\(^{-1}\))**
This is designated as \(\lambda\) (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. \(\lambda\) 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 \(\lambda\) (1/\(\lambda\)) 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 \(x/\lambda\), where \(x\) stands for the thickness of the material in metres.
Thermal insulation materials, technical characteristics and selection criteria

**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](image-url)
Thermal insulation materials, technical characteristics and selection criteria

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

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**BOX 5.1
Desirable characteristics for insulation materials for fish holds**

<table>
<thead>
<tr>
<th><strong>Thermal conductivity</strong></th>
<th><strong>Resistance/installation features</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Moisture-vapour permeability</strong></th>
<th><strong>Safety features</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Best insulation materials should have very low moisture-vapour permeability. Thus, water absorption becomes negligible. Condensation and corrosion are minimized.</td>
<td>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.</td>
</tr>
</tbody>
</table>

---

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.
The use of ice on small fishing vessels

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W m⁻¹°C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam</td>
<td>30</td>
<td>0.026/0.0224</td>
</tr>
<tr>
<td>Rigid expanded board</td>
<td>30</td>
<td>0.02/0.025/0.0172–0.0215 average: 0.0225/0.0193</td>
</tr>
<tr>
<td>Rigid expanded board</td>
<td>40</td>
<td>0.023/0.02</td>
</tr>
<tr>
<td>Rigid expanded board</td>
<td>80</td>
<td>0.04/0.34</td>
</tr>
<tr>
<td>Foamed in place</td>
<td>24-40</td>
<td>0.023–0.026/0.0198–0.0224 average: 0.0245/0.0211</td>
</tr>
</tbody>
</table>

**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/m³, 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/m³ in comparison with other grades of foam used as a structural core in boats with a density of 100 kg/m³ up to 300 kg/m³. Its resistance to compression varies according to the density of the foam, with 2–3 kg/cm² for foams with densities of 35–40 kg/m³ 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
Thermal insulation materials, technical characteristics and selection criteria

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.

**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 ºC and 65 percent relative humidity

### TABLE 5.2

**Physical properties of some grades of polyurethane foams**

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Test units</th>
<th>Test temp. (°F/°C)</th>
<th>American Society for Testing and Materials (ASTM) method</th>
<th>Grades of polyurethane foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal density</td>
<td>lb/ft³ (kg/m³)</td>
<td>74/23.3</td>
<td>D1622</td>
<td>9002-2B 9002-3B 9002-4B 9005-2 9006-4</td>
</tr>
<tr>
<td>Type ¹</td>
<td></td>
<td></td>
<td>2 (32)</td>
<td>I I I III III</td>
</tr>
<tr>
<td>Class ¹</td>
<td></td>
<td></td>
<td>2 - - 2 3</td>
<td></td>
</tr>
<tr>
<td>Compressive strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Parallel</td>
<td>PSI²</td>
<td>74/23.3</td>
<td>D1621</td>
<td>38 70 100 25 75</td>
</tr>
<tr>
<td>b) Perpendicular</td>
<td>PSI</td>
<td>74/23.3</td>
<td>D1621</td>
<td>18 36 68 20 48</td>
</tr>
<tr>
<td>Compressive modulus:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Parallel</td>
<td>PSI</td>
<td>74/23.3</td>
<td>D1621</td>
<td>1 050 1750 2 500 600 2 000</td>
</tr>
<tr>
<td>b) Perpendicular</td>
<td>PSI</td>
<td>74/23.3</td>
<td>D1621</td>
<td>450 950 1 500 500 900</td>
</tr>
<tr>
<td>Tensile strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Parallel</td>
<td>PSI</td>
<td>74/23.3</td>
<td>D1623</td>
<td>56 84 112 40 90</td>
</tr>
<tr>
<td>b) Perpendicular</td>
<td>PSI</td>
<td>74/23.3</td>
<td>D1623</td>
<td>40 65 90 35 77</td>
</tr>
<tr>
<td>Shear strength:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perpendicular</td>
<td>PSI</td>
<td>74/23.3</td>
<td>C273</td>
<td>33 50 65 26 50</td>
</tr>
<tr>
<td>Flame resistance</td>
<td>NA</td>
<td>74/23.3</td>
<td>D1692</td>
<td>none none none non-burning non-burning</td>
</tr>
<tr>
<td>Thermal conductivity, also called K factor</td>
<td>Btu/ft²·hr·°F/in</td>
<td>74/23.3</td>
<td>C177</td>
<td>0.11 to 0.16</td>
</tr>
<tr>
<td>Water absorption (2 days under 2&quot; head):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) By volume</td>
<td>%</td>
<td>74/23.3</td>
<td>D2127</td>
<td>0.04 0.025 0.02 0.04 0.04</td>
</tr>
<tr>
<td>b) By weight</td>
<td>lb/ft³²</td>
<td>74/23.3</td>
<td>D2127</td>
<td>1.6 1 0.8 1.7 1.7</td>
</tr>
<tr>
<td>Dimensional stability:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Net change in volume:</td>
<td>%</td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>1.5</td>
</tr>
<tr>
<td>1 day</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>1.5</td>
</tr>
<tr>
<td>7 days</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>2 1 1 1.2 1.3</td>
</tr>
<tr>
<td>28 days</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>2.5 1.5 1.5 1.7 2.7</td>
</tr>
<tr>
<td>b) Average linear change</td>
<td>%</td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>2 2 2.7 3.6</td>
</tr>
<tr>
<td>1 day</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>0.7 0.5 0.5 0.6 0.6</td>
</tr>
<tr>
<td>7 days</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>1 0.7 0.7 0.8 1.4</td>
</tr>
<tr>
<td>28 days</td>
<td></td>
<td>160/71.1</td>
<td>D2126 Prac. E</td>
<td>1.2 1 1 1.4 1.8</td>
</tr>
</tbody>
</table>

¹ As specified by US Federal Specification HHI-I-00530.
² 1 PSI (pound/square inch) = 0.070307 kg/cm².
Source: American Society for Testing and Materials (ASTM) Book of Standards and CPR Division. The Upjohn Co., USA.
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/cm². There are several grades of foams available with densities from 10 to 33 kg/m³, 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 Na₂O, CaO, MgO and K₂O, 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/m³ 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

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded foam Type I</td>
<td>10</td>
<td>0.057/0.049</td>
</tr>
<tr>
<td>Expanded foam Type II</td>
<td>12</td>
<td>0.044/0.038</td>
</tr>
<tr>
<td>Expanded foam Type III</td>
<td>15</td>
<td>0.037/0.032</td>
</tr>
<tr>
<td>Expanded foam Type IV</td>
<td>20</td>
<td>0.034/0.029</td>
</tr>
<tr>
<td>Expanded foam Type V</td>
<td>25</td>
<td>0.033/0.028</td>
</tr>
<tr>
<td>Rigid extruded foam</td>
<td>33</td>
<td>0.033/0.028</td>
</tr>
</tbody>
</table>
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
Thermal insulation materials, technical characteristics and selection criteria

It is available as expanded slabs or boards as well as in granular form, its density varies from 110 to 130 kg/m³ and it has an average mechanical resistance of 2.2 kg/m². 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>
<thead>
<tr>
<th>Type</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>10–18</td>
<td>0.044/0.038</td>
</tr>
<tr>
<td>Type II</td>
<td>19–30</td>
<td>0.037/0.032</td>
</tr>
<tr>
<td>Type III</td>
<td>31–45</td>
<td>0.034/0.029</td>
</tr>
<tr>
<td>Type IV</td>
<td>46–65</td>
<td>0.033/0.028</td>
</tr>
<tr>
<td>Type V</td>
<td>66–90</td>
<td>0.033/0.028</td>
</tr>
<tr>
<td>Type VI</td>
<td>91</td>
<td>0.036/0.031</td>
</tr>
<tr>
<td>Glass fibre, resin bonded</td>
<td>64–144</td>
<td>0.036/0.031</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulated loose, dry</td>
<td>115</td>
<td>0.052/0.0447</td>
</tr>
<tr>
<td>Granulated</td>
<td>86</td>
<td>0.048/0.041</td>
</tr>
<tr>
<td>Expanded cork slab</td>
<td>130</td>
<td>0.040/0.344</td>
</tr>
<tr>
<td>Expanded cork board</td>
<td>150</td>
<td>0.043/0.037</td>
</tr>
<tr>
<td>Expanded bonded with resins/bitumen</td>
<td>100–150</td>
<td>0.043/0.037</td>
</tr>
<tr>
<td>Expanded bonded with resins/bitumen</td>
<td>150–250</td>
<td>0.048/0.041</td>
</tr>
</tbody>
</table>

Source: Prepared by authors based on data from Melgarejo, 1995.
The use of ice on small fishing vessels

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.

### TABLE 5.6
Common insulating materials, “R” values, advantages and disadvantages

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

18.8 ft² 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.
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/m² density mat) and resin, or two layers of 450 g/m² mat and a finishing layer of 300 g/m² 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.
6. Containers and fish holds

6.1 DESIGN OF INSULATED BOXES AND CONTAINERS FOR CANOES AND SMALL FISHING VESSELS

Many types of containers, constructed from a variety of materials, are used for the transport of ice and fish – from simple baskets of woven reeds, bamboo, cane or grasses, to containers made from wood, metals and plastics. In order to reduce the melting of ice, insulation materials such as those discussed in Chapter 5 may be used in the construction of containers. Use of any particular type depends very much on the economic situation of the locale and fishery being pursued.

Although estimates vary, in some situations a high proportion of fresh fish caught in tropical and subtropical areas may be wasted, with the major loss in quality and value occurring between harvesting operations and first sale in landing areas. It is envisaged that with the increased availability and wider use of properly designed containers for use on canoes and small fishing vessels, there will be scope for reducing wastage of fresh fish in small-scale fisheries.

However, there are a number of factors that limit the achievement of this goal. These include the relatively high cost of insulated containers and the fact that ready-made containers are generally manufactured in industrialized countries and need to be imported. The extra costs involved in the purchase of metal or plastic boxes are sometimes sufficient to deter fishermen from using them. They opt instead for the traditional locally made containers or baskets with their lower investment cost. As a fishery becomes more developed and product quality becomes an issue, the trend to purchase plastic or metal boxes increases.

In some tropical areas, the cost and availability of ice are limiting factors, rather than the cost of insulated containers. Besides the existing technological limitations in some tropical areas, there is scope for developments in the design and construction of locally made insulated containers, which should eventually make them more easily available and inexpensive enough for small-scale fishermen.

6.2 INSULATED FISH CONTAINERS

The main functions of an insulated fish container on board canoes and small fishing vessels are:

• to make handling easier (by reducing the handling frequency of individual fish) and protect the fish from the risk of physical damage;
• to maintain fish quality, by ensuring adequate chilling and low ice-meltage rates as a result of reduced heat infiltration through container walls;
• to improve fish-handling practices and so lead to better quality fish being landed, making longer fishing trips and better fish prices possible for fishermen.

The effectiveness of insulated containers in reducing ice melting is an important criterion in the evaluation and selection of such containers. It is more likely that
The advantages that insulated containers offer will be fully appreciated by small-scale fishermen in tropical climates where ice meltage rates are much higher than in cold or temperate climates.

6.2.1 Design factors and construction aspects
The main general design features for insulated containers (both portable and fixed types) are as follows:

- They should be suitable for transportation on fishing vessels and road vehicles (which can be of different types and sizes). Therefore, portable containers should have special features, making them well suited for handling catches on board, as well as for storage and transport of fish on shore.
- They should be able to withstand relatively rough handling.
- They should have drains for ice melt water.
- They should be constructed of materials that allow easy and thorough cleaning.
- They should be of a suitable size for accommodating the range of fresh fish caught, so that they are not bent or distorted in any way.
- They should be of a suitable size for adequate manual handling or fork lifting, if these machines are available.
- Portable types should be suitable for secured stacking, so that the weight of the containers on top falls on the containers underneath and not on the fish inside the container.
- They should be constructed of lightweight materials.
- They should be strong.
- They should possess good insulating properties to avoid high heat infiltration, rapid rises in temperature of fish and quick ice meltage.
- The optimum design of an insulated container should consider an adequate storage depth to avoid crushing the fish at the bottom, i.e. it should avoid deep bulk storage. The containers should be of simple construction and the insulation should not occupy too much space.

Table 6.1 gives some information on the physical characteristics of materials that may be used for the construction of fish containers.

6.2.2 Commercially manufactured insulated containers
There is a wide range of insulated containers available, offering a variety of features according to different requirements of handling, size, insulation efficiency, modes of transportation, sturdiness, durability and construction materials. However, these insulated containers are generally an imported item in developing countries, which means that they are costly, especially when compared with non-insulated boxes and locally made traditional fish containers.

Insulated container capacity or physical size has undoubtedly also been a limiting factor in introducing these units to some markets in developing countries’ fisheries. Many such fisheries lack the infrastructure and equipment, such as cranes and fork-lift trucks, for the physical handling of large tubs when full of ice and fish. Most fish-landing sites at artisanal level still rely on manual handling, which effectively places a limit on the size of items that can be used.
Common materials used for the manufacture of insulated containers are FRP and high-density polyethylene (HDPE) often with plastic foams for insulation.

One of the most common types of insulated container used in fisheries consists of double-walled HDPE with expanded polystyrene or polyurethane foam as insulation. These are usually constructed in a single piece using a rotational moulding process. The HDPE walls vary in thickness from 3 mm to 6 mm and the total thickness varies according to the size and capacity of the insulated container. These types of containers are able to withstand relatively rough handling, and are considered to be superior to those manufactured with other materials, such as FRP, which tends to be more brittle and prone to impact damage and fractures.

However, HDPE is an expensive material, derived from a petrochemical, whose market prices are linked to oil prices. With correct handling, HDPE insulated containers can have an expected lifespan of about five to seven years. Generally, HDPE containers are not repairable and usually have to be replaced if broken. However, medium-density polyethylene containers can be repaired by welding.

HDPE is rated as capable of withstanding temperatures up to 100 °C and down to -40 °C. However, it becomes brittle at low temperatures, and for this reason HDPE containers are not well suited to use at low temperatures, in frozen fish stores, for instance. Commercially available containers vary from 50 litres capacity up to 1 100 litres. Recommendations for handling HDPE containers are given in Box 6.1. The thermal efficiency of HDPE containers varies according to
The use of ice on small fishing vessels

6.2.3 Locally made insulated containers

A wide range of materials are used in the manufacture of insulated containers in developing countries, including wood, plywood, bamboo, metal sheets (galvanized iron and aluminium alloys), nipa, palm leaves, wood shavings and sawdust, dried straw and grass, coconut husks and rice husks. More recently, plastics such as polyurethane foam, expanded polystyrene, polyethylene sheets, PVC and FRPs have been used. Small-scale fishermen in developing countries have gradually become aware of the advantages of insulated containers and efforts have been made to design suitable containers making use of locally available materials. In most tropical areas, the main innovative approach has been to incorporate insulation

<table>
<thead>
<tr>
<th>Net capacity (litres)</th>
<th>Polyurethane insulation thickness (mm)</th>
<th>Thermal conductance (W m⁻² °C⁻¹; kcal m⁻² °C⁻¹)</th>
<th>Approximate weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>30–50</td>
<td>0.546 (0.4695)</td>
<td>12</td>
</tr>
<tr>
<td>200</td>
<td>30–50</td>
<td>0.388 (0.3336)</td>
<td>25</td>
</tr>
<tr>
<td>450</td>
<td>30–50</td>
<td>0.388 (0.3336)</td>
<td>63</td>
</tr>
<tr>
<td>680</td>
<td>57–63.5</td>
<td>0.310 (0.2668)</td>
<td>66</td>
</tr>
</tbody>
</table>

Source: HDPE insulated container manufacturers from Canada and Denmark.

The intended use and design. Table 6.2 shows examples of thermal conductance of some HDPE containers used for chilled fish handling.

BOX 6.1

**Recommendations for handling HDPE containers**

- The containers should not be punctured with knives, gaffs or needles, as this can damage the HDPE layer that protects the polyurethane foam insulation, resulting in poor thermal performance and significantly reducing the useful life of containers.
- HDPE containers should not be exposed to temperatures above 50 °C or to temperatures below −40 °C; in addition they should not be exposed to direct fire.
- Despite the fact that HDPE containers are manufactured with impact-resistant materials, they should not be exposed to heavy mechanical stress (such as excessive load weights and very rough and abusive handling).
- HDPE containers, after use, should be adequately cleaned with water, brushes, sponges and detergents or foam wash, either manually or with high-pressure washing equipment. Care should be taken to store them well dried because, when they are closed, there is very little water evaporation, so if some water remains inside it could facilitate the growth of moulds and bacteria. It is important to avoid the use of organic solvents for cleaning HDPE containers.
Containers and fish holds

materials into the existing designs of locally made fish containers, therefore offering improved versions, but maintaining the traditional container’s features of being a practical and low-cost alternative well suited to local conditions.

Another approach has been to design new types of insulated containers that can be fitted in the existing canoes, pirogues or small fishing vessels, according to the type of fishing operation, and the quantities and characteristics of the most abundant species caught. However, the most critical features in the manufacture of locally made insulated containers are the proper selection and availability of insulation materials, adequately trained personnel for construction and repairs and provision of on-the-job training to fishermen in adequate handling practices for containers to minimize damage and subsequent poor performance. In several tropical areas, there have been successful attempts to introduce locally made insulated containers on board small-scale fishing vessels. Table 6.3 describes several examples of these locally made insulated containers (see also Figures 6.1 and 6.2, pp. 74 and 75).

The successful introduction of improved containers or new types of insulated containers in small-scale fisheries depends on several factors. Therefore, field trials are required to establish reliable performance and economic data under prevailing working conditions. In practice, the viability of a locally made container will depend on the priorities of the fishermen and the market requirements (export quality or for domestic markets), for example. If the containers are too heavy, or of low capacity due to the insulation occupying too much space, or not strong enough under existing working conditions on board, fishermen may not be able to use them regularly. Ease of cleaning and hygiene are also critical factors if the product is to be exported internationally.

In some tropical areas, locally made moulded expanded polystyrene containers are widely used for handling chilled fish in small-scale fishing vessels. For example, in the Philippines, moulded expanded polystyrene containers of 30–40 kg capacity (approximate inner dimensions: \( L = 51 \text{ cm} \times W = 35 \text{ cm} \times H = 35 \text{ cm} \)) are used on board outrigger canoes and small fishing vessels for chilling fish as well as for transport (sea and road) and marketing. The polystyrene is protected by external wooden frames or galvanized steel sides that help to support and protect the container, and withstand rough handling. Figure 6.3 (p. 76) shows one typical arrangement. The main advantages of these containers are that they:

- are easy to handle;
- have good insulating properties;
- are relatively cheap;
- are readily available.

Their main disadvantages are that they:

- are difficult or impossible to clean properly;
- have a weak physical structure;
- do not nest when empty;
- have a relatively short useful life.

These containers are widely used for road transport of high-value chilled fish and shrimp and it is estimated that their useful life is about 8–10 long-distance
<table>
<thead>
<tr>
<th>Geographic area</th>
<th>Characteristics of container</th>
<th>Type of fishing vessel</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia (India)</td>
<td>Capacity: 175–200 kg of ice/fish mixture</td>
<td>Traditional</td>
<td>FAO (1991)</td>
</tr>
<tr>
<td></td>
<td>Weight: 40 kg</td>
<td>5–12 m long wooden fishing vessel known as “navas”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design: FRP and polyurethane foam (70 mm thick). With 10 mm diameter drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Africa (Senegal)</td>
<td>Capacity: 0.9–1.3 tonnes of fish</td>
<td>Traditional</td>
<td>FAO (1985)</td>
</tr>
<tr>
<td></td>
<td>Weight: 200 kg (with two hatches) and 270 kg (with 3 hatches)</td>
<td>14–18 m long wooden pirogues with outboard engines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design: FRP and polyurethane foam (100 mm thickness). With PVC pipe drainage. Tailor-made to fit local pirogues</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical and financial viability studies were conducted, based on field trials with several vessels (Evaluation Report, Phase I, Project: “Amélioration de la conservation de poisson à bord des pirogues”, CAPAS, Senegal, 1983 and FAO project GCP/INT/398/NOR)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Later on, based on this design, several experiences on the introduction of insulated containers for small-scale fishing vessels were undertaken in the United Republic of Tanzania, Kenya, the Gambia, Guinea-Bissau and Guinea.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia (Indonesia)</td>
<td>Nominal volume: 5.15 m³. Approximate external dimensions: L = 4.96 m \times W = 1.33 m \times H = 0.78 m</td>
<td>Traditional</td>
<td>Putro (1986)</td>
</tr>
<tr>
<td></td>
<td>Design: CSW insulated container constructed of wood board, expanded polystyrene foam, FRP lining on the inner surface. Tailor-made to fit local purse seiner.</td>
<td>12.2 m long purse seiner (main species caught: Sardinella longiceps).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical viability studies were conducted by the Research Institute for Fish Technology in Jakarta, based on field trials with one prototype vessel. In 1986, three years after the introduction of the CSW container in the Bali Strait area, about 78 purse seiners were equipped with CSW containers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia (Indonesia)</td>
<td>Capacity: 48 kg ice/fish mixture</td>
<td>Non-motorized traditional</td>
<td>FAO (1992a)</td>
</tr>
<tr>
<td></td>
<td>Weight: 24 kg</td>
<td>fishing dugout canoes (4–6 m Loa). In practice these canoes were catching on average 10–20 kg/day of high-value red snappers with deep water handlines. Only occasionally could they catch large quantities of, say, 40 kg/day. These canoes were generally working within a motherboat system, transferring the catch at the end of the day to the motherboat’s fish hold</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External dimensions: L = 1 025 mm \times W = 295 mm (top) and 260 mm (bottom) \times H = 400 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design: FRP laminated onto an insulated container consisting of expanded polystyrene foam (25.4 mm thickness) lined with 6.5 mm plywood with an aluminium angle bar framework. Access to the insulated container is through two lids of 505 mm \times 280 mm, located at both ends of the top surface. A rubber gasket 20 mm \times 10 mm is fitted around both insulated lids. Heavy duty ropes were fitted on both ends as handles to assist in lifting the container. A single 10 mm diameter PVC pipe and plug was fitted through the insulated container at one side of the end of the container. Tailor-made to fit local canoes. Two versions were constructed. The second version was without FRP lining; it was made of a wooden framework with plywood as the outer shell, with 25.4 mm expanded polystyrene foam as insulation and an aluminium sheet lining. Both versions had similar external dimensions. The second prototype weighed 17 kg. The cost of the wooden version was about 50 percent of the FRP container’s cost. These containers were designed specifically for chill storage of red snappers, which were the most important species in the deep water operations and export marketing of the project.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial field trials were carried out on two canoes; later, the project “Cenderawasih Bay Coastal Area Development” (UNDP/FAO INS/88/0911) continued with the field tests</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Containers and fish holds

<table>
<thead>
<tr>
<th>Geographic area*</th>
<th>Characteristics of container</th>
<th>Type of fishing vessel</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America (Ecuador)</td>
<td>Capacity: several types of containers were made with nominal volumes from 1.166 m$^3$ to 1.224 m$^3$</td>
<td>Traditional small-scale fishing vessels and canoes, but these containers (type (a), (b) and (c)) were specifically designed for FRP launches (7.2–7.5 m Loa) engaged in fishing for dolphinfish (Coryphaena sp.)</td>
<td>Wood and Grijalva (1988)</td>
</tr>
<tr>
<td></td>
<td>Weight: complete with tops, from 72 to 89 kg</td>
<td></td>
<td>Acero, (1997)</td>
</tr>
<tr>
<td></td>
<td>Design: Three types of insulated containers were made, namely: a) wooden sides (consisting of a wooden framework and plywood) and wood as lining with 25 mm thick expanded polystyrene insulation; b) same as container (a) but with galvanized iron sheet as lining; c) same as container (a) but with polyurethane foam and FRP lining. The FRP laminated container was considered the most promising in terms of lightness and durability</td>
<td></td>
<td>Acero, (1997)</td>
</tr>
<tr>
<td></td>
<td>Four FRP-laminated insulated containers were constructed and long-term durability tests were carried out by the project ODNRI/ODA (Overseas Development Natural Resources Institute/Overseas Development Agency) with the Instituto Nacional de Pesca. In recent years, another tailor-made FRP-laminated container (with 50 mm polyurethane foam as insulation) was field-tested and introduced in several small-scale fishing communities by the project “Technical Cooperation Programme for Fishing” UE-VECEP ALA 92/43, with promising results. Similar FRP-laminated containers were also field-tested by the UE-VECEP ALA 92/43 project in Colombia</td>
<td></td>
<td>Tilman (1999)</td>
</tr>
</tbody>
</table>

1 Acero, 1997. Personal communication regarding field-testing of insulated containers in small-scale fishing vessels in Colombia and references to a pilot activity in Ecuador for the introduction of insulated containers by Project EU-VECEP ALA 92/43.
2 Tilman, 1999. Personal communication and references regarding the introduction of insulated containers in small-scale fishing vessels in Ecuador by Project EU-VECEP ALA 92/43.

Trips (or two months) with external wooden frame and 20–24 long-distance trips (or five to six months) with galvanized steel sides.

6.2.4 Locally made non-insulated fish boxes

Where the costs of plastic fish boxes are too high, wooden boxes are often used because the boxes are simple to construct using basic hand tools, can be repaired if damaged and are less costly than plastic imports. A typical locally made wooden box for fresh fish on ice stowage is shown in Figure 6.4 (p. 76). Generally, wood of suitable type and dimensions can be easily found locally. Another advantage of locally made boxes is that they may be made to any special dimensions required for local species. This is important as box sizes must be large enough so that fish are not bent or distorted when stowed in the box with ice.

However, there are some disadvantages to wooden boxes: they can be heavy and they absorb moisture, which may include fish slime, blood and other fish wastes and bacteria. This can then contaminate the fish stored in them causing accelerated spoilage or infection with pathogenic organisms. The problem of maintaining hygiene in wooden boxes can be addressed by immediate washing of the box after use using brushes and a disinfectant solution containing chlorine or a similar cleansing agent. Besides the regular washing and disinfecting, it is also common practice to line the box interior with clean polyethylene sheet material, effectively keeping the fish from coming into contact with the box. The polythene sheets should be discarded after use.
FIGURE 6.1
Example of a customized insulated fish box (West Africa)

Exploded view of panels

6.3 FISH HOLD DESIGN
When building a new fishing vessel, the fish hold can be designed and installed for maximum efficiency from the beginning, which overcomes the difficulties that can be encountered when retrofitting fish holds and insulating them in existing vessels.

6.3.1 Penboards, shelving or boxes: benefits and disadvantages
When considering hold design for small-decked artisanal fishing vessels, the various methods of catch stowage generally encountered are:

- piled on hold floor;
- piled in ice on hold floor;
The use of ice on small fishing vessels

**FIGURE 6.3**
Common styrofoam box with lid and protective wooden frame

Plug type lid

Frame constructed from locally available wood. Dimensions to suit size of box. In some instances, sides and ends are covered with galvanized steel sheets.

**FIGURE 6.4**
Typical locally made wooden fish box, uninsulated

Boxes vary greatly in size and shape. The primary need is to build the box of a size that will accommodate the fish being caught without distorting them. The box should not be too large or handling could be a problem.
Containers and fish holds

- stacked with ice in divided compartments;
- shelved with ice in divided compartments;
- stored in fish boxes with ice;
- stored in insulated tubs or hold tanks with ice or CSW.

Obviously, the first two methods are to be avoided if at all possible because they will produce poor quality, damaged and consequently low-value fish. Damage to the catch is also incurred by the crew walking over the pile. Further damage to fish at the bottom of pile is also caused by compression of the lower layers from the weight of the stack – the higher the stack, the more compression damage is incurred. Other damage is incurred by the lower layers of fish being bathed in waste fluids and contaminated with decay bacteria. If the pile includes ice meltwater from the fish stacked above, this will tend to have a cleansing effect, provided that sufficient quantities are used.

An advantage of stacking fish in divided compartments is that it allows the catch to be sorted according to species and size, etc. However, the problems of compression damage, weight loss and contamination are still factors to be considered.

An improvement on the above type of bulk stowage compartment is to provide shelving at pre-set heights within the compartment, which alleviates the problem of crushing fish at the bottom of the stack. Practical research work carried out on commercial fishing vessels in New England by the New England Fisheries Development Foundation Inc. found that the optimum shelving height was around 53 to 61 cm (21–24”). European and Canadian studies on shelf stowage of fresh fish are in agreement with these figures.

One disadvantage with the bulk stowage of fish is the necessity for extra handling. The catch has to be physically handled from capture to stowage in the hold and again at dockside when unloading, causing more delay and damage to fish. In some countries the handling time is costly, so efforts have been made to streamline the process. In Canada, for instance, net bags have been layered in with fish and ice, allowing the deck boom to lift fish out layer by layer instead of individually transferring them to boxes for removal from the hold. This system also has its flaws, as there is still damage to a certain percentage of the catch caused by the net during unloading. Fish pumps are also used, but primarily for small pelagics. Some pumping systems can also cause damage to the larger fish, signifying further losses of quality and consequently lower prices.

One of the best alternatives for catch preservation and minimizing handling is the use of stackable tote boxes and more recently the introduction of insulated plastic containers or tubs.

Fish tote boxes can be made from wood, metals or plastics, with each material having its advantages and disadvantages, as shown in Table 6.4.

The plastic non-insulated fish box has become the standard for fresh fish stowage on board fishing vessels in many countries worldwide because of its obvious advantages over other materials. This is especially so if export of the product is taking place or being contemplated. The export market consistently demands high quality and good standards of hygiene, which can be best complied with by using HDPE tote boxes (see Figure 6.5).
There are some differences in the plastic tote boxes available to fishermen, primarily in the storage methods for empty boxes. Some boxes are constructed in such a way that they nest one inside the other, which is a great benefit when space is at a premium, as is normally the case on many small fishing vessels. The non-nesting types tend to be used on larger fishing vessels such as wet fish trawlers, where space is not such a critical factor. All modern plastic fish boxes are designed in such a way that wastes and meltwater from the boxes in the upper layers of the stack do not drain into the boxes below.

### 6.3.2 Insulation: design considerations

Factors in the design of insulation in fish holds are principally concerned with obtaining the best R-value figures for the insulation type chosen and the best available material for the fish hold liner, without losing excessive interior volume while being economically feasible.

Basic assumptions for insulation are that heat gains in the fish hold will be greater through engine room bulkheads and working decks exposed to direct sunlight – consequently these areas will require more insulation. For more information on insulation types and suitability for fishing vessels, refer to Chapter 7.

In modern vessels, the insulating material usually chosen for installation during construction is expanded closed-cell polyurethane foam or one of its derivatives. This foam is usually sprayed in place in the hold to slightly more than the required thickness. When set, the foam surface is trimmed to uniform thickness using rotary rasps or hand tools. A sheathing of fibreglass or other suitable material

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>Depending on location or country, wood may be cheap to manufacture, and may be the only material readily available for this purpose at reasonable cost to the fishermen</td>
<td>Relatively limited lifespan of box due to rough handling procedures and constant repair. Frequent replacement required</td>
</tr>
<tr>
<td></td>
<td>Carpentry skills for manufacture and repair of boxes are readily available in most countries</td>
<td>Considerable waste of sometimes valuable forest resources</td>
</tr>
<tr>
<td></td>
<td>Can be readily made to sizes to suit local requirements</td>
<td>Difficult to keep properly clean and sanitized</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy – to be strong enough for rough handling boxes are made of heavy stock</td>
</tr>
<tr>
<td>Metal</td>
<td>Metal boxes are normally of welded lightweight alloy</td>
<td>Generally quite expensive compared to wood or plastic not always available locally</td>
</tr>
<tr>
<td></td>
<td>Relatively strong and light for handling</td>
<td>Repairs relatively easy if alloy welding equipment available</td>
</tr>
<tr>
<td></td>
<td>Resistant to rough handling</td>
<td>Very noisy to handle</td>
</tr>
<tr>
<td>Plastic</td>
<td>Reasonable cost</td>
<td>Hard to repair if damaged</td>
</tr>
<tr>
<td></td>
<td>Lightweight, strong and durable</td>
<td>Can be more costly initially than wooden boxes</td>
</tr>
<tr>
<td></td>
<td>Commercially available in most parts of the world</td>
<td>Some types do not nest one inside the other; this can cause stowage space problems for empty boxes</td>
</tr>
<tr>
<td></td>
<td>Designed specifically for fisheries use regarding ease of manipulation and stackability in fish holds</td>
<td>Easy to keep clean</td>
</tr>
</tbody>
</table>
is then applied over the foam to provide damage protection, an easily cleanable surface and protection against ingress of moisture. The use of polyurethane foam is advantageous in that it does not dissolve or break down from the effects of styrene in the fibreglass sheathing, as happens with expanded polystyrene-based foams.

Some proprietary surface finishes are also used to cover and protect sprayed-in-place foam. One such material is a type of cement plaster with polymer
additives. This is applied using a plastering trowel to a thickness of about 12 mm over the foam.

The sheathing thickness is sufficiently heavy to provide mechanical strength also, so that should blocks of ice or fish boxes be dropped in the hold, the sheathing will not easily fracture leaving difficult-to-clean crevices where bacteria will propagate.

Polystyrene-based foams have to be protected from direct contact with styrene that is present in polyester resins used in typical fibreglass lay-ups. Some methods commonly used to line holds and protect styrofoam are:

- Thin sheet metal linings, usually zinc, galvanized steel or aluminium. Zinc and galvanized steel are not to be recommended because of the toxic qualities of zinc. Aluminium is good but expensive and can be difficult to install.
- Epoxy/glassfibre laminates as a barrier layer prior to polyester laminate lay-up application. This is a good system, but depends on costly epoxy laminating resin, which is not always available in many countries.
- Ferro-cement or modified plasters. Cement workers and skilled plasterers are available in practically all countries. The ferro-cement method, when properly applied with layers of wire mesh reinforcing, is one of the cheapest, best and most readily available. This method is well proven, having been used to construct many fishing vessel hulls of exceptional strength over the past 40 years.

Other forms of insulation, such as cork board or cork granules, are also in common use, though R-values are not as high as for the plastic foams. Materials of a highly hygroscopic nature, such as fibreglass wool, rock wool, sawdust and straw, should normally be avoided in insulating fishing vessel holds, because when they become wet they lose practically all their insulating value. Also, some of the vegetable-based materials tend to attract insects or vermin of various types.

Ultimately, the selection of a hold-lining system is up to the builder or owner of a new vessel or one being retrofitted. They will make the final decisions based on what materials and skills are available locally and what they feel will give the results required within the budget available.

6.3.3 Free surface effect
Another very important aspect of fish hold design that is sometimes overlooked, or misunderstood, is that of designing the hold space to avoid the dangers of the “free surface effect”. This is a potentially dangerous situation caused by unrestricted movements of large volumes of liquid from one side of a boat to the other, causing instability by a virtual rise in the centre of gravity (CG) of the hull. The same effect can also be caused by stowing wet fish, particularly pelagics such as sardine, in a hold with either no transverse dividers or penboards, or improperly installed penboards with excessive free space above the last or top boards. Partially loaded boats are more prone to this effect as there is the potential for much more free surface effect as the boat heels.

This same danger is also present if the vessel’s fish hold or tanks are used for CSW. Without adequate thought and planning to prevent loss of freeboard when the tanks are filled, the range of initial stability available before the deck edge
submerges under heeling forces is greatly reduced. Therefore, proper planning and design by qualified naval architects are critical if vessels are to pursue this stowage method. One of the options available to address the free surface effect of CSW tanks is the use of CSW sprayed continuously over the catch for chilling, eliminating the need for tanks.

Fishing vessels have been known to sink from the instability caused by partially filled CSW tanks or movement of improperly stowed wet fish from one side of the hold to the other. Figure 6.6 illustrates some of the dangers of free surface effect and how the installation of penboards can minimize its effect on vessel stability.

![FIGURE 6.6](image)

**FIGURE 6.6**  
Free surface effect: half-full fish tanks or holds with and without longitudinal bulkheads

Vessel heeled. Wet fish in hold remain level with the water level. Centre of gravity (CG) of liquid or fish moves to new centre; vessel can become unstable.

Vessel without penboards in place. Wet fish in bulk in partially filled hold. Vessel is stable as long as it remains without heel.

Dividing fish hold into two equal parts with bulkhead reduces adverse effect on vessel stability to 25 percent of that from an undivided hold.

It is not within the scope of this publication to give detailed calculations for these effects. It is therefore very strongly recommended that a naval architect be consulted before and during any retrofitting of a CSW system to an existing boat. However, those wishing to know more on this subject may refer to Chapter 4 of Hind (1967).

6.3.4 Sanitation in fish holds
Sanitary requirements for fish holds in modern artisanal fishing vessels can be quite simply addressed if the following points are observed:

- Install the best insulation available (plastic foams) to prevent bacterial absorption and attack by vermin.
- Install a structurally sound impermeable lining over the hold surface that is non-toxic, durable and easily cleaned.
- Install a system for drainage of all waste, fish slime and contaminated meltwater to a central sump(s) from which it can be pumped overboard. Wastes must not be allowed to drain into the vessel's bilges.
- Institute and maintain a “ship cleaning” regime that is strictly adhered to, with specific crew responsibilities for cleaning each time fish are processed on deck and after discharge of catch in port.
- Keep an adequate supply of disinfectants, detergents, buckets and scrub brushes on board at all times.

In addition to the cleaning materials and instruction of crew in proper cleaning procedures, it is also necessary to have durable, easily cleaned liner surfaces in the fish hold, some of which are discussed in the following paragraphs.

Various types of linings have been used in fish holds and insulated fish boxes to provide a smooth, easily cleanable surface. The original method of fish hold lining in wooden boats is usually of wood plank or “ceiling” fastened to the inside of boat hull frames in the fish hold. This has the disadvantage of being difficult to keep clean without strong disinfectants owing to the wooden ceiling absorbing moisture, bacteria, etc. The smell of strong disinfectants could in some cases be transferred to the fish stowed in the hold. This being unacceptable, other methods of fish hold lining have been developed and used. Painting the wooden interior surface of fish holds with special paints has also been tried with limited success, but this is not a satisfactory solution as the paint is easily damaged, leaving the wood exposed to infiltration of moisture and contaminants as before.

Initially, zinc or galvanized steel sheets were used, fastened to the inside of the ceiling, the joints between sheets being sealed with bedding compound or soldered to prevent ingress of water and contaminated fish fluids. These linings allowed drainage of fluids to the bilge, where they could be pumped overboard at the crew’s convenience. This type of lining is easy to keep clean but requires maintenance to maintain impermeability at such points as fastening holes and seams that can be damaged by shovels and boxes being moved around in the hold. Other disadvantages of some metallic linings are a certain amount of toxicity that can be encountered from zinc and some anti-corrosion products.

In many countries, fibreglass laminates have largely superseded metallic linings because of their ease of application and availability at reasonable cost. Their
Containers and fish holds

resistance to damage is also superior to that of thin metal sheet linings as there are no seams or exposed fastenings to be snagged by fish-handling equipment, provided of course that sufficient thickness of sheathing is used.

In the past, drainage of meltwater and waste fish fluids was in most cases simply allowed to find its way to the bilges, through unlined ceiling and floorboard joints, where most could be pumped overboard with the existing bilge pumps. Unfortunately, the remaining wastes become a microbial breeding place causing strong “off” smells that eventually affect the fish stowed in the hold. Direct contamination is also possible if the bilge contents are sloshing around in rough weather, as waste liquids filtered into the bilge through seams can also re-enter by the same route, especially if the bilge is not pumped regularly.

Coincidentally with demands for uncontaminated quality fish products, it was found that with the advent of good fish hold linings, it became possible to direct all drainage from the fish and ice to a central sump located in the hold floor low point. From this sump a dedicated pump discharges the wastewater overboard. This system is now standard practice on many fishing vessels worldwide; even relatively small boats (26 ft) can have similar systems. Other systems can also work. For instance, in some larger vessels a longitudinal grating is installed along the length of the hold. This is helpful if the floor is relatively level, as tends to be the case on larger boats, as wastewater etc. can enter the sump at any point and need not be channelled to a central sump. On other vessels, where there is a raised shaft tunnel running through the hold, it is normal practice to install sumps on either side of the shaft tunnel. The shaft tunnel should not be used as a sump.

6.3.5 Insulation installation in older vessels

Many older fishing vessels were not built with insulation in their fish holds, usually relying on speedy trips to and from the fishing grounds, spending only a short time on the grounds to catch fish that were plentiful. This situation no longer exists in most fisheries. Today it is necessary to travel farther offshore and spend more time fishing for dwindling fish stocks. It is therefore very important to maximize yield from those fish that are caught, and insulation and ice are integral parts of this equation.

In most instances, when facing longer trips, it is calculated by the owners that adding insulation to the hold space in their uninsulated fishing vessel would be beneficial to profits. The owners’ assumption will, in the majority of cases, be correct – the costs will generally be recouped over a reasonably short period from better fish prices at landing as a result of improved quality.

The majority of older fishing vessels are of wooden construction necessitating careful attention to the maintenance of ventilation in spaces behind the ceiling, in bilges and between frames to prevent accelerated rot in these locations. It is, however, reported by some owners of wooden vessels that application of foam by the direct-spray and foam-in-place methods in frame spaces and deckhead has reduced accelerated rot. These claims pertain usually to vessels operating in temperate or colder waters, so they must be viewed with caution, especially if a
The use of ice on small fishing vessels

A sectional view of a typical insulation installation on a wooden fishing vessel is shown in Figure 6.7. Fishing vessels of metal construction are usually less problematic; they are easily insulated by spray foams, foam boards, pour-in-place foams or other materials, as available. There is a slight problem with heat bridging from the frames if the insulation does not cover them completely (see Figure 6.8). Completely covering frames to counteract this is the only option. If fibreglass or cement sheathing is to be used as a liner, it is not a problem. However, should the inner cladding be metal, it can be difficult to weld. The usual practice is to weld a series of discontinuous lugs onto the frames that protrude out of the inner face of the insulation. The metal lining can then be fitted and welded to these lugs as convenient.
FIGURE 6.8
Heat bridging through insulation on steel fishing vessels

Heat transfer takes place from shell plate through frame to inner liner.

Insulation covers frame inner face, minimizes heat bridging.
Fibreglass fishing vessels are not particularly prone to problems related to installation of insulation. In fact, manufacturers of fibreglass boats tend to have supplies of two-part polyurethane foams as part of their inventories for use in some structural applications, buoyancy tanks and, of course, for insulating fibreglass boxes and containers that will be supplied with their own boats. Builders of larger sizes of fishing vessels will in some instances hire specialist insulation contractors who have all the necessary materials and equipment to execute the work in very short order. The increasing use of sprayed foam insulation in civil construction is giving boat builders easier access to insulation that is both good quality and economical.
In this chapter some examples of basic calculations for insulated containers and fish holds are given. There is also a section on calculating ice requirements for cooling fresh fish and a section on methods for the determination of fish hold volumes.

7.1 CALCULATING THE SPECIFIC ICE MELTING RATE FOR AN INSULATED CONTAINER OR FISH HOLD

There are a number of methods for calculating the ice melting rate for an insulated container, such as:

a) theoretical mathematical and numerical methods;

b) practical methods based on ice meltage tests.

Theoretical mathematical and numerical methods are available for the calculation of ice meltage rates for containers, based on the coefficient of heat transmission (U), area through which heat is transferred (A) and the latent heat of fusion of ice (L), which is 80 kcal/kg for pure freshwater and 77.8 kcal/kg for seawater. The specific ice melting rate of a container (K₁), expressed in kg of ice/h °C, can be calculated from the following equation:

\[ K_1 = \frac{A \cdot U}{L} \]  

(equation 1)

The coefficient of heat transmission (U) (kcal m⁻² h⁻¹ °C⁻¹) is the rate of heat penetration through the container walls per m² of surface area per degree centigrade of temperature difference between inside and outside. This value depends on the thermal conductance coefficient of the materials used in the container wall (λ), the thickness of these materials and the speed at which heat can be transferred from the outside environment to the outside wall of the container, as well as from the inside wall to the contents (e.g. fish and ice mixture).

For an insulated container made up of different layers of different materials, the coefficient of heat transmission can be calculated from the following equation:

\[ U = \frac{1}{\frac{1}{\alpha_1} + \sum \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_2}} \]  

(equation 2)
The use of ice on small fishing vessels


\[ \alpha_1 = \text{coefficient of heat transmission on the outside of the wall} \]
\[ \alpha_2 = \text{coefficient of heat transmission on the inside of the wall} \]
\[ \delta_i = \text{thickness of material layers used in the wall} \]
\[ \lambda = \text{thermal conductance coefficient of the materials used in the wall} \]
\[ \phi = \text{coefficient taking into consideration the influence of stiffening ribs used in the ship's structure as well as supporting construction for the insulating wall (frames, deck beams, various elements, etc., which can create heat leakage bridges)} \]

For simplicity, the coefficients \( \alpha_1 \) and \( \alpha_2 \) are sometimes disregarded, as these factors may have a relatively small influence on the result. However, all these methods require adequate heat transmission knowledge, laboratory facilities and computer hardware and software, which are generally not available in small-scale fisheries.

The heat leak through an element can be calculated using the following equation:

\[ Q = A \times U \times (t_o - t_i) \]  \hspace{1cm} \text{(equation 3)}

where:
\[ Q = \text{total heat transfer rate through the element (kcal/h)} \]
\[ A = \text{area of the element (m}^2) \]
\[ U = \text{coefficient of heat transfer for the element (kcal m}^{-2} \text{h}^{-1} \text{°C}^{-1}) \]
\[ t_o = \text{outside temperature of the element (°C)} \]
\[ t_i = \text{inside temperature of the element (°C)} \]

Example: The following calculations are made for a steel fishing vessel with an insulated CSW hold or tanks. The calculation of the rate of heat transmission (U value) for the vessel's fish hold requires knowledge of the heat transfer coefficients for all elements involved. The following relationship is derived from equation 1.

\[ U = \frac{1}{\frac{1}{H1} + \frac{X1}{K1} + \frac{X2}{K2} + \frac{X3}{K3} + \frac{1}{H2}} \]

where:
\[ H1 = \text{outside heat transfer coefficient (kcal h}^{-1} \text{ m}^{-2} \text{°C}^{-1}) \]
\[ H2 = \text{inside heat transfer coefficient (kcal h}^{-1} \text{ m}^{-2} \text{°C}^{-1}) \]
\[ K1 = \text{thermal conductivity of steel plate, ship's side (kcal h}^{-1} \text{ m}^{-1} \text{°C}^{-1}) \]
\[ K2 = \text{thermal conductivity of polyurethane insulation (kcal h}^{-1} \text{ m}^{-1} \text{°C}^{-1}) \]
\[ K3 = \text{thermal conductivity of steel plate, tank lining (kcal h}^{-1} \text{ m}^{-1} \text{°C}^{-1}) \]
\[ X1 = \text{thickness of steel plate ship's side (m)} \]
\[ X2 = \text{thickness of polyurethane insulation (m)} \]
\[ X3 = \text{thickness of tank lining (m)} \]
Once the heat transfer coefficients have been calculated for each element of the fish hold (deckhead, fish hold flooring, engine room bulkhead, forward bulkhead, ship’s sides above water and ship’s sides below water), the heat leak through each surface can be calculated using equation 3. The area of each element has to be determined and design temperatures for inside and outside chosen.

For the fish hold or fish container as a whole, the total heat exchange rate will result from the sum of individual calculations of the Q values. Table 7.1 shows the calculated heat leaks (kcal h⁻¹ m⁻²) in a steel hull fishing vessel installed with a CSW steel tank with 100 mm thick polyurethane insulation and one without insulation. This calculation is based on ideal conditions (without frames or hangers penetrating the insulation, thus no heat leakage bridges). The main areas of the fishing vessel through which heat enters into the uninsulated CSW tank are: the deckhead, the ship’s sides above the water line and the ship’s sides below the water line, with overall heat transfer coefficients of 27.6, 27.6 and 374 kcal m⁻² h⁻¹ °C⁻¹. Other areas of the vessel, such as the engine bulkhead and tank floor, have overall heat transfer coefficients of 7.03 and 7.73 kcal m⁻² h⁻¹ °C⁻¹. However, the average overall heat transfer coefficient for a fully insulated CSW tank (under ideal conditions) was calculated to be only 0.21 kcal m⁻² h⁻¹ °C⁻¹. Temperature differences between the internal surface of the CSW tank (0 °C) and other areas of the vessel and heat leakages were as shown in Table 7.1.

Since 1 kg of ice will absorb 80 kcal when it melts, the total heat leakage load in our example for a fully insulated CSW tank will require about 7.7 kg/h of ice (185 kg/day). Therefore, for a four-day trip the ice required to absorb the heat infiltration load will be 740 kg. However, for the above-mentioned example, in practical circumstances, the heat leakage bridges in similar CSW tanks insulated to a commercial standard (due to partial insulation of the CSW tanks) can be estimated to be about 7 percent of the total heat leakage in the insulated CSW tank.

A practical and simple calculation method of the experimental specific ice melting rate of a container (Kexp), based on data of the mass of ice melted during a

<table>
<thead>
<tr>
<th>Surface</th>
<th>Temperature (°C)</th>
<th>Heat leakage Uninsulated CSW tank (kcal/h)</th>
<th>Heat leakage Uninsulated CSW tank (%)</th>
<th>Heat leakage Fully insulated CSW tank (kcal/h)</th>
<th>Heat leakage Fully insulated CSW tank (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deckhead</td>
<td>30</td>
<td>24 543</td>
<td>18.8</td>
<td>186</td>
<td>30.3</td>
</tr>
<tr>
<td>Tank floor</td>
<td>25</td>
<td>5 744</td>
<td>4.4</td>
<td>152</td>
<td>24.8</td>
</tr>
<tr>
<td>Engine room bulkhead</td>
<td>35</td>
<td>4 700</td>
<td>3.6</td>
<td>137</td>
<td>22.4</td>
</tr>
<tr>
<td>Forward bulkhead</td>
<td>8</td>
<td>1 044</td>
<td>0.8</td>
<td>31</td>
<td>5.1</td>
</tr>
<tr>
<td>Ship’s sides above water line</td>
<td>30</td>
<td>7 702</td>
<td>5.9</td>
<td>58</td>
<td>9.5</td>
</tr>
<tr>
<td>Ship’s sides below water line</td>
<td>25</td>
<td>86 814</td>
<td>66.5</td>
<td>49</td>
<td>8.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>130 548</td>
<td>100</td>
<td>613</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Note: mild steel plate thickness: ship’s side: 6 mm; CSW tank lining: 5 mm. Source: FAO, 1992b.
given time period, has been developed and found suitable for small-scale fisheries. The proposed model is based on the assumption that there is a linear relationship between the ice meltage rate in a container and time when the ambient temperature remains constant. However, in practice, there are differences of ice meltage rates for containers stored in the shade and in the sun.

The specific ice meltage rate \( K_1 \) can be calculated with the following equation:

\[
M_i(t) = M_i(0) - K_1 \times T_e(a) \times t
\]  
(equation 4)

where:

- \( M_i(t) \) = mass of ice inside the container at time \( t \) (kg)
- \( M_i(0) \) = initial mass of ice inside the container at time \( t = 0 \) (kg)
- \( K_1 \) = specific ice melting rate of the container (kg of ice/h \( ^\circ \)C)
- \( T_e(a) \) = average temperature outside the container (\( ^\circ \)C)
- \( t \) = time elapsed since icing operations in the container (h)

This methodology, described by Lupin (FAO, 1986), consists of the following steps:

1. Determine the technical characteristics of the insulated container to be tested.
2. Weigh the insulated container accurately (empty and dry).
3. Completely fill the insulated container with ice and weigh container again.
4. Record the time when the insulated container was filled with ice as well as the weight of ice placed inside (calculated by weight difference).
5. Store and handle the containers in the shade, accurately record the prevailing working conditions.
6. Monitor the ambient temperature at regular intervals so that an average temperature can be estimated. It is recommended to monitor air temperature each hour during daytime (for short trials of six to eight hours long) and use maximum-minimum thermometers for monitoring overnight experimental works. However, time-temperature recorders can be also utilized for better results if they are readily available.
7. For containers that allow melt water to drain away, the weight losses can be measured at regular intervals (say every two hours) to monitor accurately the rate at which the mass of ice placed inside the container melts.
8. This type of ice meltage test should be done using ice only, though the method can be equally valid for fish and ice mixtures (provided that ice for chilling the fish load is accounted for). In addition, some of the initial ice meltage will be the result of the heat removed for cooling the container and, in some cases, some melted water may be absorbed by the container (depending on the type of material).
9. The data of mass of ice melted (weight loss) should be plotted against time on a graph. These data should give a more or less straight line graph (however, this will depend on the variability of the external air temperature).

Figure 7.1 shows typical experimental data of ice meltage plotted against time for a 90 litre capacity insulated container stored in the shade. The experimental
specific ice melting rate ($K_{\text{exp}}$) value represents the value of the slope of the plotted line. In the example in Figure 7.1 the slope of the line is 0.1498, therefore $K_{\text{exp}} = 0.1498$ kg of ice/h (3.6 kg of ice/day) at an average ambient temperature of 28 °C.

To determine the specific ice meltage rate ($K_{\text{exp}}$) for the same container at different ambient temperatures, it will be necessary to conduct several trials at the desired temperatures. Table 7.2 shows the experimental values of specific ice meltage rates ($K_{\text{exp}}$) obtained during tests carried out at different ambient temperatures. Figure 7.2 shows the plotted graph of the relationship between the experimental data of $K_{\text{exp}}$, for the same insulated container described in Figure 7.1, obtained at different ambient temperatures. The results from Figure 7.2 can be expressed by the equation of the resulting straight line $y = 0.1233x$ and adjusted as follows:

$$K_{\text{exp}} \text{ (kg of ice/day)} = 0.1233 \times T_{\text{a}} \quad \text{(equation 5)}$$

The following example illustrates the application of the results obtained from Figure 7.2.

**Example:** Determine how much ice will be consumed in the insulated container described in Figure 7.1 if it is stored in the shade in a fishing boat over a five-day period at an average ambient temperature of 40 °C (without considering the quantity of ice needed for chilling fish).

![Typical experimental data of ice meltage against time in an insulated container](image)

**Table 7.2** Experimental values of specific ice meltage rates ($K_{\text{exp}}$) at different temperatures

<table>
<thead>
<tr>
<th>$K_{\text{exp}}$ (kg of ice/day)</th>
<th>Average ambient temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8</td>
<td>40</td>
</tr>
<tr>
<td>4.2</td>
<td>35</td>
</tr>
<tr>
<td>3.6</td>
<td>28</td>
</tr>
<tr>
<td>3.0</td>
<td>23</td>
</tr>
<tr>
<td>2.4</td>
<td>20</td>
</tr>
<tr>
<td>2.0</td>
<td>16</td>
</tr>
<tr>
<td>1.6</td>
<td>12</td>
</tr>
<tr>
<td>1.2</td>
<td>10</td>
</tr>
<tr>
<td>0.9</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: the data are based on tests made with the insulated container described in Figure 7.1.
From equation 5 the specific ice melting rate can be calculated:

\[ K^{\exp} \text{ (kg of ice /day) } = 0.1233 T_c (\circ C) \]

\[ K^{\exp} = 0.1233 \times 40 \circ C = 4.932 \text{ kg/day} \]

Therefore, the total ice consumed in the insulated container to compensate for heat losses will be: 4.932 kg/day × 5 days = 24.660 kg \( \approx \) 25 kg of ice.

In practice, it is easier to use Figure 7.2 directly. The diagram shows that an ambient temperature of 40 \( \circ C \) would melt around 5 kg per day, which will make 25 kg in five days.

**Note:** Data resulting from the above ice meltage tests for insulated containers should be used with caution. If the containers cannot be protected from direct sunlight or other radiated heat source during field-working conditions, the above calculated values of specific ice melting rates should be upgraded. In practice, it is best to store and handle insulated containers in the shade and if possible complemented by covering the container in some way (e.g. wet insulating blanket or tarpaulin laid over the container) to minimize the effects of radiated heat.

### 7.2 METHODOLOGY FOR THE CALCULATION OF ICE REQUIREMENTS FOR COOLING FRESH FISH

In general, the total amount of ice required for cooling fresh fish from any initial temperature to a final temperature (ideally to 0 \( \circ C \)) using ice can be calculated from the following equation:

\[ M_i \times L = M_i \times C_{pf} \times (T_{fi} - T_{fo}) \]

(equation 6)
where:
\[ M_i = \text{mass of ice which melts (kg)} \]
\[ L = \text{latent heat of fusion of ice (80 kcal/kg)} \]
\[ M_f = \text{mass of fish to be cooled (kg)} \]
\[ C_{pf} = \text{specific heat of fresh fish (kcal/kg °C)} \]
\[ T_{f_i} = \text{initial temperature of fresh fish (°C)} \]
\[ T_{f_o} = \text{final temperature of fresh fish (°C), normally 0 °C} \]

From equation 6 the requirement of ice for cooling fresh fish to 0 °C will be:

\[ M_i = \frac{M_f \times C_{pf} \times T_{f_i}}{L} \]

The specific heat of fish varies according to its chemical composition; for example for lean fish this value is about 0.8 (kcal/kg °C) and for fatty fish about 0.75 (kcal/kg °C). For practical purposes, however, it is acceptable to use the value of 0.8 (kcal/kg °C) in all calculations for fresh fish. This will give the simplified equation:

\[ M_i = \frac{M_f \times 0.8 \times T_{f_i}}{80} = \frac{M_f \times T_{f_i}}{100} \]

**Example:** Determine the ice requirement for chilling 40 kg of fresh fish at an initial temperature of 40 °C.

\[ M_i = \frac{M_f \times T_{f_i}}{100} = \frac{40 \times 40}{100} = 16 \text{ kg of ice} \]

Figure 7.3 gives another presentation of the relationship between initial temperature and the ice needed to chill 1 kg of fish to 0 °C. From the graph it can be seen that at an initial temperature of 40 °C, around 0.45 kg of ice will be needed for every kg of fish. This gives a total amount of 18 kg of ice for 40 kg of fish.

In practice, in tropical conditions much more ice is needed to compensate for losses of ice cooling capacity due to meltage during ice storage at room temperature. There is evidence that when ice is stored at 27 °C, there is a certain amount of water on the surface of flake ice particles at steady conditions, which represents about 12–16 percent of the total weight. For crushed block ice, this water on the surface can be about 10–14 percent of the total weight. The amount of water in equilibrium on ice particles will depend on the type of ice and storage temperature.

Additional ice losses during chilling and storage of fish are due to bad handling practices, such as ice wasted during icing operations. These losses are estimated to be about 3–5 percent of the total amount of ice used.

The total requirements of ice to chill 40 kg of fish from 40 °C to 0 °C and maintain it chilled for five days in a 90 litre insulated container are presented in Table 7.3. As can be seen, the required amount, 50 kg, is slightly above the “rule of thumb minimum” of 1 kg of ice for 1 kg of fish.
The use of ice on small fishing vessels

TABLE 7.3
Summary of ice requirements for chilling fresh fish in a 90 litre insulated container

<table>
<thead>
<tr>
<th>Consumption/loss factor</th>
<th>Ice requirements (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To compensate for heat losses in the insulated container</td>
<td>24.7 (4.932 kg/day × 5 days)</td>
</tr>
<tr>
<td>To cool down 40 kg of fish from 40 °C to 0 °C</td>
<td>16</td>
</tr>
<tr>
<td>To compensate for bad ice-handling practices</td>
<td>2.5 (estimated as 5% of total ice used)</td>
</tr>
<tr>
<td>To compensate for water in equilibrium in ice</td>
<td>7 (estimated as 14% of total ice used)</td>
</tr>
<tr>
<td>Total consumption</td>
<td>50.2</td>
</tr>
</tbody>
</table>

Note: all values are based on previous worked examples.

7.3 CALCULATING GROSS FISH HOLD VOLUME

Knowing the volume of a vessel’s fish hold is useful, especially if the hold is to be retrofitted with insulation or extra insulation, since it will allow calculation of loss of volume in the hold after insulating work is carried out. It will also allow calculation of the amount of ice and ice/fish that can be stored and so projecting optimal trip lengths and fish catches.

Following are some simple methods for calculating fish hold volumes within an acceptable range of accuracy.
7.3.1 Cubic number method

The FAO Fisheries Department has developed a relatively accurate method, derived over more than 30 years of fishing vessel design and operation, for determining fish hold volumes simply by using the cubic number (CUNO) for fishing vessels of normal form. The basis for the CUNO method is a series of three measurements on the vessel in question. The cubic number is calculated as:

$$\text{Loa} \times B \times \text{Dm}$$

where:  
- \( \text{Loa} \) = Length over all  
- \( B \) = Beam width amidships at deck level  
- \( \text{Dm} \) = Distance from deck to keel (rabbet line) amidships

Figure 7.4 shows how and where to make these measurements.

The application of the CUNO figure obtained from measurement of the vessel to arrive at an approximate fish hold volume is shown in Figure 7.5. These figures are generally accurate within 10 percent. As can be seen in Figure 7.5 the fish hold volume corresponds to CUNO \( \times 0.14 \pm 10 \) percent. As an example, a CUNO number of 150 m\(^3\) would indicate a fish hold volume of around 20 m\(^3\).

---

**FIGURE 7.4**

**Definition of cubic number**

7.3.2 Trapezoidal rule

For those who wish to use direct measurement to obtain the volume of a particular fish hold, a relatively easy calculation can be made using a simple formula applied to the measurements taken. The measurement method selected for this example is known as the “trapezoidal rule” which is used for its relative simplicity of application under field conditions, and is considered to be of sufficient accuracy for these purposes. Should the readers require more accuracy they may prefer to use “Simpson’s rules” which are somewhat more precise, though only by a very small percentage. However, Simpson’s rules require even numbers of divisions and slightly more calculation with the risk of inadvertent errors.

In order to better understand the terminology used in these measurements, refer to Figure 7.6, which illustrates the various terms used for the following calculations.

For this example the method and locations for obtaining the necessary measurements are shown in Figures 7.7 (a) and (b). Here only three measurement points longitudinally (sections) are used, one on the forward bulkhead, one at the longitudinal centre of hold and the third at the after bulkhead. If more precision is required, simply increase the number of longitudinal divisions, keeping them equally spaced. Most fish holds tend to be placed in an area of the hull that gives maximum volume; the sole is generally flat in an area close to the centreline and usually slopes upward towards the after bulkhead; sides tend to run more or less parallel fore and aft. For vessels with holds forward of the engine room, the sole tends to be level.
For most applications three sections should be sufficient; only if the fish hold is of an extremely radical shape will more sections be required to obtain volume.

The trapezoidal rule calls for evenly spaced ordinates for measurement points – they may be even or odd numbers, but should be evenly spaced. The first and last ordinate measurements are both divided by two; all figures are then added together and multiplied by the common interval, or the spacing between ordinate marks. Using the measurements from Figure 7.8, the section area can be calculated. Note that the area obtained has to be multiplied by two, as it is only half of the complete section.

Notes:
1) Ordinates have to be evenly spaced.
   Number of intervals can vary, but must be evenly spaced.
2) Measurements must be taken at 90° (level) from centre line to boat side.
3) Measurements may be Imperial or metric.
4) Hold can be divided longitudinally into as many sections as desired, but they must be evenly spaced between forward and after bulkheads.
   For small fishing vessels, three sections are usually enough, i.e. forward bulkhead, hold mid-section and after bulkhead.
5) Remember to multiply half section results by two.
FIGURE 7.7
Measurements for trapezoidal rule

Three sections, mid-section "M" located midway between bulkheads "F" and "A".

Sketch b) shows locations of three sections. More sections can be added as shown by hatched lines "x".
In this case the ordinate spacing is one unit of measurement. Units may be imperial or metric, depending on which are preferred or in common use.

The measurement of one area must be combined with the other section areas in order to work out the volumetric measure as is required. In this case, the forward and after fish room bulkhead areas are to be calculated in a similar fashion to that of the hold mid section for a total of three sections.

An example of these area calculations is shown below using the measurements illustrated in Figure 7.8.

### Fish hold, forward bulkhead area

<table>
<thead>
<tr>
<th>Ordinate number</th>
<th>Actual measured units</th>
<th>Measurement for formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.5</td>
<td>0.75</td>
</tr>
<tr>
<td>1</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>2</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>3</td>
<td>5.65</td>
<td>5.65</td>
</tr>
<tr>
<td>4</td>
<td>5.65</td>
<td>2.83</td>
</tr>
<tr>
<td>Sum</td>
<td>19.53</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{TOTAL AREA} = \sum \times \text{Ordinate spacing} \times 2 = 43.9 \text{ units}^2
\]

### Fish hold, mid section area

<table>
<thead>
<tr>
<th>Ordinate number</th>
<th>Actual measured units</th>
<th>Measurement for formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.7</td>
<td>2.35</td>
</tr>
<tr>
<td>1</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>2</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Sum</td>
<td>18.8</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{TOTAL AREA} = \sum \times \text{Ordinate spacing} \times 2 = 37.6 \text{ units}^2 \text{ at mid section of hold}
\]

### Fish hold, aft bulkhead area

<table>
<thead>
<tr>
<th>Ordinate number</th>
<th>Actual measured units</th>
<th>Measurement for formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>3.75</td>
<td>3.75</td>
</tr>
<tr>
<td>2</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>2.25</td>
</tr>
<tr>
<td>Sum</td>
<td>10.55</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{TOTAL AREA} = \sum \times \text{Ordinate spacing} \times 2 = 21.1 \text{ units}^2 \text{ at aft bulkhead of hold}
\]

Having obtained areas for the three sections, they must be processed to obtain a volumetric figure for the hold. In this case, the three section areas are simply added together and then divided by three, which is the number of sections, to give an average area. If there were more sections used, the number would be adjusted.
FIGURE 7.8
Measurements for trapezoidal rule

Notes:
In this case the vertical divisions are equally divided into four. Other divisions are possible, provided they are all of equal size.
Also note that the deck camber is not counted. This is in most cases negligible for calculations.
Calculations and examples for insulated containers and fish holds

accordingly. The resulting figure in units² is then simply multiplied by the length of the fish hold to give the volume.

\[
\text{Area of forward bulkhead} = 43.9 \\
\text{Area of mid hold section} = 37.6 \\
\text{Area of aft bulkhead} = 21.1 \\
\]

\[
\frac{(43.9 + 37.6 + 21.1)}{3} \times 15 = \frac{102.6}{3} \times 15 \\
\text{Hold volume} = 513 \text{ units}^3
\]

To obtain more precise figures it is necessary to increase the number of cross-sections measured in the fish hold. For most applications in small fishing vessels, it is thought that three sections are generally sufficient for a reasonably accurate volume calculation.

7.3.3 Multiplier factor for hold volume

Another less accurate method to estimate fish hold volumes, which works fairly well with fish holds of normal form, is the use of a multiplier factor applied to a volume that is obtained by measuring the depth and width of the hold at the longitudinal centre and multiplying by length. The volume figure obtained is a box, not a true representation of the actual volume. The multiplier factor is then applied to the box volume. This factor can vary from 0.70 to 0.95 depending on the curve of the section. Sharply turned bilges would use the higher factor, while a fairly slack bilge curve would use lower figures. This is not a hard and fast formula and requires good judgement by the person making the measurements. As the user becomes familiar with the method, it will become more accurate.

Using the set of figures from the mid-section in the trapezoidal rule example above, the following box volume will be obtained:

\[
\text{Half beam} \times \text{depth} \times 2 = 4.7 \times 5 \times 2 = 47 \text{ units}^2
\]

\[
\text{Length of hold} \times 47 = 15 \times 47 = 705 \text{ units}^3
\]

Noting that the sections in that example have a fairly slack turn to the bilge, a multiplier factor of 0.75 is chosen:

\[
\text{Volume} = 705 \times 0.75 = 528.75 \text{ units}^3
\]

Comparing this figure (529) with the original calculation of (513) gives an error of 3 percent on the high side. If a factor of 0.8 were used, the error would still be within a margin of 10 percent, which for initial rough estimates is acceptable.

7.4 LOSSES OF FISH HOLD VOLUME ON INSTALLING INSULATION

It may be necessary to calculate the losses in volume that will occur when insulation is added to the inside of a fish hold. To do this it is necessary to measure
the total surface area of the existing hold and multiply it by the thickness of the insulation material.

As an example, assume that a vessel fish hold has a measured surface area of 40 m² and a known volume of 14 m³ and is to be retrofitted with 100 mm of styrofoam insulation. What is the volume loss that can be expected?

\[
\text{Volume} = \text{Area} \times \text{Thickness of insulation} \\
= 40 \text{ m}^2 \times 0.1 \text{ m} \\
= 4 \text{ m}^3
\]

This is almost a third of the available fish hold volume. If loss of volume is a major problem, the possibility of using a better insulating material with higher R-value should be investigated. This would allow thinner insulation to be installed giving the same insulating value and reducing loss of volume in the hold. Alternatively, thinner insulation may be appropriate, while recognizing that more ice may be needed during storage to compensate for increased heat penetration.

7.5 FISH HOLD VOLUME LOSSES WITH PENBOARDS, SHELVING AND/OR BOXES

Some loss of usable stowage space is unavoidable when penboards and shelving are installed in a fish hold, 10–15 percent of total volume being a reasonable estimate. It would be anticipated that any loss of earnings from this volume of fish would be made up for by better market prices for improved quality of catch. There are also losses in weight due to crushing of fish on the bottom layers if fish is stacked more than 600 mm high. These losses may amount to 15 percent.

Obviously there is a balance point in the extra space taken up by more shelving, the extra labour needed to ice fish on more shelves and the better quality that can be expected from fish stacked in heights of less than 600 mm, and loss of quality and weight from crushing in bulk pens.

For wet fish cooled with ice, gutted and bled boxed fish give the optimum quality. It is difficult to improve the quality further without spending fairly large sums of money on refrigeration or CSW.

Boxing of fish requires more stowage space than bulk on ice – around 40 percent more – but the gains in quality and ease of discharge at the dockside generally more than compensate for this loss, at least on bigger vessels.


Annex
Form templates for monitoring hold temperatures and calibration of thermometers

Checklist No. 1: Log book for monitoring temperatures in the fish hold

<table>
<thead>
<tr>
<th>Date</th>
<th>Temperature of location</th>
<th>Temperature of fish</th>
<th>Time</th>
<th>Temperature of location</th>
<th>Temperature of fish</th>
<th>Time</th>
<th>Temperature of location</th>
<th>Temperature of fish</th>
<th>Time</th>
</tr>
</thead>
<tbody>
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</table>

Corrective action taken: ..........................................................................................................................................................................
........................................................................................................................................................................................................
........................................................................................................................................................................................................

Fishing vessel: ...........................................................................
Prepared by: .............................................................................
Trip length: ................................................................................
Verified by: ................................................................................

Explanatory note

Daily temperature checking of fish and various locations in the fish hold will enable the crew to detect hot spots in the fish hold. Adequate sensitive thermometers should be used and placed in several locations in the fish hold to monitor temperature changes. Areas of increasing temperatures should be found and corrective action taken to maintain fish quality. Adequate temperatures of fish and fish hold should be between 0 °C and 1.1 °C (32 °F to 34 °F).
### Checklist No. 2: Log book for calibration of thermometers used in the fish hold

<table>
<thead>
<tr>
<th>Date of calibration</th>
<th>Description of equipment</th>
<th>Recorded temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**Corrective action taken:**

..........................................................................................................................................................
..........................................................................................................................................................
..........................................................................................................................................................
..........................................................................................................................................................

**Fishing vessel:** .................................................................

**Prepared by:** .................................................................

**Verified by:** .................................................................

---

**Explanatory note**

Thermometers used to check fish temperatures should be calibrated against a mercury in glass (MIG) thermometer that is in accordance with national regulations, once per month by qualified personnel on board the fishing vessel and recorded in the above calibration log book.