

The use of ice on small fishing vessels



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by
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and
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PREPARATION OF THIS DOCUMENT

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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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 1.1
Advantages and disadvantages of chilling and freezing

Chilling	Freezing
Short-term storage (up to one month maximum for some species, only a few days for others)	Long-term storage (a year or more for some species)
Storage temperature 0 °C	Storage temperature well below zero, e.g. -30 °C
Relatively cheap	Relatively costly
Product resembles fresh fish	If poorly done can badly affect quality
Relatively low-tech	Relatively high tech
Low skills required	High skills required
Portable refrigeration	Generally static operations

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.

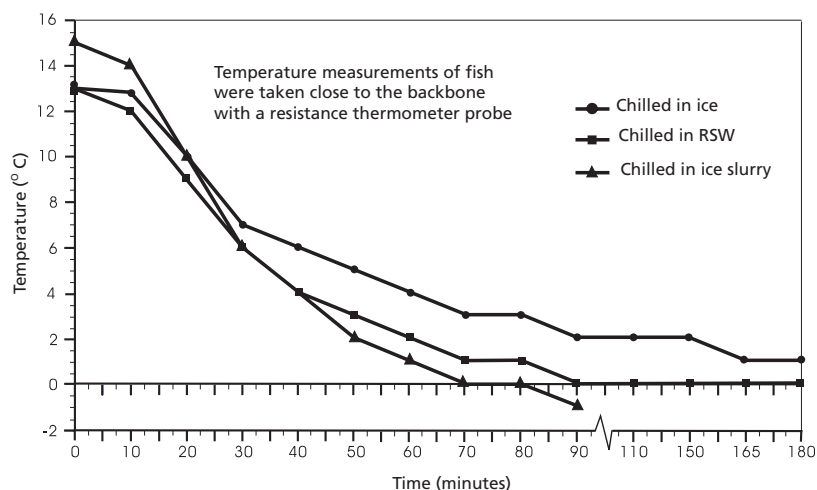
However, packing fish in ice on board small fishing vessels, whether in boxes, shelves or pounds, is a labour-intensive task and other methods have been introduced to reduce the time and labour required. Among these, the most widely used are RSW and CSW. RSW is labour saving and an acceptable chilling 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);

FIGURE 1.1
Comparison of temperature profiles for whole fish (1.6 kg/piece) chilled in crushed ice, RSW and ice slurry



- adequate contact of ice with the fish;
- the size of the ice particles.

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:

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

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 1.2
Intrinsic factors affecting the spoilage rate of chilled fish

Intrinsic factors	Relative spoilage rate of fish stored in ice	
	Slow rate	Fast rate
Shape	Flat fish	Round fish
Size	Large fish	Small fish
Fat content in the flesh	Lean species	Fatty species
Skin characteristics	Thick skin	Thin skin

Source: FAO, 1995a.

TABLE 1.3
The four phases of fish spoilage

Phase I (Autolytic changes, caused mainly by enzymes)	Fish just caught is very fresh and has a sweet, seaweedy 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.
Phase II (Autolytic changes, caused mainly by enzymes)	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.
Phase III (Bacteriological changes, caused mainly by bacteria)	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.
Phase IV (Bacteriological changes, caused mainly by bacteria)	Fish is spoiled and putrid, becoming inedible.

TABLE 1.4
Shelf-life of some marine and freshwater fish species stored in ice

Species	Shelf-life (days in ice)		Remarks
	Temperate waters	Tropical waters	
Marine species	2–24	6–35	Shelf-life for tropical fish tends to be longer.
Cod, Haddock	9–15		White-fleshed lean
Whiting	7–9		White-fleshed lean
Hake	7–15		White-fleshed lean
Bream		10–31	Lean/low fat
Croaker		8–22	Lean
Snapper		10–28	Lean
Grouper		6–28	Lean
Catfish		16–19	Lean
Pandora		8–21	Lean
Jobfish		16–35	Lean
Spadefish		21–26	Lean/low fat
Batfish		21–24	Lean
Sole, Plaice	7–21	21	Flat fish
Flounder	7–18		Flat fish
Halibut	21–24		Flat fish
Mackerel ¹	4–19	14–18	Pelagic fish; high/low fat
Summer herring	2–6		Pelagic fish; high fat
Winter herring	7–12		Pelagic fish; low fat
Sardine	3–8	9–16	Pelagic fish; high fat
Freshwater species	9–17	6–40	Shelf-life for tropical fish tends to be longer.
Catfish	12–13	15–27	Lean
Trout	9–11	16–24	Low fat
Perch	8–17	13–32	Lean/low fat
Tilapia		10–27	Lean
Mullet		12–26	Lean
Carp		16–21	Lean/low fat
Lungfish		11–25	Lean/low fat
Shad		25	Medium fat
Corvina		30	Medium fat
Pacu		40	Fatty
Bagre (type of catfish)		25	Medium fat
Chincuna		40	Fatty

¹ Fat content and shelf-life are subject to seasonal variations.

Source: FAO, 1995a.

TABLE 1.5
Comparison of shelf-life of various fish species stored in ice, RSW and RSW with added CO₂

Species	Shelf-life (days in the chilling medium)			Storage temperature in RSW (°C)
	Ice (0 °C)	RSW	RSW + CO ₂	
Pacific cod	6–9	-	9–12	–1.1
Pink shrimp	-	4–5	6	–1.1
Herring	-	8–8.5	10	–1.0
Walleye pollock	6–8	4–6	6–8	–1.0
Rockfish	-	7–10	>17	–0.6
Chum salmon	-	7–11	>18	–0.6
Silver hake	4–5	4–5	>5	0 to 1
Capelin	6	2	2	+0.2 to –1.5

Source: FAO, 1995a.

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.

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°C to -20°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°C to -2°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.

TABLE 2.1

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

Capacity ¹ (kg of ice/24 h)	Cooling requirements (kcal/h)	Refrigerant	Remarks
550	4 000	R-22	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 m ³ .
1 350	7 100	R-22	As above. It is estimated that a one-day ice production will require a refrigerated storage space of about 3.05 m ³ .
1 950	11 000	R-22	As above. It is estimated that a one-day ice production will require a refrigerated storage space of about 4.4 m ³ .
4 500	21 434	R-22, or any ozone- friendly refrigerant	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 m ³ .
8 000	36 290	As above	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.
10 000	45 363	As above	As above
12 000	54 435	As above	As above

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 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.

- 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

TABLE 2.2

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

Type of machine	Capacity (tons US & kg/24 h)	Depth (mm)	Width (mm)	Height (mm)	Weight (kg)
Flake ice "Coldisc" front discharge	1.0 t 909 kg	660	520	510	45 machine only
Flake ice, drum type	1.0–2.5 t 909–2 272 kg	965	635	1 118	250
Flake ice, drum type	6.0 t 4 272 kg	1 219	813	1 143	614
Shell ice, tube type, hot gas cycle	¹ 1.5 t 1 363 kg	1 372	762	1 555	771
Shell ice, tube type, hot gas cycle	¹ 3.0 t 2 727 kg	2 444	762	1 555	1 315
Slush ice	³ 3.3 t 3 000 kg	1 000	650	800	260
Slush ice	² 3.5 t 3 181 kg	630	580	1 700	390
Slush ice	⁵ 5.5 t 4 992 kg	1 000	800	1 900	500
Slush ice	⁷ 7.0 t 6 363 kg	660	1 010	1 700	800

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.

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;

- 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.

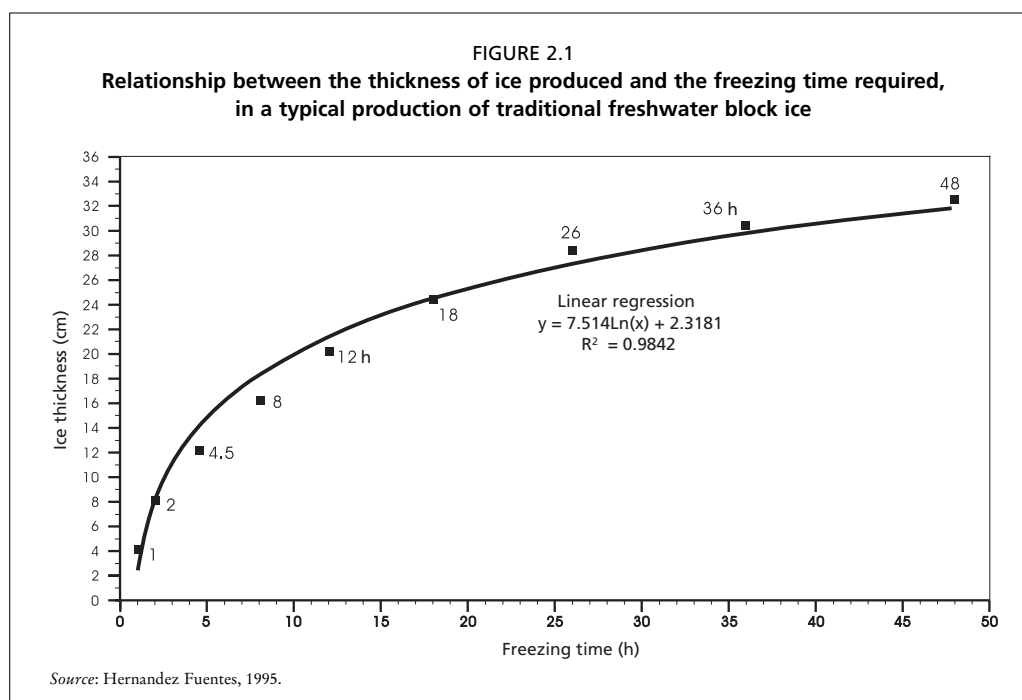
TABLE 2.3
Typical characteristics of containerized block ice plants

Ice capacity ¹ (kg/24 h)	Ice storage capacity (kg)	Space requirements (m ²)
3 000	6 000	30 (for the container)
5 000	5 000	30 (for the container)
7 500	3 000	30 (for the container)
10 000	none	30 (for the container)

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



and the relatively easy operations for starting and stopping, which take a short time in comparison with the traditional block ice-makers. However, rapid block ice plants are generally more expensive to purchase, run and maintain than conventional block ice plants and their use in the fishing industry is limited.

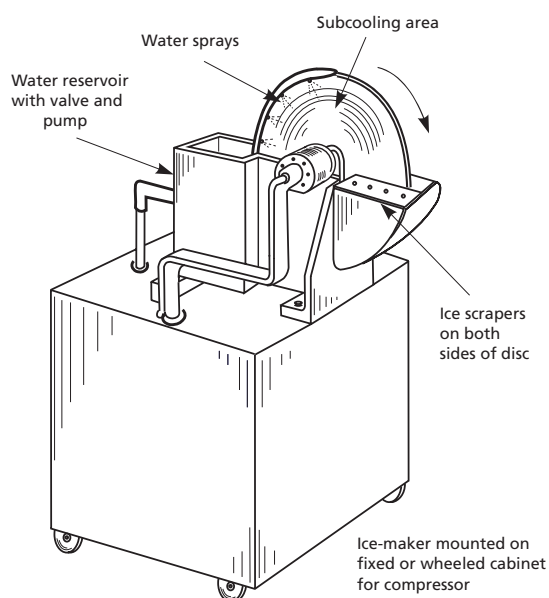
2.2.3 Flake ice

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.

FIGURE 2.2
Coldisc ice machine



This is a very compact unit producing about 1 tonne of ice (909 kg/2 004 lb) in 24 h at feedwater temperature of 60 °F (15.5 °C). Manufacturers give correction figures of 6 percent per each 10 °F (5.5 °C) rise in temperature of feedwater, so at 70 °F (21 °C) the production would drop by 6 percent or 54.5 kg to 854 kg in 24 h. Higher temperatures will cause corresponding drops in output. With high feedwater temperatures a pre-chiller unit is recommended.

Source: North Star Ice Equipment Corp., Seattle, Washington, USA.

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

TABLE 2.4
Typical characteristics of some flake ice-makers

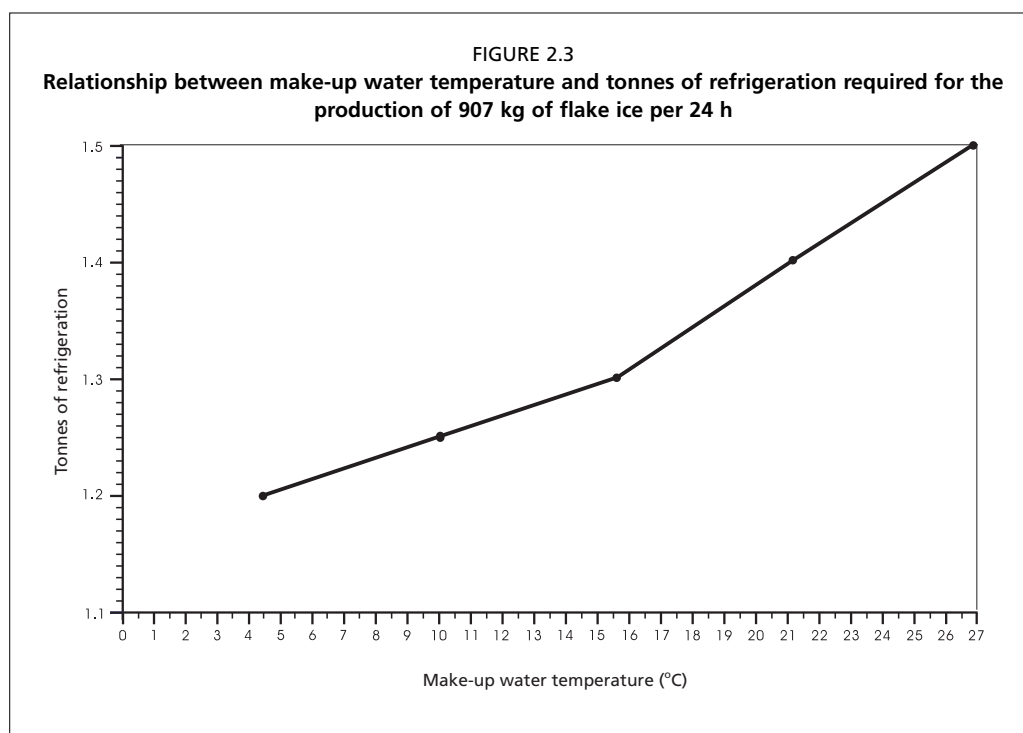
Ice capacity ¹ (kg/24 h)	Cooling requirements (kcal/h)	Refrigerant	Remarks
1 000	4 760	R-22 or any suitable ozone- friendly refrigerant	Water supply: 42 litres per hour at 16 °C and –23 °C evaporator temperature. Ice thickness: 1.5 mm. Size of the unit without ice storage: H (510 mm) × W (520 mm) × L (660 mm). Unit weight: 45 kg. (Disc unit)
2 250	10 590	As above	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
4 500	21 434	As above	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
9 000	42 867	As above	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

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).

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.



- 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.

TABLE 2.5
Typical technical features of containerized flake/chip ice plants

Standard containerized flake/chip ice plants			
Ice capacity (kg/24 h)	Ice storage capacity	Container	Remarks
3 000	13 m ³ / 5 000 kg	20 ft	Space requirements: 15.74 m ² . 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
5 000	13 m ³ / 5 000 kg	20 ft	Space requirements: 15.74 m ² . 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
10 000	13 m ³ / 5 000 kg	20 ft	Space requirements: 15.74 m ² . 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
5 000	37 m ³ / 15 000 kg	40 ft	Space requirements: 30 m ² . 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
7 500	37 m ³ / 15 000 kg	40 ft	Space requirements: 30 m ² . 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
10 000	37 m ³ / 15 000 kg	40 ft	Space requirements: 30 m ² . 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
3 000	20 m ³ / 8 000 kg	15 m ³	Type of container: 40 ft. Space requirements: 30 m ² . 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
5 000	20 m ³ / 8 000 kg	15 m ³	Type of container: 40 ft. Space requirements: 30 m ² . 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
10 000	20 m ³ / 8 000 kg	15 m ³	Type of container: 40 ft. Space requirements: 30 m ² . 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

2.2.4 Compacted blocks of small ice

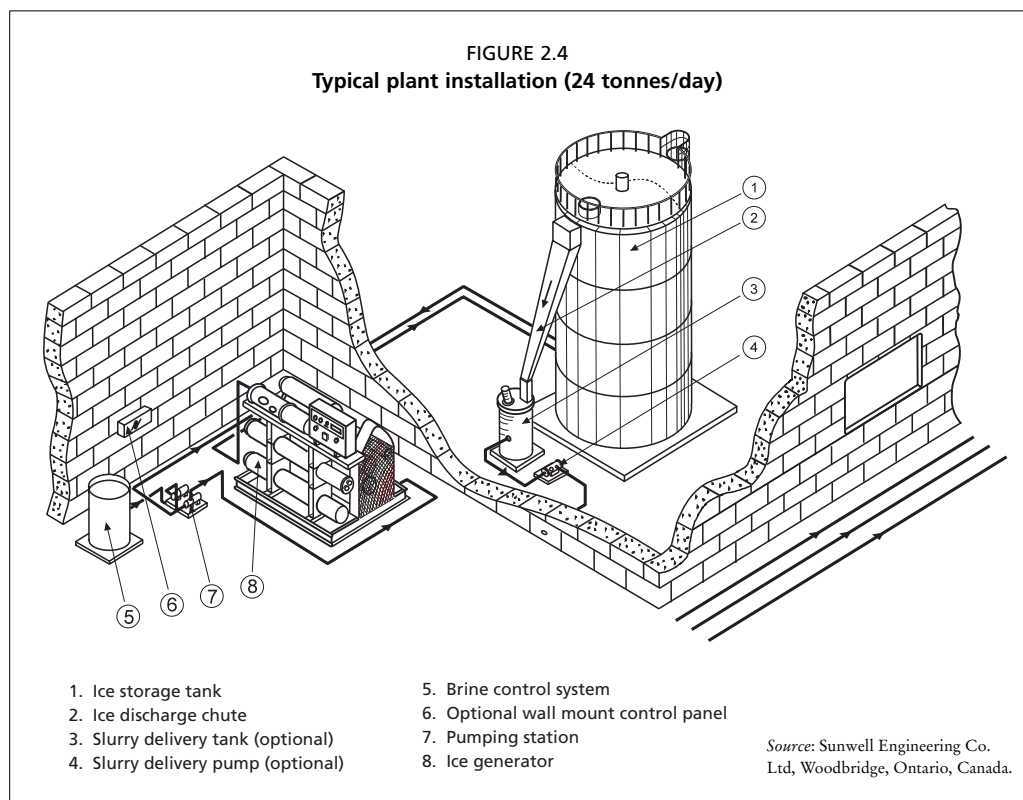
When there is a need for ice supplies to be transported over long distances, or there are preferences in certain fisheries for block ice, it is feasible to produce blocks from small or flake ice using block-compacting machines. These machines press small ice (flake or chip ice) into blocks of standard 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.

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):



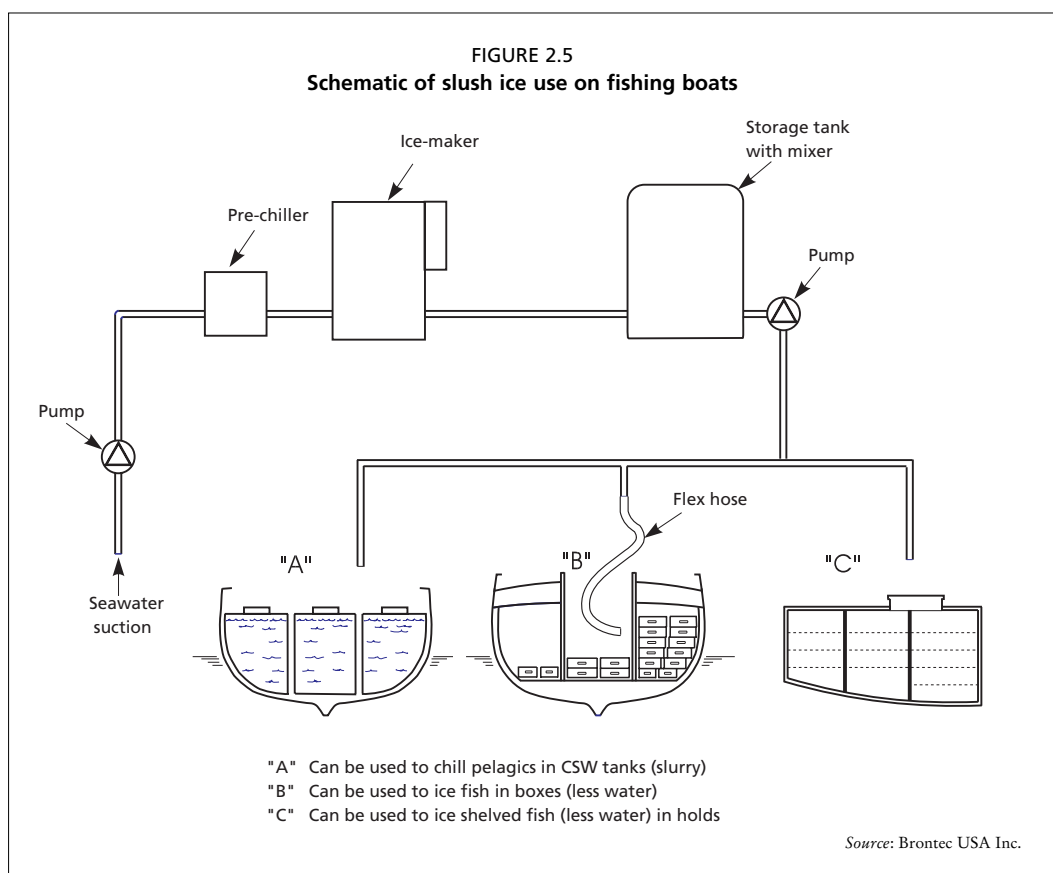
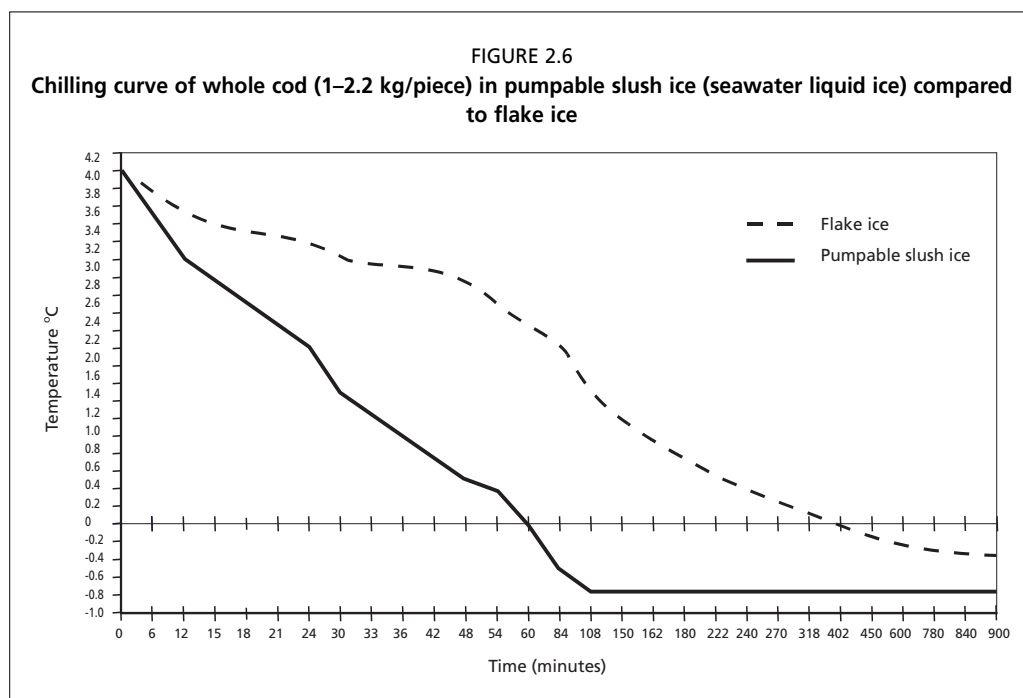


TABLE 2.6
Typical specifications for a twin-tube slush ice-maker

Capacity (kg/24 h)	Power requirements	Remarks
5 000, based on feed water at 10 °C and 3% NaCl concentration	220 volts, AC, 3 phases, 50/60 Hz; 9.6 kW	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

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.

- 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.



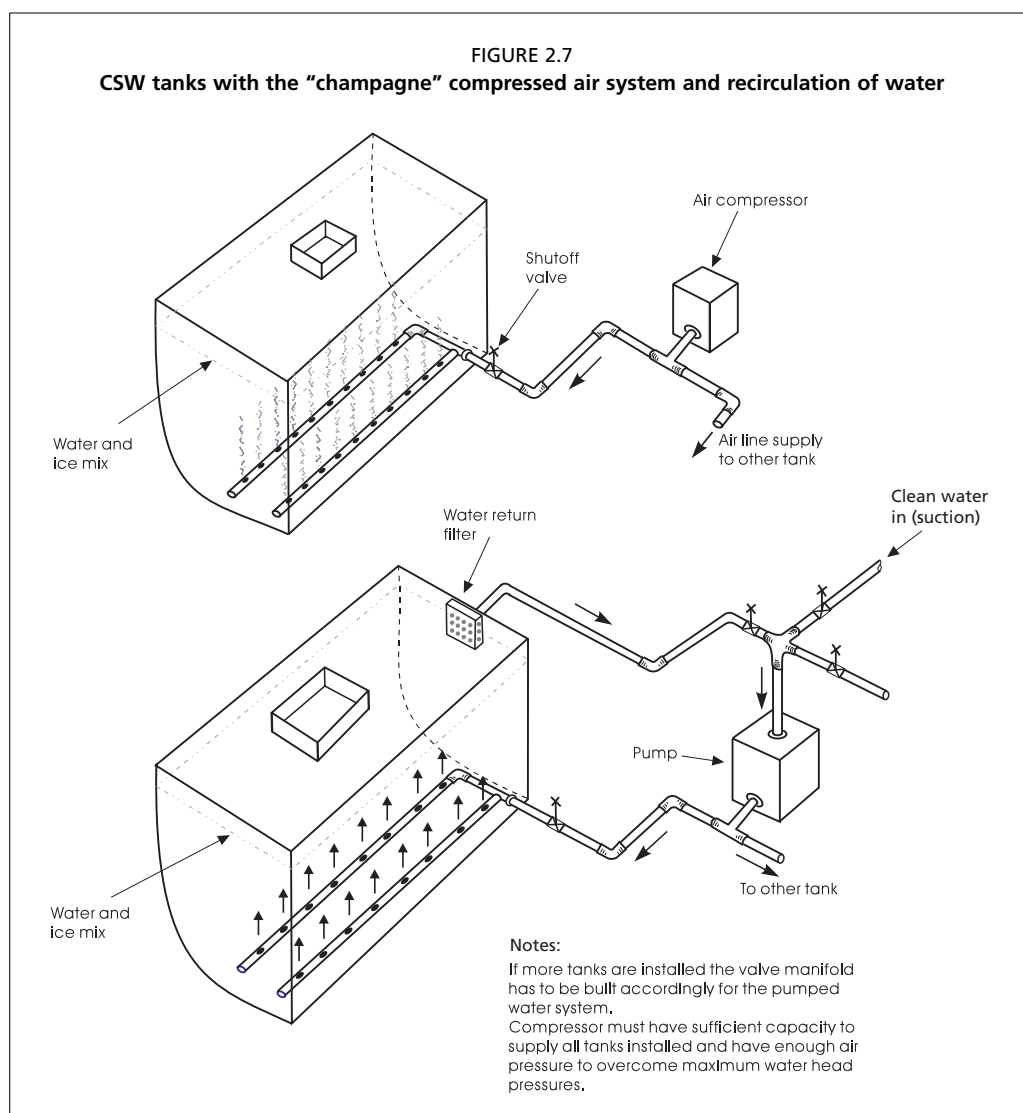
Since the “raw material” for ice production is a brine solution (3–5 percent NaCl), seawater can be used for slush ice manufacture. This allows units to be installed on board fishing vessels. The commercial application of slush ice on board industrial purse seiners has been tested for chilling small 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

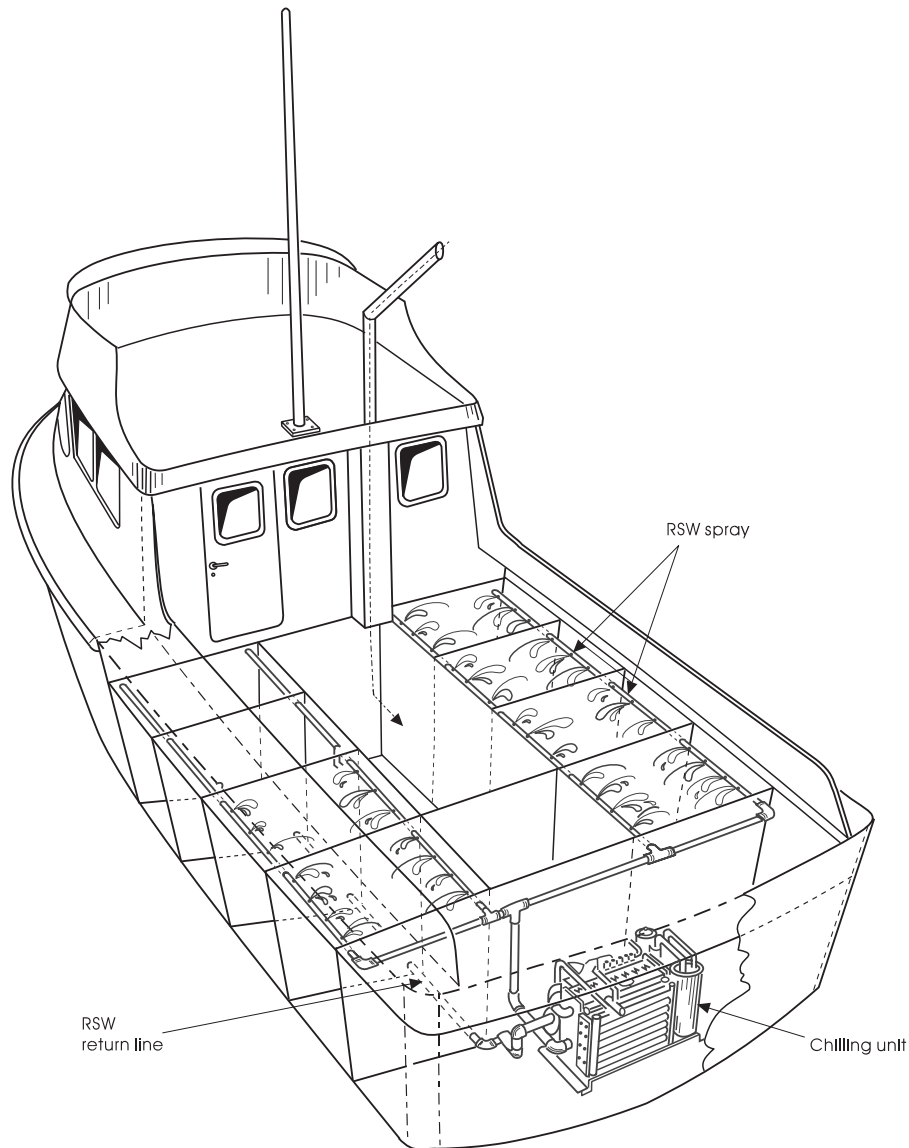


of the RSW in the tanks or holds. In normal practice this system requires a dedicated power plant, such as a diesel or diesel electric generator, providing direct power or electricity to operate the electric motors for refrigeration compressors and circulation pumps, depending on the type of drive motors used.

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

FIGURE 2.8
RSW spray system



Source: Integrated Marine Systems Inc., Pt Townsend, WA, USA.

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)

TABLE 2.7

Montreal Protocol provisions regarding ozone-depleting chemicals

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

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

Chemical compound	Lifetime (years)	Ozone depletion potential
HFC: R-32 (CH ₂ F ₂)	6.7	0
HFC: R-125 (CF ₃ CF ₂ H)	26	0
HFC: R-134a (CF ₃ CFH ₂)	14	0
HCF: R-143a (CF ₃ CH ₃)	40	0
HCFC: R-22 (CHF ₂ Cl)	14	0.047
CFC: R-11 (CFCl ₃)	60	1
CFC: R-12 (CF ₂ Cl ₂)	105	0.95

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 2.9
Brief technical data of some refrigerants used in fisheries

Refrigerant	Evaporating pressure at −15 °C (lb/sq. in)	Condensing pressure at 30 °C (lb/sq. in)	Boiling point at 1.013 bar (°C)
R-12 (CCl ₂ F ₂)	11.8	93.2	−29.8
R-22 (CHClF ₂)	28.3	159.8	−40.8
R-717 (ammonia)	19.6	154.5	−33

- 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.

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.