Ice in fisheries

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PREPARATION OF THIS DOCUMENT

Ice in Fisheries was originally published in 1968 as FAO Fisheries Report 59. In the period since then it has been in great demand, particularly for training courses. This version has been extensively revised and updated by Messrs. J. Graham, W.A. Johnston and F.J. Nicholson, of the Torry Research Station, UK. It now incorporates the advances in technology made in the last twenty years and has been reissued in the FAO Fisheries Technical Paper series in order to reach an even wider audience.

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ABSTRACT

The paper covers all aspects of the use of ice for the chilling and storage of fish. Following a review of fish spoilage, the nature and properties of ice are described. Ice manufacturing and storage equipment are outlined from both technical and economic viewpoints. Chilling of fish on land and at sea, including the use of chilled sea water, is described in detail, and a series of calculations of ice requirements and losses in storage are given.

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1. Preservative effect of chilling

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Why fish go bad

As soon as a fish dies, spoilage begins. Spoilage is the result of a whole series of complicated changes brought about in the dead fish by its own enzymes, by chemical action and by bacteria. It is necessary to understand something of the way in which these changes take place in order to make the fullest use of chilling as a means of keeping them in check.

An important series of changes is brought about by the enzymes of the living fish which remain active after its death. They are particularly involved in the flavor changes that take place during the first few days of storage, before bacterial spoilage has become marked.

Millions of bacteria, many of them potential spoilers, are present in the surface slime, on the gills and in the intestines of the living fish. They do no harm because the natural resistance of a healthy fish keeps them at bay. Soon after the fish dies, however, bacteria begin to invade the tissues through the gills, along blood vessels, and directly through the skin and the lining of the belly cavity.

In addition to bacterial and enzymatic changes, chemical changes involving oxygen from the air and the fat in the flesh of species such as tuna and mackerel can produce rancid odours and flavours.

Thus, spoilage is a natural process once the fish dies, but chilling can slow down this process and prolong the shelf life of fish as food.

Effect of temperature on spoilage

There are three important ways of preventing fish going bad too quickly - care, cleanliness and cooling. Care in handling is essential because unnecessary damage can provide access through cuts and wounds for the spoilage bacteria, thus hastening their effect on the flesh. Cleanliness is important in two ways: (i) the natural sources of bacteria can largely be removed soon after the fish is captured by taking out the guts and washing off the slime from the surface of the fish; (ii) the chances of contamination can be kept to a minimum by ensuring the fish is always handled in a hygienic manner. But most important of all, the fish must be chilled quickly and kept chilled.

The speed with which bacteria grow depends on temperature. Indeed, temperature is the most important factor controlling the speed at which fish go bad. The higher the temperature, the faster the bacteria multiply, using the flesh of the dead fish as food. When the temperature is sufficiently low, bacterial action can be stopped altogether; frozen fish stored at a very low temperature, for example 30 C, will remain wholesome for a very long time because bacteria are either killed or completely inactive at this temperature, and other forms of spoilage progress only very slowly. But, even at -10°C, some kinds of bacteria can still grow, although only at a very slow rate. Therefore for long-term storage, of many weeks or months, freezing and cold storage are necessary.

It is not possible to keep unfrozen fish at a temperature low enough to stop bacterial action completely, because fish begin to freeze at about -1°C. However, it is desirable to keep the temperature of unfrozen fish as close to that level as possible in order to reduce spoilage; the easiest and best way of doing this is to use plenty of ice which, when made from clean fresh water, melts at 0°C.

At temperatures not much above that of melting ice, bacteria become much more active and fish consequently goes bad more quickly. For example, fish with a storage life of 15 days at 0°C will keep for 6 days at 5°C and only about 2 days at 15°C before becoming unacceptable.

The chemical changes that contribute to spoilage are also kept in check by reducing the temperature; therefore it cannot be too strongly emphasised that temperature is by far the most important factor governing the rate at which fish go bad.

How long will fish keep in ice?

Generally, all fish spoil in much the same way, with 4 distinct phases of spoilage. Cod, for instance, will keep in ice for about 15 days before becoming inedible, and this time can be divided roughly into successive periods of 0 to 6, 7 to 10, 11 to 14 and over 14 days. In phase 1 there is very little deterioration apart from some slight loss of natural or characteristic flavour and odour. In phase 2 there is a considerable loss of flavour and odour. In phase 3 the fish begin to taste stale, appearance and texture begin to show obvious signs of spoilage, and the gills and belly cavity have an unpleasant smell. All these changes, which in the latter stages of storage are almost entirely due to bacteria, occur at an ever increasing rate until the fifteenth day, when phase 4 begins, the fish are putrid and generally regarded as inedible.

Other species with different storage times may also have a different division between the respective phases but the spoilage pattern will be similar. Even fish of the same species may spoil differently since factors such as the method of capture, location of fishing grounds, season of the year, fat content and fish size can affect the keeping quality.

Most studies on the spoilage of fish are done under controlled conditions, therefore, the results are more specific than they would be in most commercial situations where conditions can be variable. Published data on storage life should therefore be used with discretion and in most cases assumed to represent maximum values.

Despite the above limitations, the storage life of fish has been well researched and documented and several broad conclusions have been drawn. In general, flat shaped fish keep longer than round shaped fish; red fleshed fish keep longer than white fleshed fish; low fat fish longer than high fat fish and teleost (bony) fish longer than elasmobranch (cartilaginous) fish.

There are many references in the literature to the extended storage life in ice of certain tropical fish species compared to fish from temperate or colder waters. While it is true that some fish from tropical waters can be kept for longer periods an extensive review of published literature showed that this was not universally the case. Table 1 shows storage life of various fish species. For further information on shelf life, reference should be made to the publication "Fresh fish quality and quality changes", FAO Fisheries Series No 29. The reasons for apparent anomalies, or exceptions, are still not fully understood. Another factor which makes comparisons difficult is that different criteria are used to define the limit of storage life and, since relatively few studies have been made on spoilage in ice of tropical fish, direct comparisons are not always possible.

Fig. 1 The effect of temperature on the spoilage of lean, temperate water fish

Table 1 Shelf life in ice (FAO Fisheries Series No 29)

Species	**Shelf life (days in ice)**
Temperate water	
Marine species	
white-fleshed lean	
(cod, haddock, hake)	11-13
flatfish (sole, plaice)	15-18
halibut	21
fatty fish	
summer herring (fatty)	2-4

winter herring (lean)	12
Freshwater sp.	
trout	9-10
Tropical water:	
Marine species	
Bahrain(3 species)	13-25
Ghana(5 species)	19-22
Brunei(3 species)	18-28
Sri Lanka (5 species)	20-26
Seychelles (8 species)	15-24
Mexico (6 species)	21-30
Hong Kong (2 species)	30-31
India (4 species)	7-12
Freshwater spp	
Pakistan (2 species)	23-27
Uganda (5 species)	20-25
East Africa (4 species)	15-28

In the absence of specific information on storage life, a simple storage experiment will serve to show

how long a species can be kept in ice. All the relevant conditions pertaining to the storage period should be met. But, if seasonal changes are likely, adjustments should be made as necessary, or further storage experiments should be carried out at the appropriate time or under simulated conditions.

Although the data are limited, it is generally accepted that the overall pattern of spoilage of freshwater fish in ice is similar to that of marine species, but their storage life tends to be longer.

Definition of storage life

A wide range of terms are used in discussing storage life, such as quality, acceptability, preference, keeping time, storage time, storage life, shelf life and potential shelf life; these terms are not interpreted uniformly.

The simplest definition of the end of shelf life, or storage life, is the point at which the produce is considered to have become inedible, i.e. it is spoilt! Even this simple definition is open to different interpretations since there is no common level of unacceptability, even within small communities let alone worldwide.

At the other end of the quality scale, the "high quality life" (HQL) can be regarded as the point at which the produce retains all its characteristic properties. The equivalent definition in the EEC Labelling Directive is "retains its specific properties" and, in CODEX and US Grade Standards, the cooked product is required to have "characteristic flavours and no off- flavours".

Although HQL is more easy to define and thereby more widely acceptable, in practical terms, it may have little significance with respect to the commercial value of the product. Some personal preferences for instance, may even favour produce which exhibits "non-characteristic off-flavours".

Assessment of quality can either be done by objective or sensory methods. Again, differences in methodology may give significantly variable results.

From long experience in fisheries inspection and research, it is possible to correlate objective and sensory methods but, it is not possible to include consumer preferences in such correlations, since the "end of good or acceptable quality" is not a standard criterion which can be universally applied. Therefore, fish quality standards have to be matched to market requirements rather than absolute standards. Tables of storage lives should therefore be interpreted with caution and related to the situation and conditions which prevail for individual products.

A good deal of attention is given to TTT (time, temperature, tolerance) when compiling storage life tables but the PPP (product, processing and packaging) factors can be equally important. Thus, tables which do not specify all of these relevant conditions should be used only as a rough guide.

In summary, tables of storage lives should be used only to give rough guidance; more accurate information can be achieved by experimentation or experience when all the prevailing factors are taken into account.

Calculation of storage times

It is generally accepted that bacterial spoilage is the major reason for non-sterile unfrozen fish becoming unacceptable to the consumer. As the spoilage flora proliferates the fish become progressively spoiled.

For many years a general rule was applied, that bacterial growth, and hence spoilage rate, doubled for every 5°C rise in temperature; this can still be used as a rough guide in making comparisons. For instance, fish which have a storage life of 14 days at 0 C will have a storage life of only 7 days at 5°C. Closer studies of the effect of temperature on spoilage have been made, and it has been demonstrated that the square root of the growth rate of bacterial cultures is a linear function of temperature over a significant range up to about 1 5°C. This relationship is expressed mathematically by the following equation:

$R = b (T - T_c)$ (1)
where R = rate of growth per unit time
b = slope of the regression line
T = absolute temperature at which growth is measured
T_c = conceptual temperature (k).
Mathematically T_c is the value of T when $R = 0$.

The minimum temperature at which chilled fish is normally stored is close to 0 C. Therefore, it is convenient to simplify equation (1) and re-define the growth rate r as the rate relative to that at 0°C. By manipulating the expression in equation (1) we get

$r = 0.1t + 1$ (2)
where r = rate of spoilage relative to the rate at 0°C
t = temperature of storage (°C)

This can then be rearranged to give: $r = (0.1t + 1)2$ (3)

Using equation (3) the spoilage rate at any temperature relative to the spoilage rate at 0°C can now be calculated. For example, the spoilage rate at 5°C will be:

$r = [(0.1x5) + 1]2 = 2.25$

This means that fish maintained at 5°C will spoil at a rate which is 2.25 times quicker than the rate at 0°C, or expressed in another way, one day storage at 5°C is equivalent to 2.25 days storage at 0°C. This differs slightly from the factor of 2 derived using the "doubling rule". A similar calculation for a 1 0°C storage temperature shows that the spoilage rate is increased by a factor of 4.

Using the relationship expressed in equation (3) and making the appropriate calculations, it is possible to predict the likely storage life of fish which have been maintained for some time at temperatures higher than the ideal 0°C. For example, if fish with a normal storage life of 15 days at 0°C are held initially at 10°C for one day, and 5°C for 2 days before being reduced to 0°C for the rest of the storage time, the likely shelf life can be calculated as follows:

1 day at 1 0°C is equivalent to 4 days at 0°C
2 days at 5°C is equivalent to 2x2.25 = 4.5 days at 0°C

The equivalent storage time at 0°C of the 3 days spent at the higher temperatures is therefore 4+ 4.5 = 8.5 days. This means that 8.5 - 3.0 = 5.5 days of the potential storage time of the fish, if they were maintained at 0°C, have been lost and the total storage time is thereby reduced from 15 to 9.5 days.

The above is a simplified example used to illustrate the significant losses in potential storage life if fish are kept at higher temperatures even for short periods. In reality, the temperature history of the fish is likely to be more complicated and, in order to work out equivalent storage times, calculations will need to be made using smaller time intervals. If the facilities are available, this calculation can be done using a computer to give storage life predictions under a wide variety of conditions.

Thus, simple integration of time and temperature functions can provide a useful indication of spoilage, provided that the storage life data at some specific temperature are available, preferably, but not necessarily at 0°C.

Instruments have also been developed to continually monitor fish temperature and perform the time-temperature integration function; one model displays the number of days of potential storage life remaining at 0°C. Time-temperature growth characteristics of spoilage bacteria vary, depending on, for instance, whether they are mainly psychrotrophic, as would be the case in temperate waters, or mesophilic, in tropical waters. Time-temperature integration instruments therefore need to be programmed for the particular fish species and situation under consideration.

Why cool fish with ice?

Ice as a cooling medium for fish has a great deal in its favour; it has a very large cooling capacity for a given weight or volume, it is harmless, portable and relatively cheap. It is especially valuable for chilling fish, since rapid cooling is possible. When fish are being cooled with ice, heat transfer is achieved by direct contact with the ice, by conduction through adjacent fish and by melt-water flowing over the fish. Cold melt-water takes up heat from the fish and when it flows over ice again it is recooled. Thus, intimate mixing of fish and ice not only reduces the thickness of the layer of fish to be cooled but also promotes this convective cooling interaction between ice melt-water and fish.

As soon as ice is put on warm fish, heat flows from the fish to the ice and melts it. Heat keeps on flowing until there is no difference in temperature between the fish and ice, provided sufficient ice is present. Any further melting that occurs is due to heat from other sources, such as the warm surrounding air during the subsequent storage period.

Ice is its own thermostat and, since fish are mainly water, ice maintains fish at a temperature just slightly above the point at which they would begin to freeze; the point of equilibrium for sea fish, iced soon after catching, is near to -0.5°C, since the mixture usually includes some salt and blood.

Why not use other methods of cooling?

There are other ways of chilling fish besides using ice. For example, they can be immersed in chilled water or cold air can be blown over them. Sea water, cooled by mechanical means, Refrigerated Sea Water (RSW) or by the addition of ice, Chilled Sea Water (CSW), is a suitable alternative means of rapidly chilling large quantities of small whole fish, especially on board a fishing vessel: the use of RSW and CSW is discussed in detail in chapter 7. The use of cold air is less satisfactory, except for some applications relating to prepackaged fish which are also discussed in Chapter 7.

When cold air alone is used, as in a chillroom, the heat taken from the fish will rapidly warm the air. The warm air rises and is cooled by contact with the coils of the cooler and then moves by natural convection or fan circulation back to the fish. It does not take much heat to warm the air; it takes 10,000 times as much heat to melt a given volume of crushed ice as it does to warm the same volume of air from 0 to 0.5 C. Thus, it is important to remember that for air cooling to be effective, a good circulation of cold air must be blown over the fish. However, even when a fan is fitted in a chillroom it is difficult to achieve the rapid cooling rates possible with ice and chilled sea water (Fig. 2).

Another disadvantage of air chilling is that, without the use of ice, the fish becomes dry. Continuous air movement evaporates water from the fish surface and deposits it as frost or condensate on the coils of the evaporator. In addition, the air in some parts of the chillroom will be colder than in others. Fish in the cold spots, for example close to the evaporator, may in time become partially frozen, even though the thermostat is set above freezing point at another location within the chillroom. Slow freezing of the fish can be detrimental, since appearance, flavour and texture of the fish may be affected.

Fig 2 Fish in chillrooms still need ice

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2. Nature and properties of ice

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In order to understand why ice is so useful for chilling fish, it is first necessary to consider the nature and properties of ice, as well as to understand the simple principles and technical terms detailed in chapters 11 and 12.

Fig. 3 Ice melts at 0°C

When water freezes at a temperature of 0°C it experiences a phase change from a liquid to a solid, familiar to all as ice. A quantity of heat has to be removed from the water to turn it into ice, and the same amount of heat has to be added to melt it again. The temperature of a mixture of water and ice will not rise above 0°C until all the ice has melted (Fig 3). A given amount of ice always requires the same amount of heat to melt it; 1 kg of ice needs 80 kcal to change it into water, thus the latent heat of fusion of ice is 80 kcal/kg (Fig 4). This amount of heat is always the same for ice made from pure water, and is very little different for ice made from fresh water from almost any commercial source. Ice needs a large amount of heat to melt - it has a large reserve of "cold" - and this is one reason why it is widely used in the fishing industry as a means of chilling fish.

Fig. 4 The quantity of heat needed to melt ice

Ice is ice is ice!

There is often argument about whether ice made at one port is better than another, whether natural ice is better than artificial ice, freshwater ice is better than seawater ice, or new ice is better than old ice. In addition there are arguments about the merits of the type of ice, crushed, flake, tube, slush and so on.

The differences between freshwater ices of different origin are so small, that they are of no significance to those using ice for chilling fish. Ice made from tap water has the same cooling power as ice made from distilled water, and ice three months old is as effective as newly-made ice.

There is, however, one very important thing to remember; if some of the ice has turned to water, much of its value will have been lost, and a slushy mixture of ice and water should never be compared with an equal weight of ice alone. Remember too, that comparisons between different types of ice should be made between equal weight; what may appear to be the same amount of ice may be an equal volume, but 1 m^3 of flake ice, for instance, has far less cooling capacity than say 1 m^3 of crushed block ice (Fig. 5).

Within limits, when ice is intimately mixed with fish, the size of particle in any one type of ice makes little difference to either the rate at which it melts or the speed at which it chills. If block ice is used in the form of larger lumps, cooling times are likely to be longer due to the poor contact between fish and ice. Ice which has different shaped pieces due to the method of manufacture can also have somewhat different characteristics. Differences in the properties of crushed block ice are discussed later.

Ice made from hard water has the same cooling properties as ice made from soft water, although particles of ice made from hard water sometimes tend to stick together more during melting than pieces made from soft water.

Fig. 5 Equal weights of ice give equal cooling

Seawater ice

The effectiveness of seawater ice, in comparison with freshwater ice, is a little more in dispute. Depending on the method of manufacture, seawater ice may be less homogeneous than freshwater ice when newly made. Brine will also leach out of seawater ice during storage, so that the ice does not have a precisely fixed melting point. For this reason, fish kept in seawater ice may sometimes be at too low a temperature and become partially frozen, or the fish may possibly take up some salt from the ice.

However, where the choice is between not enough ice and plenty of seawater ice, then there is little doubt that seawater ice can, and should, be used for chilling fish that would otherwise spoil more quickly. Manufacture of seawater ice is of particular advantage on board ship for augmenting port supplies on a long voyage, or in coastal communities where fresh water is so scarce and expensive that to make ice from it would be prohibitive. It is important to remember, however, that seawater for making ice must be uncontaminated; all too often the quality of coastal or harbour water makes it unsafe for use with food.

To sum up, equal weights of ice, not equal volumes, have equal cooling capacity, no matter what the source. No single type of ice is significantly better than another when it comes to the amount required to chill a box of fish.

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3. Quantity of ice required

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It is possible to calculate the ice requirement if the operational conditions are known. These conditions are often variable and unrepetitive. Only a series of tests, under operational conditions, will establish the correct fish to ice ratio to be used to cool the fish and maintain chilled temperatures during the entire storage period.

Calculated values of ice usage can provide valuable information at the planning and design stages, and also promote a better understanding of the relative effect of the various elements which influence the rate of ice meltage. In addition, by considering all possibilities and calculating ice requirements, a more rational judgement can be made when selecting equipment and procedures to be used.

To determine the ice requirement, it is necessary to calculate the quantity of ice to cool the fish and also the quantity of ice required to maintain the fish at a chill temperature throughout the storage period. In addition, allowance has to be made to allow for losses and other contingencies in order to determine the ice manufacturing requirement.

Calculation of the ice requirement for cooling fish

The mass of ice needed to cool fish from the initial temperature to the final holding temperature can be calculated from an expression, which equates the heat taken up by the ice, on the left side of the equation, with the heat lost by the fish, on the right side of the equation.

$(Mi)\ (Li) = (Mf)\ (Cpf)\ (ts-tc)$ (4)
Where
Mi= mass of ice which melts (kg)
Li= latent heat of fusion of ice (80 kcal/kg)
Mf= mass of fish (kg)
Cpf= specific heat of fish (kcal/kg°C)
ts= initial temperature of fish (°C)
tc= final temperature of fish (0°C)

From equation (4) the ice requirement will therefore be:

$$Mi = \frac{(Mf)(Cpf)(ts - tc)}{(Li)} \qquad (5)$$

The specific heat of lean fish is approximately 0.8 kcal/kg C and this value should be used if there is a species mix or if there is a possibility that at times all the fish are of a lean species. The specific heat value, however, may be refined to take account of variations in the oil content of the fish and this refined value may be used if the fish composition is reasonably consistent.

Cpf = 0.5 XI + 0.3 Xs + 1.0 xw (6)

Where
Cpf = specific heat of fish (kcal/kg)
Xl = mass fraction of lipids (oil)
Xs = mass fraction of solids
Xw = mass fraction of water

To illustrate the effect of oil content on the quantity of ice required for chilling the following comparison is made between lean and fatty fish. Example (1) - 100 kg lean fish with 1% lipids, 19% solids and 80% water at an initial temperature of 20°C:

Cpf = (0.5 x 0.01) + (0.3 x 0.19) + (1.0x 0.8) = 0.862 kcal/kg°C

$$Mi = \frac{100 \text{ x } 0.862 \text{ x } (20 - 0)}{80} = 21.55 \text{ kg of ice}$$

Example (2) - 100 kg of fatty fish with 21% lipids, 19% solids and 60% water at an initial temperature of 20°C.

Cpf= (0.5 x 0.21) + (0.3 x 0. 19) + (1.0 x 0.6)= 0.762 kcal/kg°C

$$\mathrm{m}_{\mathrm{i}} = (M_x - M_y) \cdot \frac{24}{(x - y)}$$

The refined calculation for fatty fish shows only a small reduction in ice requirement and, since with most species the oil content is variable, it is advisable to treat all fish as if they were lean fish.

<u>Calculation of the ice requirement for the storage of fish</u>

Even if you are concerned with only one batch of fish held in identical containers, there are likely to be variations in ice meltage rates, which make it difficult to calculate the ice requirement accurately. If, for instance, the containers are stacked, then ice meltage may be different in containers located at the top, bottom, sides and within the stack.

In spite of the obvious difficulties and likely inaccuracies, a calculation of the ice meltage rate can still be useful at a planning stage to enable comparisons to be made between different options, and to allow preliminary estimates of quantities, costs and equipment to be made.

It would be difficult to identify containers which would eventually be located at more favourable locations within a stack. Therefore, all containers should be treated equally and the assumption made that each container is fully exposed to the surrounding air.

As a first step, heat transfer may be calculated using the following simple expression:

$q = A.U. (t_o - t_c)$ kcal/day (7)

Where:
q = heat entering the container (kcal/day)
A = surface area of the container (m²)
U = overall heat transfer coefficient kcal/day m² °C)
t_o = temperature outside the container (°C)
t_c = temperature inside the container (0°C)

This overall calculation of heat transfer may require to be done in parts if, for instance, the lid or base of the container is made of a different material or has a different thickness. The heat transfer through the various areas are then added together to give the total heat transfer.

The heat entering melts the ice, therefore it follows that:

$q = Li . mi$ kcal/day (8)
Where
q = heat required to melt ice (kcal/day)
Li = latent heat of fusion of ice (usually taken as 80 kcal/kg)
mi = mass of ice melted (kg/day)

In order to develop a mathematical expression for ice meltage rate during the storage period we suppose that ice meltage inside the containers is only due to heat transferred from the surrounding air. In this steady state approach, quantities (7) and (8) should be equal, therefore it follows that:

$L_1 m_i = A.U. (t_o - t_c)$ (9)

Thus, the ice requirement will be:

$$m_i = \frac{A.U.(to - tc)}{L_i} kg/day \qquad (10)$$

If the fish containers are exposed to direct sunlight during the storage period, the above calculation, which is only based on the conductance of heat due to the difference between the internal and external temperatures, will result in a under-estimation of the ice requirement. To include the element of ice meltage due to radiated heat will make the calculation extremely difficult. Therefore, if the containers cannot be protected from direct sunlight or any other radiated heat source during the storage period, the calculated values for the ice requirement should be upgraded or used with caution.

Ice meltage tests

Calculation of ice meltage rates will seldom give an accurate indication of the ice requirement, since reliable data on both materials and conditions is often not readily available. Irregularities in the construction of containers, for instance, can greatly affect the containers "effective heat transfer coefficient". Variations in ambient conditions during the storage period make it difficult to calculate the ever changing ice meltage rates, even when the data are reasonably accurate.

More accurate calculations of the ice requirement can be made if meltage tests are used to determine the overall heat transfer coefficient of the container. This type of ice meltage test may be done using ice only, and the results will be equally valid for fish/ice mixtures.

Containers should be filled with ice and weighed accurately before commencing the test, which should be done with a constant surrounding air temperature. This may not be possible over the entire test period, but reasonably constant temperatures may be achieved for shorter periods between weight loss measurements and an average used in the calculations. Significant differences will be observed between containers completely within the stack and those on the periphery with exposed surfaces.

Some of the initial ice meltage will be the result of cooling the container and, depending on the container material, some melt-water may be absorbed so that it will not be a measurable weight loss. If the weight of the container and ice is frequently checked during the test period the weight loss pattern may be similar to that shown in Figure 6, which shows a fairly constant rate of weight loss after the initial cooling period.

To ensure that the ice meltage measurements relate to heat ingress, only the time interval between "X. and "Y" in Figure 6, during which the rate of weight loss is constant, should be considered for ice meltage calculations.

Fig. 6 Ice meltage during storage

The relationship between ice meltage and heat ingress was given above by equation (9):

$Li \cdot m_i = A.U. (t_o - t_c)$ (9)

This expression can be rearranged to give the overall heat transfer coefficient U as follows:

$$U = \frac{L_i \cdot m_i}{A.(to - tc)} \quad (11)$$

Where
U = overall heat transfer coefficient kcal/day m² °C)
L_i = latent heat of fusion of ice (80 kcal/kg)
m_i = ice meltage per day (between "X" and "Y", Figure 6) (kg/day)
A = surface area of the container (m²)
t_o = temperature outside the container (°C)
t_c = temperature inside the container (0°C)

Note: If m, is measured over a period other than one full day then the rate per day can be calculated as follows:

$$m_i = (M_x - M_y) \cdot \frac{24}{(x - y)} \quad (12)$$

Where:
m_i = ice meltage rate (kg/day)
$(M_x - M_y)$ = weight lost due to meltage between "X" and "Y" (kg)
(x - y) = time interval between "X" and "Y" (hours)

In such ice meltage tests, steps should be taken to ensure that all the melt-water is drained from the container before each weighing.

A final check on whether the correct quantity of ice is being used can be done at the end of each storage period, by noting the quantity of ice remaining in each container. It is important that not only should there be ice in every container, but that this ice should be uniformly distributed, so that all fish in each container are still being cooled. A more elaborate check is to monitor the temperature of the fish. It is often possible to identify the fish likely to be most vulnerable, such as those on the outside of containers which are located on the outside of a stack and thermometers can be located at these positions. However, during handling and transportation/he relative position of containers may change with respect to their vulnerability to heat ingress, and only random temperature checks and a series of tests will finally indicate the quality of the icing practice.

If there has to be any modification in the ice usage at this stage, it can only be achieved by changing the fish to ice ratio and consequently the number of containers necessary to hold the required quantity of fish.

Saving ice

The amount of ice needed to keep fish fresh is economically more important in tropical countries, since the warmer climate means that ice meltage rates are higher. The ice required for cooling the fish from the initial temperature is fixed and cannot be reduced, Fig 7, but the use of insulation and refrigeration can considerably reduce the ice requirement during the subsequent storage period.

Another advantage of using insulated storage, is that it helps to stabilise storage conditions. Thereby, it is easier to predict and maintain the correct ice requirement.

Insulation can be used in various ways and the choice between one system and another will depend mainly on local conditions. For instance, individual boxes may be insulated or boxes may be stored in larger insulated containers or chill stores.

A standard size of fish box used in temperate climates contains about 30 kg of fish and 15 kg of ice. If this size of container was insulated not only would this be costly, but there would be a significant loss in storage space. Individual insulated boxes therefore tend to be larger and, in most cases, there is a need for some form of mechanical handling.

The effect of unit size on the ice and storage space requirements is illustrated in the following comparison between two sizes of container:

Internal volume, box A
$0.275 \times 0.66 \times 0.38 = 0.069\ m^3$
Internal volume, box B
$0.55 \times 1.32 \times 0.76 = 0.55\ m^3$

Box B has a volume which is 8 times greater than that of Box A and will therefore contain 8 times the quantity of fish.

If each box is insulated to give a wall thickness of 0.035 m, the surface area of each box will be:

Box A 1.47 m^2
Box B 5.06 m^2

Box B has a surface area which is 3.44 times greater than Box A, therefore, the ice meltage rate will be 3.44 times greater.

[Figure 7 Saving ice](#)

Table 2 Comparison between Boxes A and B

	Fish capacity	Comparative melting per unit wt	Meltage rates
Box A	1	1	1
Box B	8	3.44	0.43

The above comparison shows that although the ice meltage rate in Box B is 3.44 times greater than in Box A, the rate per unit weight of fish is greatly reduced due to the lower surface area to fish weight ratio.

Further comparisons could be made between the differences in storage space requirements and box costs. In the example given above, it would require 8 small boxes to hold the same quantity of fish as a single large box. Based on external box dimensions, the volume requirement for the smaller boxes would be about 25% greater. The surface area of the 8 smaller boxes is more than double the surface area of a single large box, therefore material costs will also be higher. Because the depth to which fish and ice is stowed is effectively doubled in the large box, consideration must be given to whether the fish is robust enough to withstand crushing. Further information on container storage is given in Chapter 9.

Total ice requirement

Factors other than higher ambient temperatures can result in an increase in the ice requirement in tropical countries.

The collection and marketing system may require that the fish and ice be separated for check weighing and sorting and, if correct procedure is followed, the old ice should be discarded and new ice used for re-icing. It is also advisable in tropical countries to precool water used during processing in order to avoid undesirable rises in fish temperature which would accelerate fish spoilage. Keeping the fish chilled at this stage also avoids the need to recool later. In more sophisticated systems, water precooling can be achieved using a mechanical refrigeration system and heat exchanger, but a more simple method is to merely add ice to the water in the supply tank.

The ice quantities given in Table 3 are typical figures for uninsulated containers which take into account losses during ice distribution. The quantities actually applied to the fish at each stage will therefore be less. More ice is generally used for prawns and other valuable shellfish species, in order to provide additional insurance against delays and other contingencies, even although the cooling requirement is much the same. The figures in Table 3 for ice requirements at different stages of handling and processing, are only a guide for the conditions prevailing in a tropical climate, and they may require modification either way as the result of experience.

Table 3 also shows that a collection, marketing and transport system which requires the fish to be periodically weighed and/or inspected will add considerably to the icing costs. Consideration should therefore be given to inspections being made by sample only or, preferably, to eliminating some of the stages where re-icing is required.

Table 3 Ice/fish ratios used to calculate ice requirements in tropical climates

Application	Fish	Prawn
On fishing vessel	1.0: 1	2.0: 1
Collection from artisanal fishermen	1.5: 1	1.5: 1
Re-icing at a collection centre	1.5: 1	1.5: 1
Re-icing for chill storage	1.0: 1	1.0: 1
Processing	2.0: 1	4.0: 1

Using the figures in Table 3 and a typical operation, the total ice requirement can be worked out as fallows:

Application	Ice/ fish ratio
Fishing and collection	1.5: 1
Re-icing at collection centre	1.5: 1
Processing and water chilling	2.0: 1

The total ice/fish for the above operation is therefore	5.0: 1

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4. The cooling rate of fish

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If we assume that ice is placed above and below a layer of fish, the fish at the centre of the layer will obviously take longest to cool, since they are furthest away from either layer of ice. It should also be appreciated that the cooling rate is not constant during the cooling period but slows down as the fish approaches the final temperature of 0°C.

These two conditions are illustrated by the following examples:

If the layer of fish is 10 cm thick, then the centre fish are 5 cm away from the nearest ice. If at the start of cooling the centre fish are at 10°C and the ice is at 0 C, there is a temperature difference of 1 0°C, and a temperature gradient of 2°C/cm. But, when the centre fish have cooled to 5°C, the temperature gradient is down to 1°C/cm, and the rate of cooling is consequently slower. As the temperature of the fish approaches that of the ice, the rate of cooling becomes extremely slow; it takes about 6 h for fish at the centre of a 10 cm layer to reach 0.5°C. When cooling times are given it is important to state the final temperature since, when this temperature approaches 0°C (the temperature of the ice), lowering the final temperature by even a small amount can make considerable differences to the cooling time.

This slowing down of the cooling rate at the end of the cooling period should be taken into account when any code of practice or legislation is introduced. Measurement of cooling times to the final equilibrium temperature will be subject to considerable variation since temperature differences will eventually to very small and thereby likely to be variable depending on the accuracy and sensitivity of the thermometer used. It is, therefore, more practical to define a completion temperature slightly above the final storage temperature, as in Table 4.

A typical curve for cooling fish in ice is shown in Fig. 8.

If the layer of fish is 20 cm thick instead of 10 cm, the middle fish are 10 cm away from the ice. The temperature gradient at the start is then 1°C/cm, that is only half the gradient at the start in the previous example; the less steep the gradient, the slower the heat will flow, and thus cooling takes longer. On the other hand, when the layer of fish is only 5 cm thick, cooling is rapid. The effect of the depth of fish in a box on the time taken to cool them is shown in Table 4, and presented in Fig. 9.

Fig.8. Cooling fish in ice

Fig. 9. Thick layers of fish take longer to cool than thin layers

Table 4. Time taken to cool fish in the centre of a box with ice top and bottom

Thickness of layer of fish (cm)	**Time to chill from 10°C to 2°C at centre (h)**
7.5	2
10.0	4
1 2.5	6.5
15.0	9
20.0	1 4
60.0	1 20

A single fillet can be chilled very quickly in ice; a thick layer of fish or fillets will chill only very slowly. Therefore, to chill fish quickly it is essential to keep the distance between each fish and the nearest piece of ice as small possible. This means in practice that ice must be distributed uniformly throughout the fish. The correct procedure for icing a box of fish is discussed more fully in Chapters 8 and 9.

Size, shape and the arrangement of the fish also have an influence on cooling rate since these factors may affect packing density, contact areas and the flow of melt-water through the fish layer. Thermal conductivity and other physical properties also have an influence on the time taken to cool fish, since this will vary depending on species and their condition. The influence of all these factors however, will be small compared to that of the thickness of the fish layer.

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5. Ice manufacturing equipment

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Classification of ice plants

Other than by description of the ice produced, there is no simple way to classify the different types of ice makers; hence we have block, slice, plate, tube, slush ice and so on. A further sub-classification may be made depending on whether they produce a "dry" subcooled ice or a "wet" ice. Generally, subcooled ice is produced in machines which mechanically remove the ice from the cooling surface. Most flake ice machines are examples of this type. On the other hand, "wet" ice is usually made in machines which use a defrost procedure to release the ice. The defrost partially thaws the ice where it makes contact with the cooling surface and, unless it has been reduced to a temperature substantially below 0° C (subcooled) the surfaces will remain wet; tube ice and plate ice systems are examples of this type.

In some machines the ice is formed and harvested concurrently to produce what is sometimes known as "slush ice" because it contains a good deal more unfrozen water than other forms of "wet" ice which have been harvested using a defrost procedure.

Types of ice maker

Block ice. The traditional block ice maker forms the ice in cans which are submerged in a tank containing circulating sodium or calcium chloride brine. The dimensions of the can and the temperature of the brine are usually selected to give a freezing period of between 8 and 24 hours. Too rapid freezing results in brittle ice. The block weight can vary from 12 to 150 kg, depending on requirements; 150 kg is considered the largest size of block one man can conveniently handle. The thicker the block the longer the freezing time. Blocks less than 150 mm thick are easily broken and a thickness of 150 to 170 mm is preferable to prevent the block toppling. The size of the tank required is related to the daily production. A travelling crane lifts a row of cans and transports them to a thawing tank at the end of the freezing tank, where they are submerged in water to release the ice from the moulds. The cans are tipped to remove the blocks, refilled with fresh water and replaced in the brine tank for a further cycle (Fig. 10). This type of plant often requires continuous attention and a shift system is operated by the labour force which may be 10 to 15 workers for a 100 t/day plant. Block ice plants require a good deal of space and labour for handling the ice. The latter factor has been the main reason for the development of modern automatic ice-making equipment.

Block ice still has a use, and sometimes an advantage, over other forms of ice in tropical countries. Storage, handling and transport can all be simplified if the ice is in the form of large blocks; simplification is often obligatory in small scale fisheries and in relatively remote situations. With an appropriate ice crushing machine block ice can be reduced to any particle size but the uniformity of size will not be as good as that achieved with some other forms of ice. In some situations, block ice may also be reduced in size by a manual crushing method.

Rapid block ice. The rapid ice plant can produce blocks in only a few hours and this means that the space requirements are considerably reduced compared with a conventional block ice plant. Block sizes vary with 25, 50 and 150 kg each being typical. In one type of machine, the relatively quick freeze is obtained by forming the block in a tank of water, around tubes through which the refrigerant is circulated. The effective thickness of ice to be frozen is a good deal less than in a conventional block ice machine. The tubes are arranged so that as the ice builds up it fuses with the ice on adjacent tubes to form a block with a number of hollow cores. These blocks are released from the tubes by a defrost procedure and they can then be harvested automatically from the surface of the tank. Some manual effort is required for storage or feeding to a breaker if the ice is required in the crushed form. In another type of rapid ice machine, the refrigerant is circulated through a jacket around each can of water and also through pipes running through the centres of the cans. Ice then forms simultaneously both at the outside and at the centre of the cam Blocks are then removed by gravity after a hot gas defrost.

An advantage of a rapid block ice machine is that it can be stopped and started in a relatively short time, since there is no large tank of brine to be cooled initially as in the conventional block ice machine in which the refrigeration system is often kept in continuous operation even when ice production has ceased.

Flake ice. This type of machine forms ice 2 to 3 mm thick on the surface of a cooled cylinder and the ice is harvested as dry subcooled flakes usually 100 to 1,000 mm² in area. In some models, the cylinder or drum rotates and the scraper on the outer surface remains stationary. In others, the scraper rotates and removes the ice from the surface of a stationary drum, in this case, built in the form of a double-wailed cylinder. It is usual for the drum to rotate in a vertical plane but in some models the drum rotates in a horizontal plane. One distinct advantage of the rotating drum method is that the ice-forming surfaces and the ice release mechanism are exposed and the operator can observe whether the plant is operating satisfactorily (Fig. 1 1). The machine with the stationary drum has the advantage that it does not require a rotating seal on the refrigerant supply and takeaway pipes. However, this seal has been developed to a high degree of reliability in modern machines. The ice is subcooled when harvested, the degree of sub-cooling depending on a number of factors but mainly the temperature of the refrigerant and the time allowed for the ice to reach this subcooled temperature. The subcooling region of the drum is immediately before the scraper where no water is added for a part of the drum's rotation and the ice is reduced in temperature. This ensures that only dry subcooled ice falls into the storage space immediately below the scraper. The refrigerant temperature, degree of subcooling and speed of rotation of the drum are all variable with this type of machine and they affect both the capacity of the machine and the thickness of the ice produced.

Fig. 10. Block ice maker

Other factors such as ice make-up water temperature also affect the capacity of the machine. Thus, the optimum operating conditions will depend on both the local conditions and the thickness of ice preferred. The normal refrigerant temperature in a flake ice machine is -20 to -25°C, a good deal lower than in other types of ice-maker. The low temperature is necessary to produce higher ice making rates, thus keeping the machine small and compact. The extra power requirement resulting from operating with a lower temperature in the ice maker is somewhat compensated for by the fact that the method does not require a defrost. There is therefore no additional refrigeration load incurred by the method of releasing the ice from the drum. The range of unit sizes for this type of machine now extends from units with a capacity of 0.5 to 60 t/24 h. However, rather than use a single unit, it is often expedient to use two or more. This gives a better arrangement for operating at reduced capacity and also provides some degree of insurance against complete breakdown. This advice is also applicable to other types of automatic ice maker.

Tube ice. Tube ice is formed on the inner surface of vertical tubes and is produced in the form of small hollow cylinders of about 50 x 50 mm with a wall thickness of 10 to 12 mm. The tube ice plant arrangement is similar to a shell and tube condenser with the water on the inside of the tubes and the refrigerant filling the space between the tubes. The machine is operated automatically on a time cycle and the tubes of ice are released by a hot gas defrost process. As the ice drops from the tubes a cutter chops the ice into suitable lengths, nominally 50 mm, but this is adjustable (Fig 12). Transport of the ice to the storage area is usually automatic, thus, as in the flake ice plant, the harvesting and storage operations require no manual effort or operator attendance.

Tube ice is usually stored in the form it is harvested, but the particle size is rather large and unsuitable for use with fish. The discharge system from the plant therefore incorporates an ice crusher which can be adjusted to give an ice particle size to suit the customer's requirement. The usual operating temperature of this type of plant is -8°C to -10°C. The ice will not always be subcooled on entering the store but it is usually possible to maintain the store at -5°C since the particle size and shape allow the ice to be readily broken up for discharge, especially with a rake system described in Chapter 4.

Fig. 11. Flake ice maker

Plate ice. Plate ice is formed on one face of a refrigerated vertical plate and released by running water on the other face to defrost it. Other types form ice on both surfaces and use an internal defrost procedure. Multiple plate units are arranged to form the ice-making machine and often these are self contained units incorporating the refrigeration machinery in the space below the ice-maker. The optimum ice thickness is usually 10 to 12 mm and the particle size is variable. An ice breaker is required to break the ice into a suitable size for storage and use (Fig 13). Water for defrost requires heating if its temperature is less than about 25°C; below this value the defrost period is too long, resulting in a loss in capacity and an increase in cost. This machine, like the tube ice machine, operates on an automatic timed cycle and the ice is conveyed to the storage area or if the machine can be located directly above the storage space, harvesting can be achieved using gravity flow.

Fig. 12. Tube ice maker

Fig. 13. Plate ice maker

Slush ice. The cooling unit for making "slush" ice is called a scraped-surface heat exchanger. It consists of concentric tubes with refrigerant flowing between them and water in the inner tube. The inner surface of the inner tube is scraped using, for example, a rotary screw. The small ice crystals formed on the tube surface are scraped off and mixed with unfrozen water. This results in a slurry of ice and water, which may contain up to 30% water by weight. This mixture may be pumped or, after removing most of the water in a mechanical separator, used as a 'dry' form of ice.

Other ice makers. A number of ice makers operate with systems that are different from those described above, but these are normally made with capacities of no more than a few hundred kilogrammes of ice a day, mainly for retail and catering services.

Refrigeration systems for ice plants

The modern continuous ice plant is designed to operate 24 hours a day, most of this time unattended. The refrigeration system, which includes the compressor, condenser, pipework, control equipment and the ice-maker itself, should therefore be designed for reliability, with safeguards against any foreseeable failure or malfunction. Most ice plant manufacturers specify the refrigeration system to be used with their ice making plant but, inevitably, individual requirements mean modifications, and installation engineers not directly connected with the ice machine manufacturer may design their own particular systems. The purchaser should therefore ensure that the system installed is suitable for unattended automatic operation, other than for routine checks and maintenance, and the control system should cater for all eventualities, with fail-safe arrangements which allow the plant to be quickly made operational again when a fault has been remedied.

The refrigeration system for the ice maker should normally be a separate unit which only needs a simple control system to maintain it at the appropriate operating conditions. In contrast, a centralised plant serving a number of separate refrigeration requirements needs an elaborate control system, particularly where the refrigeration requirements are independently variable. Centralised units usually have lower capital costs but any shortcomings in their operation compared with individual units may result in revenue losses in other areas such as quality loss in chill stores or associated freezers and cold stores. These losses may offset the saving in capital costs.

Most of the common refrigerants such as ammonia and the halogenated hydrocarbons, known by trade names such as Arcton, Freon and isceon, are normally quoted for ice-making plants. Most ice makers are suitable for use with any one of these. Refrigerant trade names are still widely used, but more correctly they should be named according to the internationally agreed numbering system. Thus, ammonia is known as R717, and the more common halogenated hydrocarbons es R12, R22 and R502. In some cases, the choice of refrigerant will depend on local availability and cost. However, there are many other complex factors to be considered when selecting a refrigerant, and the choice of refrigerant together with the type of compressor and the refrigeration system adopted should be left in the hands of a competent engineer. The ice plant manufacturer, knowing the particular requirements of his own machine, will also be able to help and the potential buyer should supply him with all the information he can about the project.

At the time of writing this document, firm decisions have been made to phase out most of the widely used halogenated hydrocarbons or chlorofluoro-carbon refrigerants (CFCs) because of concern that they are making a significant contribution to depletion of the ozone layer of the Earth's atmosphere. The current status of individual national programmes for the phasing out and availability of refrigerants should therefore be ascertained before a decision is made on the choice of refrigerant.

In multiple unit installations, special care has to be taken with refrigerant distribution to ensure that each ice maker is adequately supplied with sufficient refrigerant. Pump or gravity circulation systems, for instance, should have the refrigeration pipework designed to ensure that unequal pressure drops do not lead to dissimilar refrigeration operating conditions at each ice maker.

In all refrigeration systems, oil is carried over from the compressor sump. This oil may eventually find its way into the ice maker and foul the refrigerant side of the cooling surfaces, thus reducing the capacity of the machine. Oil separators are incorporated in a refrigeration system to minimise this carryover, but it is also necessary to ensure that there is an effective oil return from the ice maker to prevent an accumulation of oil in the mixture. This function is usually incorporated into the design of the unit but with some machines it is also necessary to follow the manufacturers instructions to clear oil from the ice maker at frequent intervals.

Capacity of ice plants

As mentioned elsewhere, a number of factors affect the capacity of an ice maker and its associated refrigeration plant. The tables produced below put into perspective, the consequences of variations in some of the operating conditions in terms of ice making capacity.

Table 5. Variation of ice maker capacity with refrigerant temperature for a small flake ice plant

Temperature (°C)	**Capacity (t/24 furs)**	**Relative capacity %**
-30	17.5	100
-25	16.0	91
-20	13.5	77
-15	10.7	61
-12	8.9	51

Table 6. Variation in ice maker capacity with water temperature

Ice make-up water temperature (°C)	Ice plant capacity (t/24 hrs)	Relative capacity %
0	43.0	100
5	41.8	97
10	40.4	94
15	39.2	91
20	38.0	88
25	36.8	85
30	35.7	83
35	34.5	80

The relationship in Table 6 will apply to most types of ice plant and it can clearly be seen that the higher temperature of the make-up water encountered in the tropics will significantly reduce the capacity of an ice plant. Prechilling the water from 35 to 5°C will increase the capacity of a plant by about 20 percent. When supply water temperatures are particularly high, a separate cooling unit should be considered, which will prechill the water more efficiently than the ice maker and may therefore be an economical addition to the plant.

Table 7. Variation in the relative capacity of a refrigeration plant with operating conditions

Condensing temperature (°C)	Evaporating temperature (°C)			
	-10	**-15**	**-20**	**-25**
20	100	79	61	48
25	94	75	59	45
30	83	66	51	39
40	73	57	43	32

Table 7 gives comparative values for the capacity of a refrigeration compressor operating over a range of conditions which may be encountered in ice manufacturing plants. The lower the cooler (evaporating) temperature and the higher the condensing temperature the lower will be the capacity of a refrigeration unit. The cooler temperature is often fixed by the requirements of the ice maker and this may only be varied slightly, whereas the condenser temperature depends almost entirely on the locality and the prevailing climatic conditions. A larger compressor will therefore be required to produce a given amount of ice in a warmer country than in a temperate one.

It can be seen from Tables 5, 6 and 7 that the ice maker and refrigeration plant have to be matched to give the required ice making capacity at the appropriate operating conditions.

The higher ice making capacities shown in Tables 5 and 6 may, therefore, only be achieved if the associated refrigeration equipment is increased in size to give the appropriate refrigeration capacity.

Making ice from seawater

When seawater is frozen slowly, freshwater ice crystals are initially frozen out of the mixture. The whole solution will not be frozen until the temperature has reached -22 C, the eutectic point. (The eutectic point is a physical constant for a mixture of given substances.) At higher freezing rates, the ice crystals will be salt-contaminated from the very beginning but this salt will eventually migrate to the outer surface and separate during storage. As the crystals are made mainly of fresh water, the residual liquid will contain an ever increasing concentration of salt as the temperature is reduced.

The special structure of seawater ice gives it different properties from freshwater ice. Seawater ice is rather soft and flexible and, at normal subcooled ice temperatures of -5 to -1 0°C, it will not keep the form of flakes; in fact, at -5°C, seawater ice will look rather wet. For this reason, seawater ice is usually produced at lower temperatures than freshwater ice, and often this adjustment has to be made to the ice maker. Otherwise the plant required is basically the same. Some difficulties have also been experienced with the pneumatic transportation of seawater ice. Even when subcooled, the conveyor raises the temperature sufficiently to make the ice soft, sticky and difficult to move.

Making ice at sea

A number of ice plants are suitable for operation at sea with little modification to their design and they may use either fresh or seawater supplies. Many vessels which process their catch at sea have ice makers installed for cooling the fish during processing. Since they are often at sea for many months at a time, it would be unreasonable for them to carry ice from a shore-based plant. Some fishing vessels have ice plants installed where it may not be economical to have a permanent shore-based plant; for example, because demand for ice is only seasonal due to the type of fishery. Other fishing vessels operate their own ice plant because of difficulties in getting regular supplies without incurring unacceptable delays in port. However, the argument is not clear-cut. The shipborne ice plant occupies valuable space on the vessel and space is also required for ice storage, since a plant which will produce ice to match the peak catching rate without buffer storage would be excessively large. The power requirement is also considerable and, if enough power is not available on board, space will be required for an additional generator. The power to produce 6 tonnes of ice in 24 hours, suitable for a vessel likely to be making weekly trips, is about 30 to 35 kW. The true cost of making ice at sea should be compared with the cost of purchasing ice from a shore-based ice supplier. Even if this is found to be unfavourable, the cost of delays in waiting for ice supplies may sway a vessel owner toward a shipborne plant. The economic factors and the question of continuity of supply, along with the need to avoid contaminated seawater (Chapter 2) have also to be considered before a decision is made.

Solar energy ice plants

In areas where there may not be an on-line energy source to operate a refrigeration plant, the energy from the sun can be used in conjunction with an absorption type refrigeration plant to provide sufficient ice to support a modest operation.

The solar energy refrigeration plant is made as a self contained unit and, for ice manufacture, the only requirement is a suitable water supply. Equipment currently available manufactures block-ice with the blocks weighing approximately 10 kg each. The standard module provides 200 kg of ice per 24 furs, but units for up to 1000 kg per 24 hrs are also available. Output will obviously depend on the hours and intensity of the sunlight each day, therefore an insulated storage facility is also supplied as part of the package, to act as a buffer against daily fluctuations. Fortunately, unlike other refrigeration systems, this unit is more efficient and productive when the ambient conditions dictate that more ice is required.

Since there are no moving parts the equipment needs no maintenance other than weekly cleaning.

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6. Ice plants

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Planning

The first step in planning is to confirm whether an ice plant is actually required. Other ice plants in the area may be a reliable source of suitable ice and, even with the additional transport costs and the manufacturer's profit, they may be able to supply ice cheaper than it can be made by the user. A large installation has many economic advantages over a small unit and it is not unreasonable to expect that it can produce cheaper ice. Other factors, such as being self sufficient, may over-ride an economic disadvantage.

The most important stage in planning is to consider the site of the ice plant, both in relation to the services required for the manufacture of the ice and, to the ease of distribution to the consumer. Ice plants require a power source, and suitable water supplies for both ice manufacture and refrigeration plant condenser cooling. In addition, some plants require a further supply of water for defrosting purposes. The cost of transporting ice is substantial, particularly in heavy traffic areas, and may be the biggest cost to the consumer. Ice plant should therefore be located where the ice is required, or sited to keep transport requirements to a minimum. Advice on layout is usually given by the manufacturer, but this information is only applicable to the type of plant he supplies. For instance, traditional block ice plants require a much larger floor space than modern automatic ice makers. Other ice makers, like the tube ice machine, require a good deal of headroom and are seldom located above the ice storage space, whereas with flake ice machines this arrangement is usual. Silo storage also requires a relatively high building structure, whereas large storage bins need plenty of floor space because of limitations on the storage depth. Space and building height limitations should therefore be considered at an early stage of planning, since any restrictions may preclude the use of some types of plant. For instance, on some sites tall buildings are undesirable for aesthetic reasons.

Unit sizes

Most ice machine manufacturers produce a range of standard unit sizes. Since each unit has a variable capacity, depending on the operating conditions, it is usually possible to meet the requirements of each customer under the most favourable conditions.

Some manufacturers produce dual units in which the unit capacity range is apparently extended upwards. However, higher icemaking capacities are usually achieved by using multiple units which may operate with a centralised refrigeration plant or each ice maker may be a self contained unit. Since the system used will have a bearing on the service provided, the choice will depend on the operational requirements. For instance, if the demand for ice is widely variable a number of individual self contained units may be selected in order to accurately match supply and demand.

Plant Requirements

Space. Modern ice makers are compact compared with conventional block ice plants, but a direct comparison of the space requirements of the various types cannot readily be made. The capacity varies with the operating conditions and it is usual to quote a capacity range when referring to its ice manufacturing capabilities. Some types of plants are more suited to high rates of production and are made in large units whereas others are made in small unit sizes only. Table 8 gives some typical figures for the space requirements for a number of the more widely used types of ice maker, producing 50 t of ice per day.

Table 8. Space requirements of ice makers

Type of icemaker	Capacity (t/24 h)	Floor space (m^2)	Height (m)
Block ice	50	190	5.0
Rapid block ice	50	30	3.5
Plate	50	14.3	1.8
Tube ice	50	3.3	6.6
Flake ice	50	2.7	3.7

The space requirements given in Table 8 are for the icemaker only. Since the ice maker is comparatively compact in modern types of plants (plate, tube and flake ice), the requirements for refrigeration machinery and handling and storage space are far in excess of the figures in Table 8. Like most machinery of this type there is an effect of scale, with larger sizes generally requiring less space per unit of ice making capacity. In some plants it is also possible to stack the units, therefore, both floor space and height can be varied to suit individual requirements. Self-contained units with a rating of up to 10 to 20 tonnes/24 hours can be located within the floor space required for storage, with the icemaker and refrigeration equipment on top. Some guidance on ice storage space requirements is given later in this chapter.

Power. Two aspects of power requirement have to be considered. The energy consumed in making a tonne of ice is important, since it influences the ice manufacturing costs. The installed power is also of interest since this will determine the power supply equipment required by the plant.

The energy required to produce a tonne of ice is not a constant; it varies with the type of plant and the operating conditions. Plants which operate with low temperatures in the ice maker, such as flake ice plants, will have a higher energy consumption. Plants operating with high condenser cooling temperatures and warm ice make-up water will also have a higher energy consumption. Thus, a plant will be more expensive to operate in the tropics than in temperate climates. Defrost procedures also add to the refrigeration load and hence the energy requirement. Tube ice and plate ice plants will therefore have an additional requirement over plants using flake ice machines which harvest the ice without a defrost. This factor is the main reason why an ice plant with a defrost process cannot economically make ice with a thickness much less than 10 mm; below this ice thickness the proportion of energy attributed to the defrost process becomes excessive. Large units tend to operate more efficiently than small units, and an ice plant fully utilised will operate more efficiently than plant operated intermittently or with a light refrigeration load. Other factors, such as the choice of refrigerant and the type of refrigeration system used, also govern the energy requirement. In climates where the ice make-up water is excessively warm, prechilling in a separate cooler can reduce energy requirements. It is therefore difficult to be precise about the energy requirements of an ice plant when it depends not only on the type of plant, but also on its environmental conditions and mode of operation. Care should therefore be taken when using manufacturer's energy consumption figures without a clear indication of the operating conditions to which they apply.

For the purpose of initial planning, the following figures may be helpful, which give the energy consumption in kWh per tonne of ice produced:

	Temperate area	**Tropical area**
Flake ice	50-60	70-85
Tube ice	40-50	55-70
Block ice	40-50	55-70

These figures are for the ice maker and associated refrigeration machinery only. There may be additional energy requirements for conveyors, ice breakers and a separate cooling system for the ice storage space. These additional requirements are unlikely to be large and, since most of them are operated intermittently, the energy requirements will be small compared with the figures for the ice maker. However, all electrical equipment should be taken into account in calculating the peak power demand, which will nominally be 1.5 to 3.8 kW (2 to 5 hp) for every tonne made each day. Ice making is usually a service industry and continuity of supply is essential. A suitable storage capacity will take care of short breakdowns, maintenance requirements and interruptions to the power supply but, in areas where the local supply is unreliable, the plant may require its own generator. Alternatively, the essential refrigeration machinery may be operated by a direct coupled engine with a small generator for auxiliary power requirements. In these cases, careful planning is required to avoid situations where large generators are used uneconomically to maintain a supply well below their rated capacity.

Water. The quantity of water required for a shell and tube condenser which rejects water to waste depends on the design temperature rise of the cooling water. This may vary, depending on the temperature of the supply water and other factors. A rise of 5°C is a widely used design value and this will result in a water requirement of about 30 to 40 tonnes per tonne of ice.This figure is only quoted in order to indicate the likely quantities of water that need to be available for the operation of a shell and tube condenser. The manufacturer or a qualified engineer should be consulted for more accurate figures.

For small plants, air-cooled condensers may be used. With commercialsized ice plants evaporative condensers or shell and tube condensers with acooling tower are normally used. An evaporative condenser or a cooling towersystem will use less than 0.5 tonnes of water per tonne of ice produced. This figure will increase slightly if a greater overspill is necessary to ensure that the concentration of solids in the reservoir does not build up to an excessive level.

Defrost water for plate ice machines must be of the same quality as the ice make-up water, since they are mixed in the process. The quantity required is roughly 2 tonnes for each tonne of ice produced. This requirement is reduced to only a nominal value if a closed circuit system with reheating is used for the defrost water.

Only water which satisfies the requirements for drinking water, or clean seawater, can be used for manufacturing ice for the chilling and storage of fish. Clean seawater can be defined as seawater which meets the same micro- biological standards as drinking water and is free from objectionable substances. Ice made from water that does not satisfy these requirements may contaminate fish with waterborne micro-organisms. These can reduce the keeping time of fish and may also create a health hazard. Water which may be polluted must therefore be suitably treated. Standards for drinking water can be obtained from the local health or sanitary authorities, and internationally recommended standards and methods for determining the impurities are given in the book "International Standards for Drinking Water" published by the World Health Organization, Geneva (1963).

In addition to hygienic quality, ice make-up water has to meet the requirements of the ice plant manufacturer in terms of its chemical properties. Excessive solids or hardness may result in the fouling of the ice-forming surfaces of some types of icemaker and may also affect the physical properties of the ice, because excessive solids in the water tend to give a soft wet ice. On the other hand, ice made from pure water gives problems, especially with flake ice machines. Ice from pure water sticks to the drum and a salt dosing device is required to overcome this difficulty; 200 to 500 9 of sodium chloride in a tonne of ice is sufficient to improve the physical properties of the ice. At this level the salt cannot be tasted and it does not affect the quality of the fish in any way. Information about the ice make-up water should therefore be supplied to the ice plant manufacturer; he will advise on any treatment necessary to make the water suitable for the efficient operation of the plant. Other than in extreme cases, all that may be required is a simple chemical treatment of the water in a storage reservoir.

Storage of ice

Ice manufacture and demand rates are seldom in phase, therefore storage is necessary to ensure that the plant caters for peak demand. Storage allows the ice maker to be operated 24 hours per day. It also acts as a buffer against any interruption to the ice supply due to minor breakdowns and routine maintenance procedures. Therefore, the potential buyer should calculate the storage capacity necessary to satisfy the above requirements. Account should be taken of both short-term and seasonal variations and also variations in the capacity of the icemaker. Peak demand for ice in the warmer seasons also coincides with adverse plant operating conditions when make-up water and condenser cooling water temperatures are higher. There is no general rule for estimating ice storage capacity requirements. Usually this is done by plotting the likely pattern of ice production and ice usage over a period of time, and selecting a storage capacity which will ensure that ice will be available at all times. In most cases, ice storage capacity is never less than twice the daily rate of production and more usually it is 4 or 5 times this value.

Storage space requirements for different types of ice vary in relation to their bulk density, Table 9. Although flake ice requires more storage space for a given weight, this subcooled ice can be stored to a greater depth in a silo, thus floor space requirements will be much the same as for more compact types of ice.

Table 9. Storage requirements for various types of ice

Type of ice	Storage space requirement (m^3/t)
Flake	2.2 - 2.3
Tube	1.6 - 2.0
Crushed block	1.4 -1 .5
Plate	1.7- 1.8

<u>Silo storage.</u> Silo storage is generally used with a free-flowing subcooled ice such as flake ice and, in order to be effective, it must have an independent cooling system to maintain the ice in this subcooled condition. The cooling is usually by means of an air cooler in the jacket space between the silo and the outer insulated structure. The air cooler is normally placed at the top of the jacket space adjacent to the ice maker and the air space is cooled by gravity or fan circulation (Fig 14).

Ice is collected by gravity flow with the aid of a chain agitator which scrapes the ice from the walls of the silo. The silo allows for a first-in- first-out (FIFO) system of storage but, if the storage space is not cleared periodically, only the central core of ice is used, leaving a permanent outer wall of compacted ice. An access hatch should therefore be provided at the top of the silo so that a pole can be inserted to collapse the outer wall of ice into the central core at least once daily.

Silo storage is expensive for small quantities of ice and although units are made for as little as 10 tonne, this method of storage is more suited for storing 40 to 100 tonnes of ice.

Fig. 14. Silo ice store

Bin storage. Bin storage may mean anything from a box holding no more than 500 kg to a large installation of 1,000 tonnes or more. Bin storage can be used for any type of ice and may incorporate a separate cooling system. Whatever the size of system used, ice storage should always be within an insulated structure since the saving made by reducing ice meltage, particularly in warmer climates, is always worth the extra cost of the insulation. An insulation thickness of 50 to 75 mm of polystyrene or its equivalent in one of the many other suitable types of insulation, is suggested. Small bins may be arranged with the icemaker above the storage space; the bin is filled by gravity and a FIFO system is operated by removing the ice at a low level. This simple bin system is suitable for processors making and using their own ice. When the ice has to be distributed, the bin arrangement is such that the unloading system is at a level suitable for filling road vehicles or for cross-quay transportation to fishing vessels (Fig. 15). Bins of up to about 50 tonnes capacity can be constructed without a mechanical unloading system. This type of storage would usually be a high structure with a sloping base and access to dislodge compacted ice. Any ice left undisturbed for a few days will compact and fuse together. Ice which is free flowing when used daily may require a mechanical unloading system if used infrequently.

Large bins require considerable floor space because the recommended maximum depth of storage is limited to about 5 m, due to the fact that excessive storage depth increases pressure and results in fusion of the ice. A large capacity storage bin will require a mechanical unloading system. Some of the systems are discussed below.

Block ice storage. Block ice cannot be stored in silos or bins unless the ice is crushed beforehand. This type of ice is therefore stored in block form in refrigerated rooms. A conventional block ice plant also has a considerable amount of extra storage in the ice making unit, since it is usual to maintain the ice cans filled, even when demand has fallen below the plant's rated capacity.

Ice handling and conveying

Some types of ice maker can be sited above the storage space and new ice is therefore added directly by gravity flow. This arrangement can only be used when the ice maker produces a dry subcooled ice. With other types of ice it is necessary to drain excess water, usually in the conveyor system, before storage. Silos, and the smaller size of vertical bin, require no ice distribution system within the storage space to ensure uniform loading. Larger bins, however, require a means of distributing the ice uniformly, irrespective of whether they have the ice maker situated above the storage space or the ice is supplied by conveyor. A variety of harvesting methods can be used with bin storage and some of these are also used to distribute the ice uniformly over the store area. One system of unloading uses a combined rake and scraper arrangement, which breaks up the surface ice and then conveys it to the end of the bin, where an adjustable gate regulates the flow into a discharge conveyor (Fig 16). Another system uses a scraper bucket to move the ice to the discharge conveyor. Both these systems can operate as ice distributors, but have the disadvantage of discharging the newly-made ice first. Since long-term storage of ice is undesirable, these bins should be emptied periodically. This can be more readily accomplished in larger installations if two bins are used.

Fig. 15. Bin ice store

Another method of harvesting from large bins ensures a FIFO operation by removing the ice from the bottom of the bin. A travailing screw conveyor moves along the length of the bin, undermining the ice and discharging it to another conveyor running alongside. This is a heavy piece of expensive mechanical equipment requiring additional floor space outside the bin area. It also requires a good deal of power to operate and special structural work is necessary to support the bin wall on the side the ice is discharged. This system also requires additional mechanical equipment for uniform distribution of the ice, usually a conveyor running the length of the bin along its central line with means of off-loading the ice on both sides.

Both dished belt conveyors and screw conveyors are used extensively for transporting ice. Screw conveyors allow both horizontal and vertical movement of the ice but are limited in the distance over which they can operate; there is also some breakdown in the size of ice particle due to agitation. Belt conveyors are generally used for long distances and special belts with a ribbed flange arrangement can be used on an incline to raise the ice. The final discharge to the lorry or fishing vessel is usually by gravity with a mobile tube to direct the ice.

Pneumatic systems are also used for moving ice but their use should be restricted. A good deal of energy is required to move ice at velocities of about 20 m/s and this energy, along with the heat introduced by the transporting air, will cause meltage. In addition, the ice is fragmented by impact on the ducting walls with the result that a good percentage of the ice appears as "wet snow" at the point of discharge. This ice is unsuitable for further storage. The use of pneumatic systems is therefore confined to filling boxes at sea or in fish processing factories.

Weighing ice

When small quantities of ice are involved, measurements are usually made by volume; the weight being ascertained by filling a standard container such as a bag, bin or hopper. With block ice, delivery weights are calculated by counting the number of blocks before they are discharged through the ice- breaker.

In larger installations, ice can be weighed automatically on the supply conveyor belt by using electronic weighing devices which have an accuracy of + /-2 percent. This method can be used with a system which allows remote control of the discharge operation. It can also be integrated with an automatic accounting system which identifies individual customers and allows a self-service operation. The complete system simplifies delivery control, bookkeeping and invoicing procedures.

Fig. 16. Large bin ice store with rake discharge system

Transport of ice

One of the main advantages of the compact modern ice plant is that it can usually be located at the place where the ice is to be used, therefore transport distances are kept to a minimum. Transport to distribution points or to the consumer is usually done in bulk and, for short journeys in temperate climates, this may be in a covered uninsulated vehicles. However, if long journeys are made, the ice should at least be covered and, in warmer climates, insulated transport or even refrigerated transport may be economical.

Ordering ice plant

The general rule in ordering ice plant is that the buyer should supply as much information as possible. The more facts the buyer supplies, the easier it will be for ice plant manufacturers to submit competitive tenders which can be compared on a common basis. At this stage of planning, some decisions should have been made and specific instructions given on such things as type of ice required, site location, building layout and services available.

The following is a check list of the information the buyer should provide when ordering an ice plant:

Main purpose for which ice is intended Type of ice required (block, flake, tube, plate, freshwater, seawater ice, etc) Ice production capacity (tonnes of ice/24 h) Local maximum ambient temperature and humidity or exact location of plant

Information on ice make-up water:

Purity (details of hygienic quality, hardness, etc.) Temperature range (°C) Pressure (kg/cm^2)
Information on condenser cooling water:
Type available (tap, well, river, sea, etc. with details of quality) Quantity available Cost Temperature range Pressure
Information on electricity supply:
Reliability
Voltage
Frequency (Hz)
Phase
Maximum installed power (kW)
Maximum starting current allowable
Details of separate power source if required (generator, direct drive, engine, etc.)
Refrigerant preferred (R12, R22, R502, ammonia, etc.)
Ice storage capacity (tonnes of ice or m^3)
Type of storage preferred (silo, bin, bin with mechanical unloading of ice)
Whether a prefabricated or site-built store is required

Preferred method of discharging ice (gravity, rake, bucket or screw)
Rate of discharge required (tonnes of ice/in)
Details, with sketch, of any existing plant and store buildings

Details of site if the plant is to be built inclusive of building, services, etc Details of the discharge requirements (to lorry or over quay to fishing vessel, etc.) Details of ice-weighing equipment preferred (continuous belt weighing, standard bin, etc.) Details of local maintenance facilities Details of local skill available for installing and servicing the plant Spare parts and refrigerant supply requirements Technical instructions, specifications, drawings, etc. for installation and maintenance required and in what language.

The above list is extensive but it may not have exhausted the information available which may influence the choice of the plant and the layout. Additional information such as building rules and regulations are important, and as much detail as possible should be given to the potential supplier.

Finance of ice making

Cost. An accurate cost can be made of an installation only at the time of purchase. If an ice plant is planned from the start, the costs to be taken into account are numerous and varied and depend very much on local conditions. For example, they may include cost of land, buildings, roads, electrical and water supply services and drainage. Annual fixed costs will take into consideration depreciation, maintenance, interest on capital, insurance, taxes and overheads. The main operating costs to be considered are power, labour, water and, if applicable, delivery costs. A number of 1990 prices for equipment are given in Table 10 in order to give the reader some idea of the capital required for the ice plant machinery only. The prices are the figures at the port of dispatch and the total cost will have to be increased to include transportation and other delivery charges.

It cannot be emphasized too strongly that all costs and coatings in this document may not apply to any particular country or situation and they therefore must not be used other than as a guide. Local costs should be ascertained and related to local conditions when making calculations which involve any financial commitment.

Table 10. Approximate f.o.b. prices of ice-making equipment (as per 1990)

Description	Capacity (tonnes/24 h)	Cost (US $)
Flake icemaker only	1-100	9,000 - 150,000
	10	36,000
Flake icemaker and refrigeration equipment	1-100	14,000 - 322,000

	10	85,000
Rapid block ice, complete automatic equipment for 25 kg blocks	1-50	30,000 - 578,000
	10	155,000
Packaged block ice maker for tropics complete equipment for 25 kg blocks	0.5-50	15,000 - 318,000
	10	95,000
Plate ice plant, complete with refrigeration equipment	5-100	75,000 - 400,000
	10	100,000
Silo with agitator end conveyor	2-10	37,000 - 95,000
Bin ice store	1-10	12,500 - 26,000
Rake system for bin store	300	60,000
Refrigeration plant complete with compressor, condenser, cooling fans, pumps, etc (add 25% if two compressors are supplied)	0.5-100	8,000 - 180,000
	10	45,000
Diesel-driven generation system for typical power requirements	20	29,000
	10	15,000
Block ice store equipment	5-50	3,500 - 7,500

Costing. An early costing may influence the size of plant to be installed, since many costs are virtually independent of the plant size and ice is therefore cheaper to produce in larger installations. The potential user of ice may also decide to become a supplier of ice by installing a plant larger than is necessary for his own requirements. Labour costs are much the same whatever the size of a modern automatic plant; also space and power requirements get less for each tonne of ice produced as the size of the installation increases.

Maintenance costs may be a major consideration in remote areas. Although modern plants operate with the minimum of attention, they require routine expert maintenance, and this attention may be costly if suitably qualified labour is unavailable locally. Capital and running cost of the different types of ice plant vary, but the comparison often depends on the site of the installation and the choice of operating conditions. Any direct comparison of costs would therefore, either cover a wide range of conditions or, include so many controlling factors that the comparison will have little value for general use. Some plants require high capital costs, but have comparatively low running costs, for others it is the reverse. Therefore individual circumstances must be considered in this respect, when making a decision on a cost basis on the type of plant to be installed.

In order to give some idea of the method used to determine the manufacturing cost of ice, an investment analysis for a 20 t/24 hour block ice plant is given below. The figures used are 1990 UK costs converted to US dollars and, since costs and conversion rates may change rapidly and also differ from costs in other countries, the values used may have little relevance to any other situation. It is the method of costing that is of primary interest. Where possible local costs and other factors should be used even to give a rough estimate for guidance purposes.

CAPITAL COSTS	**US$**
First cost:	
Buildings	190,000
Land	7,000
Ice plant, installed	150,000
	347,000
Annual fixed charges:	
Depreciation (10 %)	34,700
Interest (10%)	34,700
Insurance and taxes (4%)	13,800
Capital maintenance (2 %)	6,900
	90,000
RUNNING COSTS	
Operating costs:	
Power -	Assume 5-day week full capacity: 5 x 52 x 20 = 5200 t/year
	Power at 45 kWh/t + 15% for auxiliaries: 45 x 1.15 = 51.7 kWh/t;

	at US$ 0.08/kWh: 51.7 x 5200 x 0.08 = US$ 21507/year	
Water-	For ice	5,200 t
	For evaporative condenser losses	2,600 t
	Add 20% for other wastage	1,560 t
		9,360 t at US$ 0.30/t
		= US$ 2,808/year
Labour:		
Based on	2,000 in/year for day labour 8,760 in/year for shift labour	
Operating engineer- 8,760 x US$ 6.50/h		=US$ 56,940
Office manager and accountant - 2,000 x US$ 6.50/h		=US$ 13,000
Day labourer- 2,000 x US$ 5.0/h		=US$ 10,000
		US$ 79,940/year

Note: Administrative costs may be shared with several other services or operations.

Supplies:	
Refrigerant, salt, oil, office supplies, etc.	US$ 4,000/year
Delivery costs:	
2 drivers + 2 helpers - 4 x 2,000 x US$ 5.0	40,000
Parts, repair, fuel, etc	6,500
Rental and depreciation	5,000
	US$ 51,500/year
Summary of annual operating costs:	

Power	21,507
Water	2,808
Labour	79 940
Supplies	4,000
Delivery	51,500
	US$ 159,755
<u>Total annual charges:</u>	
Fixed	90,000
Operating	159,755
Total charges	US$ 249,755
Cost of ice:	249,755/5,200 US$ 48.03/t
Based on selling price of US$ 60/t:	
Income US$ 60 x 5,200 = US$ 312,000/year	312,000
Less Total annual charges	249,755
Annual profit	US$ 62,245
	62,245 100
$m_i = \frac{A.U. \quad (to \quad - \; tc)}{L_i} kg \quad / \quad day$	

Analysis of the above costing shows that manufacturing and delivery costs in this particular case are made up as follows:

Fixed costs	36%
Electricity, water, supplies	11.4%
Labour	32%
Delivery	20.6%

This pattern can change considerably from plant to plant, but it is clear that many of the costs are fixed and independent of ice production. Therefore, in order to keep the cost per tonne of ice down, the plant should be fully utilized.

<u>Selling price.</u> The 1990 selling price of the ice in the United Kingdom varied between US$ 30 and US$

45 per tonne. Whether these figures reflect real differences in the manufacturing costs, or merely indicate differences in the marketable price of ice between different areas is difficult to ascertain. However, the lowest prices are often charged by manufacturers with old plant supplying large quantities of ice throughout the year, hence there is little depreciation and overhead costs are widely spread. On the other hand, manufacturers with small plants supplying fluctuating seasonal markets often charge comparatively high prices, as also do manufacturers operating plants at a level well below their rated capacity, perhaps due to reduced demand in the area. It is therefore important to ensure that the proposed plant matches the anticipated demand for the future. It is often the practice to cater for present requirements but plan a layout with the possibility that more ice-making units may be added at a future date. The delivery costs above are only 20% of the total. Where transport times are longer delivery costs may rise to 50% of the total.

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7. Other methods of chilling

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In addition to ice, refrigerated seawater and, to a lesser extent, superchilling systems have been successfully used to preserve fish. Eutectic plates, solid and liqulfied forms of carbon dioxide, liquid nitrogen, air-cooling and other systems have also been used, but mainly to keep already cooled fish at chill temperatures during transportation.

Refrigerated seawater

The terms refrigerated seawater (RSW) and chilled seawater (CSW) describe seawater which has been cooled to just below 0°C. In some cases, a brine of about the same salinity as seawater is used. There is no clear distinction between the two terms; RSW is generally used when a mechanical refrigeration unit cools the water and CSW is more often used when ice is added for cooling. For the rest of this document RSW will be taken to mean either system.

RSW has by no means displaced ice, but it has found use as a cooling medium in certain fisheries because of the following advantages:

(1) Greater speed of cooling
(2) Reduced pressure on the fish
(3) Lower holding temperature possible
(4) Ouicker handling of large quantities of fish with little delay or labour involvement
(5) In some cases, an extended storage time

The method also has disadvantages. These include excessive uptake of salt, uptake of water by species with a low fat content, loss of protein, problems with anaerobic spoilage bacteria, and modification of characteristics of fish traditionally used as quality indicators, e.g. "bleaching" of gills, dulling of skin, and leaching of soluble end products of spoilage changes.

Applications. RSW systems have been used for sardine, salmon, halibut, menhaden, shrimp, mackerel, herring, blue whiting and many other species. The most successful commercial projects have been confined to bulk applications where the fish are to be used for canning or other industrial processes. In order to give the reader an idea when RSW systems can be used with advantage, some of the more successful commercial applications are briefly described:

(i) Salmon. The method has been used for storing and transporting large quantities of salmon prior to processing into a canned product. In this application salt uptake is relatively unimportant and the ease of handling, usually by brailing, gives the system an advantage over iced storage.

(ii) Industrial fish. Industrial fish such as menhaden are chilled in RSW systems to maintain the quality until such time as they are unloaded for processing into fish meal. Previously the fish were processed within a day of capture, but longer trips have made it necessary to cool the fish in order to keep them firm and suitable for processing.

(iii) Purse seiners. Purse seine fishing vessels use RSW systems for chilling catches mainly of pelagic fish. Unlike drifters, which bring the catch slowly on board, purse seiners have large catches which require to be handled and chilled quickly. The fish are therefore pumped or brailed from the net directly into RSW tanks.

(iv) Large freezer and factory trawlers. RSW systems are often used on freezer and factory trawlers when there are likely to be delays between catching and processing. Fish stored in bulk and unrefrigerated between catching and processing will deteriorate quickly, especially in warmer climates.

To sum up, RSW systems have been successfully used:

(1) Where the disadvantages of salt uptake are not important, so comparatively long periods of storage are possible.
(2) For chilling industrial fish to allow longer trips, improve handling and reduce losses.
(3) For bulk chilling on fishing vessels which have to handle large quantities of fish quickly.
(4) For bulk chilling fish prior to processing, without the need for excessive handling.

Clearly, the above applications cover a wide range of circumstances depending on the species of fish and the prevailing climatic conditions; it is difficult to generalise on both the description and use of RSW systems. It is advised that, if a commercial scale application is contemplated, a prior investigation of all the factors should be made, taking into account seasonal variations in the quality of the fish concerned and the intended end product.

Salt uptake. Salt uptake is probably the most important factor which limits the application of RSW systems. Fish intended for normal processing and marketing can acquire a salt fish taste which would make them unacceptable. The salt uptake in industrial fish is also critical since it is concentrated during processing. The upper limit is usually equivalent to a concentration of about 0.5 percent in the raw fish.

Salt uptake depends on:

(1) Species
(2) Size of fish
(3) Salt content of the RSW
(4) Ratio of RSW to fish
(5) Time
(6) Temperature

Table 11 shows the progressive uptake of salt in cod stored in an RSW system with a fish to water ratio of 2 to 1. The experimental results are given as salt percentages in the fillets.

Table 11 Salt uptake by cod in RSW

Storage (days)	**% salt in fillets**	
	RSW	**Ice (control)**
5	0.3	0.1
9	0.5	0.1
15	1.0	0.1

In the above experiment, a taste panel detected an undesirable salty taste after only three days storage; thus storage life in RSW may be very short for many applications. In contrast to the above case for cod, eviscerated halibut does not become unacceptably salty even after storage lasting several weeks. This species difference appears to be related to the size of fish, the fattiness and the resistance of the skin to salt penetration.

Another element which dictates the limit of salt uptake is the preference of the consumer. Therefore, acceptability limits may have to be established not only according to the species and the end product but also in relation to the tolerance of the consumer.

Salt content of RSW. The salt content of seawater is remarkably steady throughout the oceans at about 3.5 percent. However, this varies locally depending on such factors as dilution by river waters and concentration by high rates of evaporation. The addition of freshwater ice as a cooling medium will also change the salinity. The salinity also changes as the fish takes up salt from the water. Whether a fish floats, sinks or has a buoyancy equal to its weight is important in the design and operation of RSW tanks. The properties of RSW vary with salinity (Fig. 17) and many of these variations are important. Cold dead fish will normally sink in cold seawater but species, fat content, the amount of air in the swim bladder, degree of spoilage and other factors all have an effect. The method of filling and the degree of agitation will to some extent be governed by whether a fish floats or sinks.

Pure water has a density of 1 kg/l and this maximum value occurs at a temperature of 4.0°C. The density of salt water and the temperature of maximum density vary, as shown in Table 12, and the freezing point of seawater also changes with salinity. With high salinities, lower storage temperatures are possible but care should be taken to guard against slow freezing of the fish for the reasons given in Chapter 1.

- Water with a low salinity may give rise to difficulties with the cooling system since there is an increased possibility of the build-up of ice on refrigerated surfaces. This will result in a reduced efficiency or, in extreme cases, permanent damage to some types of cooler. Some coolers are designed for freezing ice on the cooling coils. This ice can be used as cooling storage which can provide rapid cooling of a bulk charge of fish. It should be borne in mind that the formation of ice on the coils will increase the salinity of the remaining seawater. Oxygen content and, as described later, carbon dioxide solubility are also important in relation to bacterial spoilage of the fish, and the solubility of both these gases changes with salinity. Salinity control, or the lack of it, may therefore be an important factor in the success of an RSW system.

Fig. 17. Specific gravity and freezing point of seawater

Table 12 shows the variation in some of the properties mentioned above with salinity changes.

Table 12. Properties of salt water

Salt content (%)	0	1	2	3
Freezing point (°C)	0	-0.53	-1.08	-1.64
Maximum density	1.000	1.008	1.016	-1.024
Temperature of maximum density (°C)	4.0	1.8	-0.5	-1.64
Solubility of oxygen (litres/litre of water)	0.010			0.009
Solubility of carbon dioxide (litres/ litre of water)	1.70	1.61	1.54	1.46

Loss of nitrogenous constituents. It has been widely reported that fish lose some of their nitrogenous constituents including proteins during storage in ice. It would seem that the loss is greater with RSW systems, probably due to an acceleration of the leaching-out process because the fish are totally immersed. Some results have shown that the loss in RSW is double that which would be expected with good icing practice, but no greater than the loss if fish in ice are stored in bulk.

Weight gains by fish in RSW. Fish immersed in ice water gain weight at first, then slowly lose weight during subsequent storage. Fish in RSW also gain weight, but the gain is slow and continues for two or three weeks in some cases. Weight gain depends on species and a number of other factors. A gain of 2 to 5 percent is normal for most species after a period of one to two weeks. Some flat fish increase greatly in weight even in a short period of storage. Because the maximum storage period of cod is limited due to other factors such as salt uptake, the weight gain is usually about 0.5 percent. The problem of water uptake is less critical with fatty fish such as herring and mackerel.

Spoilage of fish in RSW. There are many contradictory reports which either favour storage in RSW or storage in ice or find that there is little difference between the two. The reasons for this are that comparisons are made under widely differing circumstances using different parameters, and also range from small-scale laboratory tests to full-scale commercial enterprises. In the RSW system fish can be handled and cooled quickly. This gives them an early advantage over iced fish which may be subjected to delays at higher ambient temperatures because of the labour involved in sorting and stowing the catch. It also seems that for short stowage periods, RSW fish may have a distinctly better appearance than fish stored in ice, as there are no indentations which occur with many types of ice, and the fish are generally firmer. The major factor against the storage of fish in RSW is the possible growth of anaerobic bacteria, which give rise to objectionable flavours and odours, with hydrogen sulphide being predominant. Ice contains a good deal of air space in its bulk and the usual methods of storage often allow air to circulate to some degree over shelves and around boxes; therefore, anaerobic bacteria do not flourish. With RSW storage, however, oxygen will tend to disappear, giving rise to anaerobic conditions. Another disadvantage of an RSW system is that spoilage may affect an entire catch, whereas ice storage may confine the problem to the immediate locality where adverse conditions prevail. Thus, RSW systems have often been condemned because of inadequate cleaning of the entire system between trips.

Carbon dioxide in RSW. Dissolving carbon dioxide in RSW has been shown to inhibit bacterial growth and extend the storage life of fish. Results with some species of fish have shown that the addition of carbon dioxide to the RSW can increase the storage life by up to one week, if bacterial spoilage is used as the only criterion. However, other control factors may terminate storage long before the advantages of using carbon dioxide are realised and, in some cases, there may be little to be gained by adding this facility.

Carbon dioxide is also an extremely toxic gas with an upper threshold limit of only 0.5 percent, although it has been suggested that it is possible to work an eight hour day in an atmosphere of 1.5 percent. Within the confines of a fishroom, special care would have to be taken to avoid dangerous concentrations. Because of this, and the limited benefits likely, carbon dioxide enriched RSW has not been widely adopted commercially.

Storage tanks. When designing the layout of the RSW tank system for a fishing vessel, consideration has to be given to the stability of the vessel and the storage conditions within the tanks at each stage of the operation. During filling, precooling, storage and unloading, the stability of the vessel must not be impaired to a critical degree. The operation of the system should also ensure that adequate quantities of prechilled water are available for the fish and that movement of water and fish within the tanks is minimal. Partly filled tanks not only affect the stability of the vessel but cause excessive movement of fish and water during storage which can result in damage to the fish.

The tank layouts shown in Fig. 18 are typical three tank and six tank systems used on small fishing vessels. With single and dual tank systems it would be difficult to achieve the safety and fish quality requirements noted above.

Fig 18 Refrigerated seawater tank arrangements for small fishing vessels

Storage tanks should be watertight, easily cleaned and should not contaminate the fish. Tanks of aluminium, glass reinforced plastic and steel have been used. Aluminium, however, requires special welding techniques which may not always be readily available and glass reinforced plastic tanks can be damaged by some mechanical unloading systems. Steel tanks, therefore, have the widest application and are usually coated with suitable anti-corrosive protective substances; zinc galvanizing (not suitable for direct contact with food), epoxy resins, thiocol rubber-based coatings and non-toxic bituminous paints have all been used. Tanks constructed from marine plywood have also been used, particularly in wooden fishing vessels; the tank is usually built from a double layer of plywood with all joints staggered and a suitable waterproof coating applied to the inner surface. Wooden tanks are not normally insulated and a space is left between the tank and the ship's side for good ventilation and drainage to discourage wood rot. Metal tanks are always insulated, because, where ice is carried and used as the cooling medium, a poorly insulated tank will require more ice. A tank welded directly to the ship's frames, and only insulated in the inter-frame space, can have a heat leak ten times higher than a tank with a complete layer of insulation between the tank surface and the fishroom framework (Fig. 19). Apart from the extra cost of ice required in the inadequately insulated tank, the extra ice, volume also means that less storage space is available for fish. Therefore, at least 50 mm of a good insulation should separate the tank from the fishroom framework.

Tank storage is usually divided into a number of compartments and the space between the water and the tank top kept to a minimum in order to prevent excessive movement of fish and water.

Fig. 19. Insulation for seawater tanks

Pumps and piping. Circulation of the water for cooling is effective even with a fish to ice-water mixture ratio as high as 4 to 1. To avoid damage to the fish the rate of circulation should not be high and need only be sufficient to ensure even temperature distribution throughout the tank. Circulation rates for systems using ice for cooling should only be sufficient to agitate the water to give an even temperature. Tanks with mechanical refrigeration systems, on the other hand, require the circulation rate to be sufficient to cool the fish quickly. Pumps for ice chilled systems are required to deliver about one change of water an hour, whereas with water chillers the pumping rate is about 5 times this value. The circulation arrangement within the tank is also important and delivery and suction should be designed to give an even flow throughout the tank. Circulation from bottom to top of the tank is usually preferred but top to bottom has been used since it allows circulation in partially filled tanks during the precooling process. One method that has given good results has a large suction screen installed in a vertical position on one side of the tank. The water is supplied to the tank through a distributor at the bottom arranged to give a gentle even flow throughout the tank. Another method is to spray the pumped water along the sides of the tank.

When the tank is partially loaded the fish block the vertical screen and the water is forced to flow through the mass and over the top to the open part of the screen. Separate pumps may be installed for each tank on a vessel or one pump may serve a number of tanks with a parallel flow arrangement. Centrifugal pumps are normally used, and care should be taken to match their characteristics to the design requirements. For instance, incorrect pump selection may give rise to separation of the circulating water resulting in excessive frothing.

Plastic pipework, normally a grade of polyethylene, has been successfully used with RSW systems. This type of pipe and associated fittings are corrosion-resistant and have smooth inner surfaces which are easily cleaned. Only in places where there is likely to be some physical damage will other pipework materials be required. The use of dissimilar metals however, should be avoided since electrolytic corrosion may be severe.

Refrigeration requirement for RSW systems. A total review of local commercial conditions is the only way to determine accurate figures for the refrigeration requirement. However, the method of calculation shown below will give figures which may be used with a high degree of confidence at the design stage. Subsequent substitution of data, obtained during commercial use, into the various equations will improve the accuracy of calculated values for other installations.

Three stages of the operation have to be taken into account when considering the refrigeration requirement: the precooling stage when the water and tank are cooled prior to loading the fish; the fish chilling stage when the fish are reduced in temperature; the storage stage when the temperature of the fish and water mixture is maintained at the final chill temperature. The refrigeration rating during the fish cooling period usually exceeds the rating during the precooling and storage periods, and it is therefore on this condition that the refrigeration requirement is based.

In many cases limitations imposed by power availability, space requirements and cost may mean that the refrigeration rating has to be reduced to give a longer fish cooling time than desirable, especially when particularly large quantities of fish are likely to be caught at one time.

Calculation of the refrigeration requirement for cooling the fish is straightforward using the expression in equation (13) below.

$$h = [(Mf \times Cp) \times (ts - te)] \quad (13)$$

where:
h= heat to be removed during cooling (kcal)
Mf= mass of fish (kg)
Cp= specific heat of fish (0.8 kcal/kg °C)
ts= starting temperature of fish (°C)
te= final temperature of fish (°C)

A similar expression can be used to calculate the precooling refrigeration requirement. The calculation of the refrigeration requirement for the storage period is more complicated and a detailed knowledge of the tank structure is required. The following example indicates the information required for this calculation and Table 13 shows the calculated heat leak into a storage tank with and without insulation.

The calculation is based on the following assumptions:

1. Storage in a tank with three separate compartments each with storage capacity for 25 tonnes of fish.
2. Tank insulated throughout with 100 mm of polyurethane foam.
3. Ship's side of 6 mm and internal tank lining of 5 mm mild steel plate.
4. No frames or hangers penetrating through the insulation.

5. Temperatures as follows:	Air	30°C
	Sea water	25°C
	Engine room	35°C
	Forward fish room	5°C
	Tank	0°C

6. As a simplification, the tank is considered to be a rectangular parallelepiped 7.80 m wide x 3.80 m long x 2.44 m high.

7. The water line taken as reaching half the tank depth.

8. Surface areas:	Deckhead	29.64 m²
	Tank floor	29.64 m²
	Engine room bulkhead	19.03 m²
	Forward bulkhead	19.03 m²
	Ship's sides: above waterline	9.28 m²
	below waterline	9.28 m²
9. Heat transfer coefficients:		kcal/ m² h °C
Deckhead moving air outside		29.3

Tank floor still air under	8.0
Engine room bulkhead: air on engine room side	7.1
Forward bulkhead: air on fish room side	7.1
Ship's sides above water: moving air outside	29.3
Ship's sides below water: moving water outside	1720
Inside the tanks: gently agitated water	515
10. Conductivities:	kcal/ m h °C
Steel	38.9
Polyurethane foam	0.0211
11. Material thicknesses (from 2 & 3 above):	
Insulation	100 mm
Steel plates: ship's side	6 mm
tank lining	5 mm

12. Overall heat transfer coefficients:

Overall heat transfer coefficients are derived from the following equation:

$$\frac{1}{U} = \frac{1}{h0} + \frac{x1}{k1} + \frac{x2}{k2} + \frac{x3}{k1} + \frac{1}{ht} \quad (14)$$

where:
U = overall heat transfer coefficient (kcal/m² h °C)
ho = outside heat transfer coefficient (kcal/m² h °C)
x1 = thickness of steel plate, ship's side (m)
k1 = conductivity of steel (kcal/m h °C)
x2 = thickness of polyurethane (m)
k2 = conductivity of polyurethane (kcal/m h °C)

x3 = thickness of tank lining (m)
ht = inside heat transfer coefficient (kcal/m² h °C)

If the overall heat transfer coefficients are calculated using the relationship in equation (14) above the heat ingress through each surface area can then be determined using the following relationship:

q = U x A x (to-tt) (15)

where:
q= heat leak (kcal/h)
U= overall heat transfer (kcal/m² h °C)
A= area (m²)
to= outside temperature (°C)
tt= inside temperature {°C)

The results of these individual calculations are summarized in Table 13.

Table 13 shows the importance of insulation in order to reduce the refrigeration requirement for maintaining the tank contents at 0°C. In many installations however, the effectiveness of the insulation is far less than ideal since it is sometimes difficult to build a tank system without structural members penetrating the insulation. For the example given in Table 13, tanks insulated to a commercial standard may have a heat leak far greater than the ideal of about 10,000 kcal/h which is still no more than about 7% of the uninsulated value.

Table 13. Summary of RSW tank heat transfer calculations

Surface	**Surface area (m²)**	**Temperature difference (°C)**	**Overall heat transfer coefficient (kcal/m²°C)**		**Heat lead (kcal/h)**	
			Ideal insulation	**Uninsulated**	**Ideal insulation**	**Uninsulated**
Deckhead	29.64	30	0.209	27.6	186	24 542
Tank floor	29.64	25	0.205	7.83	152	5 802
Engine room bulkhead	19.03	35	0.205	7.03	137	4 682
Forward bulkhead	19.03	5	0.205	7.03	20	669
Ship's sides above water line	9.28	30	0.209	27.6	58	7 684

Ship's sides below water line	9.28	25	0.211	374.0	49	86 768
Total					602	130 093

Ice cooling. Ice can be used to supply a proportion of the high cooling load. The ice should be added directly to the tank with the fish. Normal pump circulation will be adequate to maintain a uniform distribution of water to give an even temperature. A small particle ice, like flake ice, should be used. Its large surface area to volume ratio will ensure quick cooling of the mixture and

its small particle size will reduce the possibility of the pump being blocked. The addition of freshwater ice to seawater will result in a reduction of salinity which is an advantage where salt penetration of the fish is a problem. However, the freezing point of the water will be higher. This may not always be acceptable since it will result in shorter storage life. The addition of ice also reduces the storage capacity of the tanks since high fish to water ratios will not be possible.

Ice alone is used in many RSW installations, eliminating the need for a mechanical refrigeration system and thus avoiding the problem of operation and maintenance of this equipment. Ice may be used with pump circulation. It is possible to pump mixtures of flake ice and water with the water content as low as 10 percent. Agitators are also used to ensure an even temperature distribution throughout the tank. Usually, once the fish have been cooled and the fish-ice-water mixture is at a uniform temperature, very little or infrequent agitation is required to maintain uniformity, provided the ice is evenly distributed throughout the tank. As in normal icing practice, a major problem is anticipating the ice requirement for a trip and catering for unforeseen delays due to bad weather, poor fishing and other reasons. Adequate quantities of ice have therefore, to be carried for these eventualities and if necessary, ice should be added to the tank periodically.

The ice required for cooling the fish-ice mixture can be calculated using the following heat balance equation:

$(M_i \text{ x } L) = h$ (16)

Hence we have the weight of ice required $= M_i = h/L$ (17)

Where:
h = the heat removed during cooling [from equation (13)1
M_i = mass of ice (kg)
L = latent heat of fusion of ice (taken as 80 kcal/kg)

The ice required during storage is calculated from the sum of the heat leaks listed in Table 13 using a heat balance equation as follows:

$(M_i \times L) = q_t$ (18)

Thus we have the ice required = $M_i = q_t/L$ (19)

Where:
M_i = mass of ice (kg/h)
L = latent heat of fusion of ice (taken as 80 kcal/kg)
q_t = sum of the heat leaks from Table 13 (kcal/h)

Other heat sources, such as the energy input from the circulation pumps and the heat removed when cooling the tank structure, may have to be taken into account when calculating the refrigeration requirement. In these cases the heat load in health should be added to the above mechanical refrigeration requirement or converted to an ice requirement using the relationships in equations (4) or (6) above.

Cleaning of RSW systems. The RSW system must be kept scrupulously clean; lack of attention to this important requirement has been the main reason for the failure of some installations to operate successfully.

The initial charge of seawater should be as clean as possible therefore, tanks should not be refilled in harbour or inshore near river estuaries. Cleaning should begin as soon as the fish have been landed, while the system is still wet, otherwise slime and other material will dry hard and be difficult to remove. The tanks should be cleaned, using clean water from a hose, brushing if necessary to remove any material adhering to surfaces. The piping system, including pumps and heat exchangers, should be flushed out thoroughly then cleaned by circulating hot water or an approved cleaning solution. Sometimes a weak solution of disinfectant is left in the piping system until the tanks are required again, then the entire system is thoroughly flushed with clean seawater before being refilled.

Chilling packaged fish

The temperature of the contents of prepackaged fish products can rise to the prevailing ambient temperature during processing. Thus, when they are finally packed in cartons and stacked during chilled storage, the recooling time can be prolonged resulting in a loss of potential shelf life.

This type of product is usually prepared using a continuous process, therefore recooling must be quick; in most cases, ice or iced water cannot be used. Air chilling however, can be used in this situation without drying the product since the product is packaged. In order to achieve a short recooling time, the air temperature requires to be a good deal colder than the temperature used with other forms of chilling.

Some results achieved when re-cooling fish fillets, which were packaged in polystyrene trays with an overwrap, are given in Table 14. It can be seen that acceptable recooling times were only achieved with very low air temperatures and this results in partial freezing of the product. However, this freezing is very quick; only a thin layer at the surface is frozen for a relatively short time during the early stages of the temperature equalisation period. A taste panel assessment of fish subjected to this partial freezing effect showed that quality was virtually unaffected. Application of this technique will depend on the market intended and the food legislation in the country of sale.

Table 14. Results of pre-storage chilling tests

Product	**Chilling method**	**Initial temperature**	**Final temperature**	**Cooling time (mins)**
Unwrapped fillets	Air at - 1°C	19°C	2°C	38
	0 m/s			
Unwrapped fillets	Air at - 1°C	19°C	2°C	20
	1 m/s			
Unwrapped fillets	Air at - 1°C	19°C	2°C	21
	3 m/s			
Unwrapped fillets	Air at -35°C	21°C	2°C	3.5
	3 m/s			
Unwrapped fillets	Air at -35°C	21°C	2°C	2.3
	8 m/s			
Wrapped fillets	Air at -35°C	20°C	2°C	15
	3 m/s			
Wrapped fillets	Air at -35°C	20°C	2°C	5.8
	8 m/s			
Individual fillets	Immersion in iced water	19°C	2°C	8.2

The above methods of quick recooling extended the potential shelf life of the product by 1.5 days, which is a significant improvement when the potential storage life of this product using current practice may only be 4 to 5 days at 0 °C. It would seem however, that shelf life extension can be best achieved by ensuring that the temperature rise is always kept to a minimum during processing. One suggestion is that water for washing the fish after separation from ice should always be prechilled since, even in temperate countries water temperature can be 15 to 20°C during the summer months.

Superchilling

Superchilling (also termed "partial freezing " or "deep chilling") means reducing the temperature of fish uniformly to a point slightly below that obtained in melting ice, thereby extending the storage life of the fish.

When fish is kept in melting ice, the temperature of the fish falls to about -0.5 C. This is because salt, blood and other substances in the mixture of fish and ice depress the temperature below 0°C, the natural melting point of freshwater ice. White fish consists of about 80 percent water, and all of this water remains unfrozen at -0.5°C.

When the mass of fish and ice is further refrigerated, some of the water in the fish begins to freeze and the temperature falls. In present practice, superchilling means reducing the fish to a temperature of -2.2° C, at which point half the water is frozen (Fig. 20.). At this temperature bacterial activity is slowed down, the rate of spoilage reduced and the fish remain edible longer. In deep chilling the temperature may be reduced to -3°C or lower.

Slow freezing of fish flesh is undesirable because large ice crystals form which can damage the structure of the muscle and other changes, due to chemical and biochemical reactions, reduce the eating quality. At the recommended superchilling temperature of -2.2°C only half the water in the fish is frozen and the number of large ice crystals and other factors are not critical, but at -2.8°C three quarters of the water is slowly frozen and damage to the fish may be excessive. Hence, very close control of superchilling temperature is essential if the damaging effects of slow freezing are not to offset the benefits of storage at a lower temperature.

White fish in crushed ice remains edible for about 15 days, whereas at -2.2°C the fish will remain edible for about 26 days. At -2.8°C shelf life may be as long as 35 days, but damage due to ice formation makes the fish unsuitable for a number of end uses. With superchilling, the temperature of cod for instance should not be lower than -2.2°C and at this temperature, the extension of storage time over conventional iced storage can be as much as 11 days under ideal conditions, and at least 6 days using commercial practices. Other fish however, may not have the same extension of storage life as cod, particularly oily species and fish from warmer waters. Trial experiments should therefore be made before commencing a full-scale commercial enterprise. Fig. 21 shows the typical cooling pattern for boxed fish in an air temperature of -3°C.

Fig. 20. Freezing of fish muscle

Because of the longer potential storage life, superchilling can be used when fishing trips are extended beyond the normal keeping time in ice. Also, if the box system described later is used, superchilling allows transport and storage ashore when distances and time make ordinary icing unsuitable.

This type of storage has only had a limited commercial use since it requires precise control of the fish temperature to achieve optimum results. Marketing can also be difficult, since the product cannot be classified and handled as either chilled or frozen.

Fig. 21 Temperature history of superchilled fish

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8. Chilling fish at sea

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Proper handling and storage of fish at sea ensures that the catch stays as fresh as possible until it is landed. The important requirements are to chill the fish rapidly as soon as they are caught, to keep them chilled, and to maintain a good standard of cleanliness on the fishing deck, in the handling area or shelter deck, and particularly in the fishroom or stowage area.

A well designed vessel can make handling of the catch easier, but few ships are ideal in this respect. Good stowage practice can help maintain freshness of the catch even in badly designed vessels, or in small boats where stowage facilities are primitive. Bad handling, even on a well designed ship, can only result in poor quality fish.

The importance of good practice at sea cannot be over-emphasised because, fish begin to spoil as soon as they die. Neglect on board, even on short fishing trips, can sometimes result in poor quality fish after only a few hours. Moreover, since the time the fish is on board ship is often longer than the time on shore between landing and consumption, the fisherman may bear much of the responsibility for the freshness of the fish reaching the consumer.

In many countries there are now schemes for inspecting and grading the catch on landing. Therefore, the care with which the catch is stowed as well as the length of the trip will affect the value put upon the catch. Under these conditions there is usually a financial incentive to the fisherman to bring back the catch in top condition, since the penalty for poor practice may well be downgrading or even withdrawal of the catch from sale.

The art of good stowage can vary to some extent with the species being handled, the type of fishery being pursued, the size of vessel and the length of voyage. There are, nevertheless, certain broad principles that apply to almost all fisheries and these are outlined here. Although the advice is based mainly on that given to the north Atlantic trawling industry, most applies equally to the smaller inshore vessel, whether fishing in temperate or tropical waters. However, where necessary the special problems of tropical stowage are discussed in more detail.

Methods of handling and stowage

Lean fish. Lean fish are those in which the fat content of the flesh is usually less than 1 %; the bulk of the fat is contained in the liver as opposed to fatty fish in which most of the fat is in the body tissues. Lean fish are also usually bottom-living species, caught principally by trawl, seine or long line. Fatty fish are typically surface living fish, caught for example by purse seine, midwater trawl, gill net or hand line.

Lean fish caught by large vessels in colder waters are usually gutted at sea, but in some inshore fisheries, the small number of crew may exclude the possibility of gutting large numbers of small fish; this is often true of many tropical fisheries. It is generally true that gutting is desirable in order to remove one of the main sources of bacteria and proteolytic enzymes, particularly if the stomach of the fish is full of food. Where stomachs are consistently found to be empty and the fish are not required to be bled, it is sometimes permissible to omit the gutting stage, particularly if this avoids any long delay before chilling.

However small the vessel and however short the trip, ice should be carried aboard and used to protect the catch. After gutting and washing, the fish should be stowed as soon as possible in crushed ice or in ice which has inherently small pieces. There are two main methods of stowage in general use, either bulk stowage in ice within the fishroom or stowage area of the ship, or with ice in containers, usually boxes of some kind, which can be removed from the ship on landing without disturbing the catch. Most methods of stowage in ice, sometimes with minor variations or refinements in practice, fall into one of these two categories.

On small boats in which the boxed iced fish has to be stacked on the open deck, an insulated cover will not only help to further protect the fish from adverse ambient temperatures, but also reduce the rate at which the ice melts and hence the demand for ice storage where space is at a premium.

Fatty fish. Most fatty fishes, for example herring, sardine, mackerel and so on (are usually caught in large quantities), are too small and too numerous to gut at sea. Because they are fatty and are left whole, they spoil much more quickly than lean fish and consequently there is even greater need to chill them as quickly as possible. Small fatty fish do not withstand bulk stowage in ice very well; they are fragile and easily squashed or damaged. Therefore iced stowage in containers, or in RSW, are the main methods of keeping them on board ship.

Principles of good stowage

Immediately after capture, all fish should be chilled rapidly to keep spoilage to a minimum. Fish stowed in plenty of ice are typically at a temperature of -0.5°C (see p. 53). The ice has to do more than just chill the fish; it usually has to remove heat from the surrounding structure of the box or the fishroom; it has to absorb the heat input through the structure during stowage from the warm air and sea outside, and it may also have to remove heat produced by the spoilage process in the fish themselves. It is therefore essential that plenty of ice is properly distributed throughout the catch to ensure efficient cooling.

Ideally, each fish should be in contact only with ice and not even with other fish. Fish touching one another do not cool as rapidly as those completely buried in ice. Apart from this, when a fish is stowed so that it is against a smooth surface, like the side of a box or a large area of another fish, air may be completely excluded. Some spoilage bacteria, in the absence of air, can rapidly produce foul smelling odours which spread throughout the flesh of the fish, resulting in what are known as stinkers or "bilgy fish" in north Atlantic fisheries. Fatty fish as well as lean fish are sometimes affected by this kind of spoilage. There are usually innumerable small pockets of air between small pieces of ice, so that fish properly surrounded by ice does not become spoiled in this way.

When the ice melts, some cooling of the fish is done by the melt-water running over the fish, probably because contact is much better between the fish and the ice cold water than between fish and ice; the meltwater acts as a carrier of heat as it flows from fish to ice and fish to ice again within the fish/ice mixture. Because of the shape and size of the pieces, flake ice usually melts more quickly in direct contact with the fish than crushed block ice, and therefore cools the fish more rapidly. A continuous flow of melt-water is desirable to preserve the fresh moist appearance of the fish.

Besides helping to cool the fish, the melt-water also washes away bacterial slime, spoilage products and traces of blood, and thus helps to preserve the fresh appearance and smell of the fish. It follows therefore that small fish should never be so tightly packed that the flow of melt-water is prevented. At the same time, it is important to provide adequate drainage so that the fish do not become immersed in dirty water.

The surrounding temperature should be kept just above ice temperature to permit the ice to melt, but not so high that ice is needlessly wasted. A fishroom temperature of 1-2°C is usually suitable. If the air temperature around the iced fish is too low, say -1°C to -2°C, uncontrolled slow freezing of the outermost fish can occur, whilst those in the middle of the stowage may be inadequately cooled, since only fish in direct contact with the ice will be cooled quickly if insufficient melt-water flows over them.

Iced fish should not be in too thick a layer in a box or a fishroom without some intermediate support, because the bottom fish will be crushed and damaged, and also lose a significant amount of weight. Boxes should be shallow and bulk stowage and stowage in large containers should have supporting shelves at intervals of not more than 0.5 m.

Cleanliness is an important part of good stowage. Much of the care exercised in chilling can be wasted if the boxes or the stowage space are dirty, or if dirty ice from a previous trip is used on fresh fish. All unused ice should be discarded at the end of each trip. Although it may look clean, unused ice may be heavily contaminated with spoilage bacteria. Fish stowed in dirty ice spoil faster than fish stowed in clean ice. After discharging the fish at the port the fish room should be cleaned out with suitable detergent and disinfectant.

In fishing vessels which have a proper fishroom, some of the points to watch for in good stowage practice are as follows.

Bulk stowage. Always cover the bottom of the fishroom with a layer of ice 10 to 15 cm deep. The actual depth will depend on how well the fishroom is insulated, the length of the voyage and the temperature of the sea outside. If the fishroom is a metal one, or the floor is uninsulated, increase the thickness of the bottom layer of ice, especially if the floor is a bare steel tanktop. If no ice remains between fish and floorboards when the ship is discharged, then not enough ice has been used. The bottom layer of fish will have warmed and will probably be spoiled.

The first layer of fish should be placed on the bed of ice, more ice sprinkled over the fish, and additional ice placed against the fishroom lining, particularly when the ship's sides are uninsulated. As each further layer of fish is added, a sprinkling of ice should be put over it until the space is almost full. A top layer of ice about 5 cm thick should be added. For long trips in temperate climates, about one tonne of ice should be used for every 2 tonnes of fish; in tropical waters about one tonne of ice to one tonne of fish is usually necessary for safe keeping. There should always be some ice remaining throughout the fish on landing (Fig. 22).

Where the shelves for bulk stowage are made of portable boards, they should be filled so that the weight of the shelf of fish above is resting on the shelf supports rather than on the fish below. The advantage of keeping bulk-stowed fish in shallow layers not more than 0.5 m deep will be lost if fish and boards rest on top of other fish, and the catch will be crushed, damaged, provide lower yield and spoil more rapidly.

Successive shelves of fish and ice should be added in the correct manner until the stowage is full; the topmost fish should be covered with 10 to 15 cm of ice to protect them against heat coming through the deckhead.

Corrugated shelf boards have the advantage that dirty melt-water at the bottom of the stowage is carried away to the sides and does not run through onto the fish stowed below.

Bulk stowage can be improved by making the layers as shallow as possible, the ideal being a single layer of fish on each shelf, with ice above and below the fish so that crushing is virtually eliminated, and every fish is adequately protected by surrounding ice. This ideal method of storage can only be achieved at the expense of a poorer stowage rate of about 4.5 m^3/tonne of fish.

Bulked fish often suffer a certain amount of rough handling during discharge from the fishroom into some kind of container at the port market.

Fig. 22 Bulk stowage

Boxed stowage. Boxing at sea can produce better quality fish on landing than bulking, with less weight loss, and can also help to ensure that the fish continues to be well protected after landing, by remaining in the same box with ice.

Design of the box is important; first and foremost it must be big enough to hold the required weight of fish and sufficient ice to chill the contents and keep them chilled at least until landing. It should not be so deep that the bottom fish are crushed and should be long enough to accommodate, without bending, most of the larger fish which are caught. At the same time, it should not be so unwieldy that it cannot be handled by one or two men as required, both at sea and in port. The boxes should also nest/stack when empty, so that there is plenty of working room at the start of stowage.

Drain holes in the box should be so arranged that melt-water drains down the sides or the ends of the box below, rather than down through the fish in the box below. Although the melt-water helps to cool the fish quickly it eventually becomes dirty so it is undesirable to have it flowing over too many layers of fish. The box should be capable of being cleaned easily, and should not taint or contaminate the fish. It should be robust enough to withstand rough handling on board ship and should where necessary be suitable for onward transit on shore, leaving the contents undisturbed. In tropical fisheries, where it may not be possible to keep the boxes in an insulated fishroom, it is an advantage to insulate the box itself and fit it with a lid, so that it can be used for onward carriage on land without the need for an insulated road vehicle.

Stowage in a box should consist of a bottom layer of ice, about 5 cm deep, layers of fish sprinkled with ice, and a final top layer of ice again about 5 cm deep. As with bulk stowage, the test of whether enough ice has been used is how much is left when the box is discharged; in tropical fisheries, particularly, the thickness of the top and bottom layers may have to be increased if little or no ice remains on and among the fish on landing.

Some fishermen tend to overfill fish boxes with a resultant loss in quality, yield and shelf life. Overfilling boxes to the extent that fish are protruding above the edges of the box results in the fish being crushed when the boxes are stacked. Overfilling also means that the space available in the box for ice is reduced and insufficient ice may then be added to last the entire storage period (Fig. 23).

Fig. 23. Box stowage

The species of fish, seasonal variability and intrinsic quality are factors which will greatly affect the extent of losses incurred by overfilling so that the following results from boxing trials are only indicative of likely losses. The results are from one trial with haddock, but in another with similar fish of a poorer intrinsic quality the results were significantly different.

Standard nest/stack type plastic boxes designed to hold 30 kg of fish and 15 kg of ice were Overfilled with 50 kg of fish and stacked 7 to 8 boxes high for a period of 6 to 7 days and a comparison made with good boxing practice.

The following losses were incurred:

3.3% extra drip loss
8.8% less fillet yield, mainly due to the need to trim damaged fillets
2 days loss in potential shelf life based on a taste panel assessment

The above are overall losses but there were significant differences depending on the location of a box within the stack. The best results were for fish in boxes on top of the stack and the greater losses were evident in boxes at the bottom.

Boxes at the bottom of a fishroom should be on battens to keep them off the floor, and the intervening air space should be filled with ice. Alternatively, the bottom layer of boxes can be charged only with ice to provide the necessary thermal barrier. Similarly, boxes against ship's sides or bulkheads should be supported by battens with ice between the boxes and the lining, particularly when the fishroom is uninsulated. Robust boxes can be stowed full height in a fishroom without any supporting structure in the form of stanchions and shelves, so that full use can be made of the stowage space.

If full advantage is to be taken of boxed, iced stowage, the buyer at the landing place has to be prepared to buy by sample. If every box has to be emptied and the contents checked for quality and weight, the catch may be handled and disturbed as much as when stowed in bulk, However, if a sample box (or boxes) is truly representative, the balance of the catch can be taken on trust and the whole operation of discharge and sale can be simplified.

How much ice should be used at sea?

A simple rule of thumb has already been given, one tonne of ice to 2 tonnes of fish in temperate waters, one tonne of ice to one tonne of fish in tropical waters. Many factors can affect the amount of ice required. Sea and air temperatures, the insulating efficiency of the fishroom or the container, the size and temperature of the fish as they come out of the sea, delays in handling the fish, the efficiency of icing, the mean temperature of the fishroom and the length of the voyage all have an effect. The only safe way of judging the ice required in a particular fishery is to examine the catch on discharge. The core temperature of the fish should be close to 0°C and there should be a reasonable amount of ice remaining amongst the fish. Otherwise insufficient ice has been used. Particular attention should be paid to vulnerable parts of the stowage such as, fish close to ship's side or tanktop, boxes against a bulkhead and so on.

Further points on good stowage practice

After completing the stowage of a haul of fish, the top fish should be covered with a protective sprinkling of ice, even though the shelf or box is not full.

Draughts of warm air, for example from open hatches, should be excluded from the fishroom.

Extra ice should be used wherever the insulation is known to be poor or for example, against an engine room bulkhead, to absorb the incoming heat.

Additional ice should be used on the topmost layer of fish to protect it against heat from lights, warm air and a hot deck. Even where cooling grids are fitted, extra ice on the top of the fish will reduce the risk of unwanted drying and partial freezing. Lights should be switched off, and hatches closed, when not in use.

Remote reading thermometers should be fitted at appropriate points in the fishroom so that air temperature can be monitored throughout the trip. Deck awnings should be rigged when the deckhead temperature is high, and if necessary, the deck should be hosed to reduce the amount of heat entering the fishroom.

Ice which becomes contaminated during the trip, by fish or dirty boots for example, should be discarded and not used for stowage.

Fishroom design and equipment

Provided sufficient ice is available, fish can be stowed satisfactorily in almost any kind of container. It is obviously desirable to have a structure that is durable, hygienic, convenient for stowage and discharge, and resistant to entry of heat.

Insulation. The ice in an unrefrigerated fishroom has to absorb the heat coming into the fishroom as well as cool the fish. Insulation can help to keep the ice consumption at a reasonable level, especially in warm seas. Insulation should be all round the fishroom or stowage space, not just on the deckhead. About two thirds of the fishroom is surrounded, more often than not, by warm water so that insulation on ship's sides and tanktop is just as important as on the deckhead and bulkheads. The insulating material should not absorb water, and should be capable of being inserted in all the awkwardly shaped spaces between beams or frames, around drains and stanchions and so on. Cellular expanded plastics are often most suitable for fishroom insulation. Where wood is used for, or behind, the lining of an insulated fishroom, it must be protected by a suitable preservative against rot, since damp air will inevitably penetrate behind the lining. In temperate waters, about 5 cm of an expanded plastic insulant is usually sufficient for a chilled fishroom, but in tropical waters a layer of insulation 10 cm thick may be necessary to give adequate protection.

For boxed stowage, no internal fishroom structure is normally necessary; for bulk stowage, the shelves and partitions should be portable and of simple design. Boards should as far as possible be of the same size, easily cleaned, and sufficiently strong. As much as possible of the internal structure should be removable, so that ice can be easily placed wherever it is needed without having to manoeuvre round intervening partitions.

Refrigeration. The simplest form of fishroom refrigeration, other than the use of ice, is the fitting of cooling grids on the deckhead and sometimes also on bulkheads and ship's sides. The ability to precool the fishroom on the way to the fishing ground without using too much ice is particularly useful in tropical waters. But the cooling coils cannot be expected to chill the catch effectively, only ice can do that job. Once fishing has begun, the main function of the cooling coils is to cope with heat leaking into the fishroom, and to cool warm air coming in through open hatches, leaving the ice to do the main job of chilling the fish. The refrigeration system should be controlled by a thermostat, with the bulb carefully placed so that it is representative of the average fishroom air temperature. It should be set to cut out at about 0.5°C and to cut in at about 2°C. Fans should not be used to blow air about the fishroom, since the fish will dry out rapidly wherever they are exposed to moving air.

Reliable and sufficient insulation, together with ample ice, augmented where necessary by a simple deckhead cooling coil, usually suffice to protect the catch in any climate.

Dos and Don'ts of good stowage practice: A summary

If the fishing vessel is decked and has a proper fishroom, stow the fish below in ice as quickly as possible. If not, do not delay chilling.

Adequate icing is essential even on the shortest voyages; fish begin to spoil as soon as they are dead, and they go off four times more quickly at 1 0°C, the temperature on a cool day, than at the temperature of melting ice.

Always use clean fresh ice; discard dirty ice and ice left over from a previous trip.

Use small pieces of ice; large pieces mark the fish and may not chill as quickly.

Use plenty of ice; a layer below the fish, more ice among the fish and another layer on top. This applies whether stowage is in boxes or in bulk on supporting shelves.

Even when fish have not been gutted, do not delay, ice them quickly.

Don't overfill a box or shelf; the next box or shelf on top will squash the fish below.

Don't leave out shelves even when fishing is heavy; fish will be crushed and lose weight.

Use too much ice rather than too little; there should always be plenty of ice left among the fish when you land.

Put extra ice against linings and bulkheads where most of the heat leaks in.

Put a thick layer of ice on top of fish close to the deckhead; this protects them from warm air and stops then drying out.

Don't pack fish so tightly that melt-water cannot flow; the fish are chilled more rapidly when ice cold water runs over them, but fish in a stagnant puddle of water and blood can spoil quickly.

Lay gutted fish belly downwards, so that puddles of dirty water cannot lie in them.

Lay battens under the bottom-most boxes to keep the fish off the warm floor, and to prevent bilge water contaminating them; put some ice between the battens.

Keep boxes off the engine room bulkhead by fitting vertical battens; put ice between these as well.

Put off fishroom lights whenever they are not required. Open only one hatch at a time, and close it whenever the work is done.

Do not operate the fishroom below 0°C or above 2°C.

If the vessel is undecked, box the fish with ice and protect the boxes with a cover of some kind, preferably with good insulating properties; ice can be carried out to the fishing grounds in the empty boxes.

Use insulated boxes where practicable in the tropics, particularly if the fish can remain in them for onward inland transport.

If ice is not available at your port, find out if there is sufficient support among other catchers and merchants for a small ice plant, perhaps on a co-operative basis; the improvement in quality is always very much worthwhile.

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9. Chilling fish on land

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At the quayside

Lean fish. Where fish have been chilled to ice temperature at sea, they should be handled on shore so that this temperature is maintained, as far as possible, throughout the distribution chain. Once the fish are allowed to warm, it is extremely difficult to chill them again. Where fish are landed without ice, they should be chilled in ice as soon as possible after landing.

At large ports, where the catches from a number of vessels may be sold at the same time, discharge may have to begin several hours before sale time. Fish left for hours on a warm quayside without much ice on them can warm rapidly, particularly in tropical countries.

At smaller ports, or at landing places where no marketing facilities exist, the fish are sometimes landed and carried away immediately, but whenever there is a delay at the quayside the fish should be well iced. Where there is no covered market, the iced fish should be protected from the sun by covering the boxes in some way. A temporary awning or shelter can be rigged, an insulated blanket can be used, or at the very least a tarpaulin can be laid over the stack of boxes.

If adequate icing at the quayside is impracticable, delay in moving the fish away should be avoided. For example, some mechanical handling may be possible at larger ports and careful timing of the arrival of transport can prevent unnecessary warming of unprotected fish (Fig. 24).

Uniced fish may be as warm as 15°C on landing in temperate climates and perhaps 30 to 35°C in the tropics. Unless the fish can be cooled rapidly on shore, the catch will deteriorate in a very short time. Ice must be distributed throughout the fish to chill them effectively. Warm fish in boxes which are stacked together will remain warm when ice is sprinkled only over the top of the stack. Each box must have ice in it to chill the contents and, where it is possible only to ice the top of the box, a shallow box is better than a deep one.

Fig. 24. Handling fish at small ports

Chilling is equally important once the fish have been sold. They should be removed from the market as quickly as possible and kept iced until they are sold to the consumer, or used for processing.

Fatty fish. Because mackerel and other small fatty fish are usually caught in quantity over a fairly short period of time and often not far from port, they are usually of fairly uniform quality on landing. Sale can often be by sample, and the main bulk of the catch can be unloaded direct from fishing vessel to road vehicle without delays on the quayside. If the fish are going to a factory near the quay at a large port, it is sometimes practicable to move the fish from the vessel's fishroom to factory reception by pump or conveyor.

It is sometimes impracticable to ice small fatty fish adequately at sea, and in any case the voyage to port may not be long enough to allow the ice time to chill the fish properly. It is therefore all the more important to chill them once they are landed. Again, ice over the top of a large heap will be ineffective; the centre of the heap will remain warm for a long time, and fish at the bottom will be crushed. The catch must be split into small lots, and each lot iced separately, so that chilling can be rapid.

Alternatively, refrigerated seawater can be used to chill large quantities of small fatty fish, either at the quayside or, if they are going to a nearby processing plant, at the factory itself. Uniced herring, still warm on discharge from the ship, dispatched to a factory or market some distance from the port, can be completely spoiled at the end of a journey of only a few hours' duration.

Shellfish. In many cases shellfish are landed live a relatively short time after catching. During this period it is usually sufficient to cover the shellfish so that they are not exposed to direct sunlight and, with most species, it is also necessary to keep the shellfish moist. On landing, the shellfish should be iced as soon as possible and mixed intimately with the ice to ensure quick cooling. If the fishing trip is of longer duration the advantages of rapid chilling by icing are just as important as for fish. Since shellfish are usually more valuable than other types of fish, more generous quantities of ice are used in order to ensure that sufficient is available to maintain the fish at chill temperature in the event of any unforeseen delays.

At the port merchant's premises

When fish are sold at the quayside to a port merchant or processor they should be moved to his premises as quickly as possible. His main functions may be simply to pack and transport them to the main centres of population, or to process the fish in some way, perhaps filleting, smoking, salting or drying, or possibly quick freezing followed by cold storage for long term preservation. Whatever the ultimate outlet for the fish, the handling of the raw material is much the same.

As soon as the fish arrive at the merchant's premises from the quayside, they should be iced or re-iced if they are not to be processed immediately. It is not sufficient to put the fish in a chillroom without ice; cooling will be very slow because air is a poor conductor of heat. The fish should first be mixed with small pieces of ice and then put in a chillroom so that the job of the ice will be confined to chilling the fish and not the warm air outside. A chillroom can be used to keep fish that have already been chilled to ice temperature, but even then some ice is needed on top of exposed fish to stop them drying out.

Ungutted fish may require to be gutted as a first procedure on shore, because the contents of the intestines rapidly decay and spoil the surrounding flesh. Further dressing, such as heading, filleting or splitting, will depend on market requirements. Any operation should be done in cool surroundings;

during delays the raw material should be protected by the judicious use of ice and chillrooms.

When filleting is done by hand, the fish are usually kept in a tank or trough of water and taken out one by one. The water in the trough is often warmer than the fish, and the fish warm up. Where practicable ice should be added to the water in the filleting trough to chill it or, all process water can be put through a central chilling system. As soon as enough fillets have been cut to fill a box, the top of the box should be iced over, and the box removed to chill storage. Whatever other operations are carried out, whether by hand or machine, the same principles apply; keep delays between operations as small as possible. Wherever practicable, use ice to keep the product chilled at every stage.

Typically, fish warm considerably during handling and processing. Even in temperate climates, although the fish entered the premises close to 0°C, the fillets produced a few hours later may reach 1 0°C or more by the time they are to be packed. Such temperature excursions result in a measurable increase in the rate of spoilage or loss of quality.

Retail display

Fish on display in a shop should be kept on a bed of ice. A further sprinkling of pieces on and around the fish will keep it chilled efficiently and enhance its appearance to the customer.

Insulation beneath the display counter will help to conserve the ice and it is possible to use a refrigerated display unit, provided the temperature is kept above ice melting point. The fish should not be displayed without ice in such a unit. As in the chillroom, uniced fish will dry out, become dull and unattractive, and may become partially frozen. Temperature control of refrigerated display units is sometimes difficult and inaccurate, but ice is its own thermostat.

A glass or transparent plastic shield round the display area will help to maintain a pool of moist air around and above the fish, and will restrict draughts of warm air which can dry the fish. Fish on display should be in thin layers so that they can be kept adequately chilled; fish piled high will warm up and remain warm. The display unit should be hygienically designed and have adequate drainage, so that the fish do not become waterlogged or contaminated by dirty melt-water (Fig. 25).

Smoked fish products should not be laid directly on ice, but they can be displayed in the same unit as fresh fish simply by putting the fish on trays laid on the bed of ice. As with fresh fish, the main stock of smoked fish should be kept in a chillroom, and only small amounts displayed for sale at one time.

Finally, it should be remembered that fish remains fresh only for a limited period even when surrounded by liberal quantities of ice. Stock should be replenished at frequent intervals and, if there is any doubt about the freshness of fish, it should not be sold. If in doubt, throw it out!

Fig. 25. Retail display of fresh fish

Icing practice for transportation

Once the fish have been dressed or filleted to suit the needs of the market, they are then packed in containers for onward distribution from the port. All too often, insufficient ice is used for the journey, and put in the wrong places.

An interesting method used in East Asia to pack medium or large size gutted fish is shown in Fig 26. The plastic foil used reduces heating up of the fish by protecting the content of the basket from heat gains, which would be due to air convection and diffusion of moisture during transport.

The ice packed in a box of fish is intended to do two things, firstly to chill the fish to 0°C and secondly to keep it at that temperature, despite the heat entering the box from its surroundings. Fresh fish is rather a poor conductor of heat, that is to say the heat takes a long time to pass through the fish. It is common practice in some fisheries to pack fillets about 10 cm deep in a box with a layer of ice 2 to 3 cm thick on top; it takes about 24 h to cool fillets from 1 0°C to 0°C in this way. The time taken for a fish or fillet to cool depends on its distance from the ice layer, as explained in Chapter 2, so that fillets at the bottom of the box cool very slowly indeed; even when there is ice remaining on top of the fish at the end of the journey, there may still be fillets at°5 C or above in the box. Ideally, the fish or fillets should be cooled close to 0°C before packaging.

It is thus very important to put ice in the right places in the box. If ice is placed only at the ends of the box, for example, it may take several days to chill the fish in the middle of the box, if they are ever chilled at all.

In other words, ice correctly and check temperatures whenever possible as well as observing the presence or absence of ice during transportation.

Fig. 26. A manner of icing gutted fish

Fig. 27. How to ice a box of fish or fillets

The best practice for boxes of fillets is to place a layer of ice in the bottom of the box and a layer at the top (Fig. 27). Provided enough ice is used in the first place, all the fish should then reach their destination after a journey of several hours with temperatures close to 0°C. The fish in the centre are the slowest to cool, and the thicker the layer of fish, the longer cooling takes. Table 15 shows that after 18 h with a layer of ice only on top, a 7.5 cm layer of fish initially at 1 0°C has cooled only to 4°C. When the fish are iced top and bottom, it can be seen from Table 16 that it takes four times as long to chill a layer 15 cm thick as it does to chill a layer 7.5 cm thick. Although the initial temperature of the fish has some effect on the time taken to cool it, the thickness of the layer has much more effect, as shown in Table 16.

Table 15. Time to cool a layer of fish iced only on top

Thickness of layer (cm)	Time to cool from 10°C to 4° C (h)	Time to cool from 10°C to 2°C (h)
1.3	<1	4
2.5	2	18
5.0	8	>24
7.5	18	>24

Table 16. Time to chill a layer of fish, well iced top and bottom, from various starting temperatures

Thickness of layer (cm)	Starting temperature at centre of box (°C)	Time to chill to 2 C at the centre (h)
7	5	1.5
7.5	10	2
7.5	15	2.75
15	5	6
15	10	9
15	15	2.5°C after 10

Number of boxes required

It is relatively easy to calculate the number of boxes required for each load of fish if the proportions of fish to ice are known. However, if the fish have to be graded either by species, size, source or other criteria, the box requirement will invariably increase, since all the boxes may not be fully utilised. In these situations a contingency factor will require to be applied, which may be based on previous experience or a reasoned estimate.

When considering the box requirement, it is also necessary to examine the total operation and determine likely box movements and locations. The best way to do this is by plotting, step by step, the box movements over a few days to establish both the normal pattern and, also, the consequences of stoppages at weekends and at other times. The box requirement is then worked out to ensure that there will be no delays in handling the fish, and a further factor applied to allow for losses and damage.

Box movements can be plotted as a line diagram showing the various routes, and operations. The example shown in Fig. 28 is based on a fish collection and processing operation where the following conditions apply:

1. Small boats supply fish to a collecting centre where the nominal daily maximum catch is iced in 150 boxes ready for transfer to the processing factory.
2. A trawler also supplies the collection centre with 150 boxes of fish daily.
3. The trawler's catch is boxed at sea and this may be reboxed at the collection centre or transferred to the factory in the same box.
4. All fishing craft leave at 0500 h and land their catch at 1100 h daily.
5. The work at the collection centres is completed by 1800 h and the fish are transported to the factory to arrive at 2400 h.
6. Boxes are stored at the factory overnight.
7. The boxes are emptied and washed next day and are ready for returning to the collection centre by 1200 h.

The procedure used to arrive at the final box distribution diagram, shown in Figure 28, is sometimes one of trial and error. The main requirement is that boxes must be available at each stage for stowing the fish and, in this case, the starting point was the need to have 300 filled boxes at the collection centre ready for transporting fish to the factory at 1800 h. In addition, if the trawler fish was reboxed, there would be 150 dirty boxes to go for washing. The daily pattern clearly shows that 900 boxes are required to sustain the fish collection system and, with a contingency factor of about 10%, 1000 boxes should be purchased. If it is anticipated that the pattern will change during the week, the movement of boxes will need to be determined over a longer period.

In the above example, other containers were used on the small fishing boats, and between the landing places and collection centre. If this is also an integrated boxing system, a similar box location diagram will be required to determine the number of boxes for this operation.

In order to avoid contamination of the finished product, fish are washed prior to processing, and boxes used for transportation are also kept separate from the boxes used in the factory. Again, it will be necessary to prepare a box location diagram for the factory operation in order to determine the number of boxes required.

Fig. 28. Box distribution diagram

Air shipment of chilled fish

Seafood packaged for transport by air usually has to conform to exacting standards laid down by individual airlines. These standards are mainly set to avoid the possibility of leakage from the packages which in the past has resulted in corrosion of airframes and contamination of other goods. Standards are also set for package weights and dimensions and these may depend on the type of aircraft.

The following information on packaging for air shipment is based on current practice in both the USA and Australia. The methods described will conform with the standards set by most carriers. It is essential that shippers of chilled seafood check with all airlines involved to ensure that their proposed method of packaging is acceptable.

The product should be prechilled before packaging, and prechilling the packages and containers will also be helpful. Prechilling reduces the quantity of coolant required and thereby reduces the weight and space requirements. Quick prechilling is also good practice since it eliminates the possibility of a long cooling period during which spoilage proceeds at a faster rate.

An early consideration is the selection of suitable packaging materials. Different products may have different requirements in order to achieve durability and water tightness and also provide the necessary insulation properties at as low a cost as possible. Local considerations may also influence the choice of materials.

Both the coolant and the product may be required to be packed in water- tight sealed bags. Polyethylene is suitable for this purpose and the thickness should be suitable for the type of product. Thicker material, for instance, may be required for shellfish if there is a greater likelihood of the bag being punctured. Absorbent material is often placed within the container even when there is no fluid loss from either the product or the coolant. Under certain conditions, water vapour in the surrounding air may condense on the cold outer surfaces of the packages and this should not be allowed to leak or be absorbed and thereby weaken the material used for the outer container.

Although high quality insulation such as polyurethane may be expensive it may be more economical to use. Better quality insulation will reduce the coolant requirement or, if the same insulation value is maintained, the better insulation properties of the polyurethane will reduce the insulation thickness and thereby save space. Expanded polystyrene is another popular insulation material. Although this material is waterproof and light, it has poor impact resistance. Consequently, when polystyrene boxes or containers are used they should be placed inside a strong waterproofed cardboard carton as protection against damage. When containers are made from materials such as cardboard or fibreboard, they should be waterproofed by applying a polyethylene coating or by wax impregnation.

Coolants such as gel refrigerants, dry ice (solid carbon dioxide) and water ice are all used to cool fish transported by air. Gel refrigerants have the advantage that they do not produce any gaseous or liquid effluent during the storage period. If they are used on a non-return basis they will prove to be more costly than the other coolants. When dry ice is used, gaseous carbon dioxide is evolved. This displaces oxygen in confined spaces, so dry ice is classified by airlines as a potentially dangerous substance and is subject to special regulations with respect to how and where it can be used. One precaution to be made is that the carbon dioxide gas must be vented to prevent rupture of the package or container. There may also be regulations to limit the quantity of dry ice which can be loaded into the hold of an aircraft. Therefore each package should be labelled showing the initial weight of dry ice used. The cargo handling office of the airline will advise on the packaging and labelling instructions to be followed.

Water ice has less cooling capacity for a given weight than the other coolants but, providing it is retained within the container, it is harmless and relatively cheap. Water ice also controls the temperature at a desirable 0°C, whereas, with the other coolants, care has to be taken to ensure that there is no partial freezing of the product. The coolants should be arranged within the package to ensure uniform cooling (Fig. 29).

Container storage of chilled fish

Generally, boxes are containers which can be lifted easily by one or two persons. A storage container can be classified as a unit which is bigger than a box but is not a fixture in a fishing vessel, chillroom or transport vehicle. Containers may be insulated or uninsulated, but generally when this type of storage is used in tropical climates the containers are insulated. The one advantage of using larger containers rather than smaller boxes is that it is more economic to insulate one larger container. Containers are therefore more likely to find a use in tropical countries than in cold or temperate countries where ice meltage rate is lower.

The arguments against deep bulk storage and consequent crushing of the fish may also apply to containers. The optimum size of container usually means a storage depth of about one metre, but it is recommended that storage depths of fish should be limited to about 300 mm. However, a case can be made for the use of containers, and they are now available in a wide range of sizes, shapes, materials and insulation properties.

Insulated containers and chill stores

Uninsulated boxes may be stored in large insulated containers or insulated stores to achieve savings in the icing requirement. The likely magnitudes of these savings of ice are shown in the Table 17, which compares the relative ice meltage rates for a number of iced storage methods.

Figure 29 Packaging for air shipment

Table 17. Relative ice meltage rates

	Fish holding capacity (kg)	**External surface area (m^2)**	**Relative ice meltage per unit weight of fish**
Uninsulated box	30	1.19	10.64

Insulated box	30	1.47	8.08
Insulated container	240	5.06	2.59
Insulated room	2400 (80 boxes)	34.5	1

As can be seen from Table 17, insulation of a fish box significantly reduces the ice meltage rate during storage. Increasing the unit size to an insulated container also reduces the ice requirement. Storage in a larger insulated room, even if the boxes are uninsulated, will result in a further reduction in the ice meltage rate.

Ice usage can be reduced to an almost negligible amount by storing the fish boxes in a refrigerated space. In most cases, the additional refrigeration cost can be more than offset by the savings in ice. This system is often used where it is important to save storage space as well as reduce ice meltage. The use of uninsulated boxes and the absence of large quantities of ice allow a greater payload of fish to be carried. Typical applications (of refrigerated systems) are on larger fishing vessels and during transportation.

Some of the benefits described above in terms of reduced ice meltage are based on simple relationships determined for a single box or container which do not truly reflect commercial conditions. For instance, fish boxes are usually stacked and under these conditions ice meltage for a load of fish will be considerably reduced. However, it is reasonable to consider only one box or container as a guide. Icing practice must be suitable for all eventualities. Boxes may either be stored singly or be located on the outside of a stack where meltage will be much the same as for individual units.

The choice of an insulated box will not only depend on the potential ice savings achieved during normal storage but also on the conditions during the entire handling and storage period. For instance, if boxes are exposed to high ambient temperatures, even for a relatively short time, it may be necessary to have them insulated since all the benefits of using insulated or refrigerated rooms for most of the rest of the storage period may be lost. The type of container and the choice of materials used in its construction not only depend on potential ice savings but also on other costs, hygiene, availability of materials and handling aspects.

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10. Temperature measurement

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This chapter gives advice on how to measure the temperatures in and around fish, which influence its keeping qualities and handling and processing requirements.

Temperature is the most important factor controlling the rate at which fish go bad. For instance, as mentioned in Chapter 1, cod will remain edible for up to 15 days at a temperature of 0°C, whereas it may be unfit to eat after only 6 days at 5°C. Therefore it is important to know the temperature of the fish to a reasonable degree of accuracy.

Thermometers

To many people a thermometer means only the familiar mercury-in-glass type. This relies on the expansion and contraction of mercury to indicate the temperature on a calibrated scale. However, this type of glass thermometer is unsuitable for measuring the temperature of fish. This is because of the danger of breakage, the slowness of response to temperature change and the comparatively large temperature-sensitive bulb which does not allow spot measurements to be taken for example, at the centre of a small fish. Glass thermometers protected by a metal casing are suitable for temperature control checks in a number of processes but, again, they should not be used where breakage might lead to dangerous contamination of the fish.

Changes in temperature also change other properties of materials, such as electrical resistance, and thermometers can be constructed based on measurement of these changes. Generally, they are now constructed as compact, hand-held units which give a direct digital readout of temperature and utilise probes, safe to use with fish.

A brief description follows of various types of sensor which are commonly used for fish temperature measurement and also for temperature control during fish handling and stowage.

Thermocouples. When two lengths of wire made from different materials are joined at both ends to form a closed circuit, any difference in temperature between the two junctions will cause a small voltage to be generated. This tiny voltage is related to the difference in temperature. Thus, if one junction is kept at a fixed temperature, it is possible to measure directly the change in temperature at the other. The voltage is usually measured by an instrument called a potentiometer which can be constructed to give the temperature directly. The thermocouple is made in the form of a twin-core insulated cable using wire to suit the particular requirement. The temperature sensitive junction is a minute welded or soldered junction giving a rapid response, and can be incorporated in a hand probe suitable for direct insertion into fish. The wire of a thermocouple can be any length without altering the calibration of the instrument. It can be used therefore for remote reading of temperature only if compensated voltage, currentless equipment is used. Instruments for use with thermo-couples can be made to show either a single reading on a dial or a number of readings in succession by means of switches. Alternatively, the temperature can be recorded on a chart. Thermocouples made for temperature measurement of fish and fish processes are usually made from copper-constantan (type T), but care should be taken to ensure that the material specification is within the range of the instrument's calibration.

Resistance thermometer probe. This instrument depends on the fact that the electrical resistance of a metal changes with temperature. Fine wire of a suitable material is wound into a minute coil and this may be constructed in the form of a probe suitable for inserting in fish. The probe is connected by a flexible cable to a portable instrument which gives a reading on a temperature scale. Some of these instruments are not equipped with compensation for cable resistance so the length of the cable is important. This type of instrument may not be used indiscriminately with varying lengths of cable.

Thermistor probe. The electrical resistance of some semiconductors exhibits large changes with temperature variation. This property is applied in thermistor thermometers and, for most purposes, this type of instrument can be used in a similar manner to a thermocouple. However, unlike thermocouples, thermistor junctions cannot be made readily by the user. The instrument and temperature sensitive probes have to be matched carefully.

Dial thermometer. This type of thermometer is designed to give a permanent visual indication of temperature. It may be used to indicate the temperature of chillrooms, fishrooms, brine tanks, RSW systems and for many other similar applications. The instrument consists of a liquid-filled bulb, connected by a narrow tube to a dial which indicates temperature. Similar instruments rely on the expansion of a gas within the bulb or changes in the vapour pressure of a liquid to operate the dial. These instruments are available with a range of tube lengths not normally greater than 5 to 10 m. The degree of accuracy and rapidity of response, although a good deal less than the probe type instruments described above, can be selected to suit the application. Stainless steel and other noncorrosive materials should be used to construct the temperature sensitive elements for fish processing applications.

Circular chart recorder. The simplest form of this instrument works on the same principle as the dial thermometer but, instead of a temperature indicator, the temperature sensitive element is mechanically coupled to a pen which continuously records the temperature on a chart. Charts are normally suited for 24 hour or 7 day operation and this type of instrument is often used for process control.

Temperature measurement of fish

It is important to know the temperature of the warmest fish in a batch since the quality as a whole may sometimes be dependent on this data. The warmest fish may be at the centre or the outside, depending on whether the fish are being cooled or warmed at the time of measurement. It is advisable in any event to take a number of readings at random. For example, in a stack of boxed fish, boxes from the centre, the outside, the top and the bottom of the stack may be selected, and the temperature of individual fish within each box taken. Thermometers which respond slowly are not suitable for measuring fish temperatures. A thermometer with a large sensitive element would also be unsuitable since often the temperature at a precise position in the fish or package is required. Many probe type thermometers are suitable and these should be inserted in the fish so that the temperature sensitive element at the end of the probe is located at the point to be measured with at least 75 to 100 mm of the probe in the fish, if possible (Fig. 30).

Fig. 30. Insertion of thermometer in fish

This eliminates any error introduced by conduction of heat along the probe. An instrument for this purpose should have an accuracy of +/-0.5°C. The scale should be graduated in not less than half degree divisions.

The following guide rules should be remembered when measuring fish temperature:

1. Always measure the most significant temperature; that is check those fish which are slowest to cool or quickest to warm, or at the highest temperature.
2. Penetrate the fish with as great a length of the thermometer as possible to avoid errors due to conduction of heat.
3. Measure the temperature quickly with little or no handling of the fish.
4. Use an instrument that responds quickly to temperature changes and which reads to within one quarter of a degree of the true temperature.
5. Use an instrument with a small temperature sensitive element.

Measurement of process temperatures

Keeping a continuous record of temperature at all stages of processing is good practice and should be encouraged. If the plant is big enough, a network of thermometers with a continuous chart recorder or data logger may be considered, otherwise circular chart or dial thermometers may be used.

An instrument used for indicating chillroom temperatures should be capable of detecting small changes in the temperature fairly quickly and the detector bulb should be placed to indicate temperature fluctuations caused by such things as opening of the door. It should not be so near the door or cooling grids that it registers a temperature unrepresentative of the chillroom as a whole. In a large room, at least two thermometers should be fitted, particularly where there is likely to be uneven temperature distribution due to the position of the coolers and doors. If there is any doubt about the positioning of room thermometers, a temperature survey of the room should be made to ascertain the temperature pattern. Then the thermometers should be placed in positions which give representative temperatures.

When temperatures are measured in the fishroom of a fishing vessel, the requirements are much the same as for chillrooms. In both cases, when a position has been chosen to give a temperature representative of the room, this should also be the location of the temperature sensitive element of the refrigeration system's thermostatic control. The scale markings on the indicator should be in divisions of not more than one degree and the instrument indication should not deviate by more than one degree from the true temperature.

Preferably, other process temperatures should be recorded, since at least the changing of a chart ensures periodic checking of the temperature history. The instrument should be robust and its accuracy should be commensurate with the requirements of the process. Apart from these general rules, the instrument should be specially selected for the particular application.

In some modern processing plants, temperature monitoring and control often forms part of a totally integrated system of plant monitoring and control which may be interfaced to a computer programmed for display, alarm settings and analyses.

Calibration of thermometers

All thermometers need to be checked at frequent intervals as a routine. Invariably each instrument has some means of resetting if it should be in error. The most suitable method is to check the instrument over its whole range against a certified standard thermometer, but a single check at only one point may be satisfactory. Ice made from water of domestic quality will melt at 0°C and, for most thermometers used for chilling operations, a single check at this temperature will be acceptable. At least a bucketful of a mixture of ice and water should be used with the ice finely crushed; the water added should be clean tap water. The ice-water mixture should contain a high proportion of ice once the temperature has stabilised at 0°C, and the mixture should be vigorously stirred while temperatures are being checked.

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11. Technical terms

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Knowledge of some of the terms associated with heat transfer will promote a better understanding of the elements which contribute to the effective cooling and storage of chilled fish.

Hot and cold

Hot and cold are only relative terms and therefore do not give a quantitative expression of either the heat content or temperature of a body.

Heat

Heat is a form of energy; it is the addition or removal of heat which results in a temperature change or a change of phase. It is therefore easier to understand what is happening during cooling if this is correctly thought of as a transfer of heat and not as the addition of something called "cold". Heat can be measured, "cold" cannot. Heat transfer occurs in the direction of decreasing temperature. In simple terms, this means that fish cannot be cooled without using something colder to act as a recipient for the heat to be removed from the fish. For instance, if ice is colder than the fish, heat can be transferred from the fish to the ice, and the fish are thereby reduced in temperature.

Specific heat

Specific heat is heat which results in a temperature change. The specific heat of a substance is a measure of the quantity of heat required to raise a unit mass of substance one degree in temperature provided that no phase change occurs. The specific heat of pure water is one calorie per gram under specified conditions. Therefore, if the specific heat of fish is given as 0.8, it is both an absolute value of 0.8 calories per gram and the ratio of the specific heat of the fish to that of water. Specific heat may not be a constant value, but can vary with temperature, for example. Specific heat values may also change with a change of state. For instance, the specific heat of frozen fish is about 0.4, which is approximately half the value of the specific heat of unfrozen fish.

Phase change

The three phases in which a material can exist are solid, liquid and vapour/gas. Thus, if water is frozen to form ice, it has experienced a phase change. Similarly, there is a phase change when water is evaporated to form a vapour. Ice melts to give water and vapour condenses to give water.

Sublimation

It is possible for a material to experience two phase changes at the same time or, more correctly, to miss out the intermediate phase, for instance, by changing from a solid to a vapour. If ice changes directly into a vapour without first becoming a liquid, this double phase change is known as sublimation. Sublimation also occurs when frozen fish dehydrate during low temperature cold storage.

Latent heat

Latent heat is the amount of heat absorbed or evolved by a unit mass of material during a phase change. Thus, there is a latent heat of liquification (when ice turns into water), a latent heat of evaporation (when water turns into vapour) and, a latent heat of sublimation (when ice turns to vapour). In each of these phase changes heat is added but, if the changes are reversed with a change of vapour to liquid, liquid to solid or vapour to solid, heat is removed or lost during the phase change.

Heat transfer

If a substance experiences a temperature change or a change of phase then a transfer of heat has occurred. Heat is transferred in three basic ways: by conduction, convection and radiation. In most practical situations where a heat transfer takes place, two, or even all, of these heat transfer methods may apply.

Conduction

Conduction is heat transfer achieved by direct contact. Fish being cooled by direct contact with ice will experience heat transfer by conduction.

Convection

Convection is heat transfer by natural or forced movement of a fluid (liquid or gas). Fish in a chillroom can be cooled by convective heat transfer due to natural circulation or fan circulation of the air. Similarly, fish in refrigerated seawater are cooled by convection resulting from the pumped circulation of the chilled water.

Radiation

Radiation heat transfer from a heat source to a body is achieved without heating the intermediate space and without the need of an intermediate material. Fish will be exposed to radiated heat from the sun if they are left uncovered outdoors. Fish exposed to a light source indoors will also experience a radiant heat transfer.

Newton's Law of Cooling

The rate of cooling of a hot body which is losing heat both by radiation and natural convection is proportional to the difference in temperature between it and its surroundings. In practical terms, this means that when fish is cooled in ice, the initial cooling rate, when the temperature difference is greater, will be higher than the cooling rate later, when the temperature of the fish has been reduced.

Factors affecting heat transfer rates

Whether heat transfer is in a steady state, for example between outside air and a chilled container, or in an unsteady state, for example between ice and a fish being cooled, the factors affecting it are similar.

The rate increases with increasing temperature difference, with larger heat transfer coefficients, and with larger surface areas.

Factors affecting rates of temperature change

It is important to distinguish between the rate of heat transfer and the rate of temperature change. For example, if we have two fish of similar shape, one 40 cm long and the other 30 cm long, the surface areas would be in the ratio of about 16:9. Thus, if both were cooled by melting ice, the heat transfer from the larger fish would be almost twice as much as from the smaller. However, the mass of the two fish is likely to be in the ratio of about 64:27. The temperature change depends on specific heat, and on mass, so although the larger fish has a higher heat transfer rate, it has a lower rate of temperature change. For small thicknesses of material, the ratio of mass to surface area is an indicator of the rate of temperature change. When considering fish in ice, the other factors are fixed, so that mass to surface area is the only variable (since mass is essentially proportional to volume, this ratio can be taken as volume to surface area). Small fish can be chilled more quickly than large fish; flat fish or fillets more quickly than round fish of the same thickness (but generally more slowly than round fish of the same weight or length).

When very large thicknesses of material are to be cooled, heat transfer through the material itself becomes significant. No matter how good the surface heat transfer is the actual cooling rate is approximately proportional to the square of the material thickness.

Thermal conductivity

Heat transfers through substances at different rates. The property which indicates these rates is thermal conductivity. It is the rate of heat transfer through a section of material of 1 m^2 in area and of thickness one metre when there is a temperature difference of 1°C. The units are kcal/m/m^2h C or simplified as kcal/mh C.

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12. Some useful facts about water and ice

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Properties of water and ice

Properties	**Metric Units**	**Remarks**
Pure water		
Density at 15°C	1 kg/l 1 t/m^3	Pure water becomes denser as the temperature falls, until at 4°C it is at its densest, ie 1 kg/l. For practical ice-making calculations, the density of water can safely be assumed to be 1 kg.1
Specific heat	1.0 kcal/kg°C	
Latent heat of fusion	80 kcal/kg	
Thermal conductivity (at 10°C)	0.5 kcal/mh°C	
Freezing point	0°C	
Boiling point	100°C	
Sea water		
Density	1.027 kg/l	At 0°C and salinity of 3.5%.
	1.027 t/m^3	
Specific heat	0.94 kcal/kg°C	At 0°C

	0.93 kcal/kg°C	At 20°C
Latent heat of fusion	77-80 kcal/kg	Approximate values at salinities of up to 3.5%. Indeterminate owing to presence of salts.
Freezing point at salinity of:		Salinity varies from sea to sea but for practical purposes the world average of 3.5% is sufficiently accurate.
1.0%	-0.6°C	
2.0%	-1.2°C	
3.0%	-1.6°C	
3.5%	-1.9°C	
4.0%	-2.2°C	

Ice		
Density		
Freshwater ice	0.92 kg/l 0.92 t/m^3	At 0°C
Seawater ice	0.86-0.92 t/m^3	Depending on salinity and amount of trapped air.
Specific heat:		For calculating the amount of ice to use on fish, a value of 0.5 is sufficiently accurate. Specific heat of seawater ice can be very
0°C	0.49	

-20°C	0.46	much higher near to melting point.
Latent heat of melting	80 kcal/kg	
Thermal conductivity:	kcal/mh °C	
0°C	1.91	
-10°C	1.99	
-20°C	2.08	
Melting point	0°C	Melting point of seawater ice is indeterminate, since salt content is rarely uniform throughout the ice, but should on average be about -2°C.
Stowage rates	m^3/t	
Block ice in blocks	1.4	
Crushed block ice	1.4-1.5	
Flake ice	2.2-2.3	
Tube ice	1.6-2.0	
Plate ice	1.7-1.8	

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13. Conversion factors

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Metric and British units

	To obtain	From	Multiply by the following
3.281	metres (m)	feet (ft)	0.3048
10.76	square metres (m^2)	square feet (ft^2)	0.0929
35.32	cubic metres (m^3)	cubic feet (ft^3)	0.0283
0.22	litres (l)	UK gallons (UK gal)	4.546
0.264	litres (l)	US gallons (US gal)	3.785
0.0353	litres (1)	cubic (ft^3)	28.3168
2.205	kilogrammes (kg)	pounds (lb)	0.454
0.00142	kilogrammes per square metre (kg/m^2)	pounds per square inch (lb/in^2)	703
0.0624	kilogrammes per cubic metre (kg/m^3)	pounds per cubic foot (lb/ft^3)	16.0185
3.97	kilocalories (kcal)	British thermal units (Btu)	0.252
1.341	kilowatts (kW)	horsepower (hp) (UK or US)	0.746
0.00156	kcal per hour (kcal/h)	hp	642
1.163	kcal/h x 1000	kilowatts (kW)	0.860

0.3307	kcal/h x 1000	ton of refrigeration (US)	3.024
0.2048	keal/m^{2}h°C	Btu/ft ^{2} h°F	4.882
8.064	kcal/m h°C	Btu in/ft ^{2} h°F	0.1240
1	kcal/kg °C	Btu/lb °F	1
1.8	kcal/kg	Btu/lb	0.5556
Multiply by the above	To convert	To	

Metric, Imperial and SI units

The International System of Units (SI units) is now widely used and some conversions relating to the above units are given below:

	To obtain	**From**	**Multiply by the following**
9.807	kg/m^2	Newtons per square metre, Pascals (N/m^2) (Pa)	0.1020
0.9807	kg/m^2	milk bar (mbar)	1.020
6895	lb/in^2 (psi)	Pascals (N/m^2) (Pa)	0.000145
0.01450	mbar	lb/in ^{2} (psi)	68.95
4.187	kcal	kilojoules (kJ)	0.2388
0.9479	kJ	Btu	1.055
1.163	kcal x 1000	kWh	0.8598
0.2778	MJ	kWh	3.6
3.413	W	Btu/h	0.293
1.341	kW	hp (UK & US)	0.746
1.359	kW	hp (metric)	0.736

12	ton refrigeration (US)	Btu/h x 1000	0.08333
3.517	ton refrigeration	kW	0.284
1.163	kcal/h	W	0.8598
1.163	kcal/m^2h0C	W/m^2 °C	1 0.8598
0.317	W/m^2	Btu/ft^2 h	3.155
0.1761	W/m^2 °C	Btu/ft^2 h°F	5.678
1.163	kcal/m h°C	W/m °C	0.8598
6.935	W/m °C	Btu/in/ft^2 h°F	0.1442
0.2388	kcal/kg °C	kJ/kg°C	4.187
0.2388	kJ/kg °C	Btu/lb °F	4.187
Multiply by the above	To convert	To	

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