FISH

FREEZING

PREPARATION OF THIS DOCUMENT

FAO Fisheries Technical Paper No. 167 entitled "Freezing in Fisheries" was published in 1977 and reflected the rapid changes in freezing technology, one of the most important preservation methods for fish. The paper was reprinted in 1981 and another FAO Fisheries Technical Paper No. 214 "Refrigerated Storage in Fisheries" was published. Both papers have been in great demand and are now out-of-print. Since that time significant progress in the technology and practice of freezing and cold storage have been made and it was becoming evident that substantial revision of both publications was required. It was decided to combine them into one publication entitled "Freezing and Refrigerated Storage in Fisheries".

The preparation of this Technical Paper is a Regular Programme activity of the Fishery Industries Division, Fisheries Department, FAO, Rome. The publication was prepared by a team from the Torry Research Station in Aberdeen[1] in association with the Fish Utilization and Marketing Service, FAO Fisheries Department.

It is hoped that this publication will answer some of the queries raised by governments, organizations and/or individuals and enable them to up-grade the quality of their frozen fish.

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ABSTRACT

This document is intended to serve as a background paper as well as an introduction to the operations and equipment used in the freezing and cold storage of fish both on shore and at sea. It gives a broad outline on how deterioration of fish quality can be reduced by the application of low temperatures. It reviews various types of freezing equipment for use ashore or at sea; the requirements for cold stores and their construction; the factors affecting cold storage conditions, etc. In addition, the publication describes the methods used to calculate cold storage refrigeration loads as well as the costs of freezing and cold storage. Safe operation of cold stores is also covered. A list of publications on the subject is given in the list of references.

[1]On 1 April 1994 Torry Research Station changed its name to CSL Food Science Laboratory, Torry, 135 Abbey Road, Aberdeen AB9 8DG, UK.

1.0 BIOLOGICAL ASPECTS

One of the important issues affecting fish preservation is the large biological variations existing from one region of the world to another and from one species of fish to another. This, combined with the fact that catching methods and consumption habits vary, has a considerable influence on the handling and preservation of the product.

In order to choose and operate refrigeration systems in the best possible way, some knowledge of the fish biology and factors influencing the quality are essential.

1.1 Composition of Fish

The fish has a skeletal or cartilaginous structure which provides support for the body. The muscles which form the edible part account for most of the weight of the fish. The skin forms a cover, often with an outer layer of scales, and secretes a slimy mucus, which lubricates the fish and seals the surface. The gills are the main part of the breathing mechanism and take up oxygen from the water. The organs in the body cavity, including the stomach, intestine and liver are known as the guts. Removal of the guts is normally the first step in handling and preservation. Shell fish has no backbone, but a hard outer cover or shell exoskeleton, which gives the necessary support and protection.

The principal components of the fish muscle - water, fat and protein - must be preserved with little or no changes. The protein content is usually in the region of 15-20 percent, whereas the fat content varies widely from species to species and from season to season. It can be as low at 0.5 percent in lean starved fatty fish and can reach over 20 percent in some species. In lean fish the bulk of the fat is stored in the liver and not in the muscle. Water is the main constituent, with considerable variations, typically 80 percent in lean fish and 70 percent in fatty fish. Carbohydrates, minerals, vitamins and some water extractable components are examples of other minor substances present.

1.2 Spoilage of Fish

As soon as a fish dies, spoilage begins. Spoilage of fresh fish is a rather complex process and is caused by a number of inter-related systems, some of which are suppressed by others. The factors which principally contribute to the spoilage are the degradation of protein with a subsequent formation of various products like hypoxanthine, trimethylamine, development of oxidative rancidity and the action of micro-organisms.

In live fish, food in the gut is reduced to simple substances, such as sugar and aminoacids, which are absorbed into the blood stream. The blood conveys these essential substances to sites where they are required, notably in the muscles. Production of these substances is induced by enzymes, which act as catalysts to chemical reactions, both in the gut and in the flesh. The enzymes remain active after death and thus bring out self-digestion, affecting the flavour, texture and appearance of the fish. After a fish dies, stiffening of the muscle called *rigor mortis* sets in and commences, due to the action of enzymes. Subsequently softening of the flesh occurs as self-digestion proceeds.

Self-digestion can take place rapidly in fish, especially in small fatty fish full of feed, where the gut enzymes are particularly active. The well-known phenomena "Burst Belly", which can occur in only a few hours after catch in sardines, herring and some other fish, is caused simply by a weakening of the belly wall due to self-digestion. The rate of selfdigestion is much dependent on temperature. Chilling of the fish to just above the freezing point does not stop, but retards self-digestion. Enzyme action can be stopped by heating; it is controlled to some extent by other methods, such as salting, frying, drying and marinating.

Micro-organisms are present in the surface slime, on the gills and in the intestines of the fish, but the muscle is sterile. Although it is not known with certainty how long it takes for the bacteria to penetrate the skin of the muscle three to four days is a reasonable estimate, but each species may be somewhat different. Fresh fish is seldom the cause of food poisoning, since the bacterial growth tends to make the muscles or flesh unpalatable before any toxins develop.

The environmental microflora introduced by cooling medium and by handling are also responsible for spoilage after the initial phase of self-digestion. Soon after the fish dies, bacteria will enter at a number of points, through the gills and into the blood vessels, through the lining of the belly cavity and eventually through the skin. Once in the flesh they can grow and multiply rapidly, producing disagreeable odours and flavours.

There are many different types of micro-organisms, each type having particular conditions for optimum growth. Thus it has been found that certain types of microorganisms dominate, depending on the initial infection, the properties of the food material, the temperature and other conditions. By cooling the fish to around 0°C, some of the bacteria groups responsible for the spoilage will cease to grow and the rate of spoilage will thereby be reduced.

Ambient conditions, such as the amount of moisture and oxygen available, have a marked effect on the microbiological activity. In melting ice the rate of fish spoilage is to some extent dependent on the rate of melting. Providing there is sufficient ice to maintain the desirable fish temperature of 0°C a higher melting rate can give slightly better results than a lower melting rate presumably due to the washing effect. Where the fish is in contact with surfaces such as wood, metal or other fish, foul odours can arise due to the action of certain anaerobic bacteria, which thrive in the absence of oxygen.

As microbiological action is the main and fastest cause of spoilage, great care must be taken to avoid conditions which accelerate the growth of micro-organisms. The growth rate is highly temperature-dependent and the principal preservative measure, besides good hygienic conditions, is to cool the fish as soon as possible after catching. Other supplementary measures have been tried, for example the use of antibiotics and different gases. So far only marginal improvements have been achieved and these supplementary methods have not found any wide applications.

Some of the chemical changes are caused by enzymatic reactions, the first taking place even before any serious changes are caused by microbiological activity. These enzymatic reactions are associated with *rigor mortis*. The result of those changes is that some constituents are chemically altered and some even disappear, altering the sensory properties -odour and flavour. Some of these substances, commonly known as extractives, are the first to be changed by the microbiological activity and the protein of the muscles will change considerably later.

The extractives are present in varying amounts from species to species. Herring and mackerel contain large amounts of amino-acid histamine, whereas cod and haddock only contain traces. Skate, dogfish and shark contain large quantities of urea which is absent in cod.

Trimethylamine oxide, which is available in all the salt water fish is usually absent from fresh water species. The breakdown of trimethylamine oxide into trimethylamine (TMA) is an important reaction, as the chemical determination of TMA may be used in quality assessment of salt water fish. Equally important is the determination of ammonia in some species, eg., sharks. Ammonia being formed during the breakdown of urea.

Chemical denaturation of proteins to a noticeable degree appears normally late in the deterioration process, as does oxidation of fat.

Development of oxidative rancidity is extremely variable in fresh fish. The ease with which some fish undergo oxidative rancidity is in part, explained by the large proportion of the highly unsaturated fats that many fishes contain. There is, however, a great difference between fatty species, such as mackerel and herring and fish such as cod and haddock. The former group have a high lipid content, free fat content and proportion of triglycerides, while the latter have a low lipid content, chiefly in the form of phospho lipids and lipoprotein immediately associated with muscle proteins. Even within a single fish itself there is a difference in the ease with which different portions undergo rancidity. Seasonal variations in susceptibility to rancidity have also been found.

2.0 INFLUENCE OF TEMPERATURE

Fish begins to spoil immediately after death. This is reflected in gradual developments of undesirable flavours, softening of the flesh and eventually substantial losses of fluid containing protein and fat. By lowering the temperature of the dead fish, spoilage can be retarded and, if the temperature is kept low enough, spoilage can be almost stopped.

Rigor mortis, over a period of hours or days soon after death, can have a bearing on handling and processing. In some species the reaction can be strong, especially if the fish has not been chilled. The muscles under strain tend to contract, therefore, some of the tissue may break, especially if the fish is roughly handled, leaving the flesh broken and falling apart. If the muscles are cut before or during *rigor*, they will contract and in this way fillets from fish can shrink and acquire a somewhat rubbery texture. In many species, however, *rigor mortis* is not strong enough to be of much significance.

The freezing process alone is not a method of preservation. It is merely the means of preparing the fish for storage at a suitably low temperature. In order to produce a good product, freezing must be accomplished quickly. A freezer requires to be specially designed for this purpose and thus freezing is a separate process from low temperature storage.

2.1 What happens during freezing

Fish is largely water, normally 60-80 percent depending on the species, and the freezing process converts most of this water into ice.

Freezing requires the removal of heat, and fish from which heat is removed falls in temperature in the manner shown in Figure 1. During the first stage of cooling, the temperature falls fairly rapidly to just below 0°C, the freezing point of water. As more heat requires to be extracted during the second stage, in order to turn the bulk of the water to ice, the temperature changes by a few degrees and this stage is known as the period of "thermal arrest". When about 55% of the water is turned to ice, the temperature again begins to fall rapidly and during this third stage most of the remaining water freezes. A comparatively small amount of heat has to be removed during this third stage.

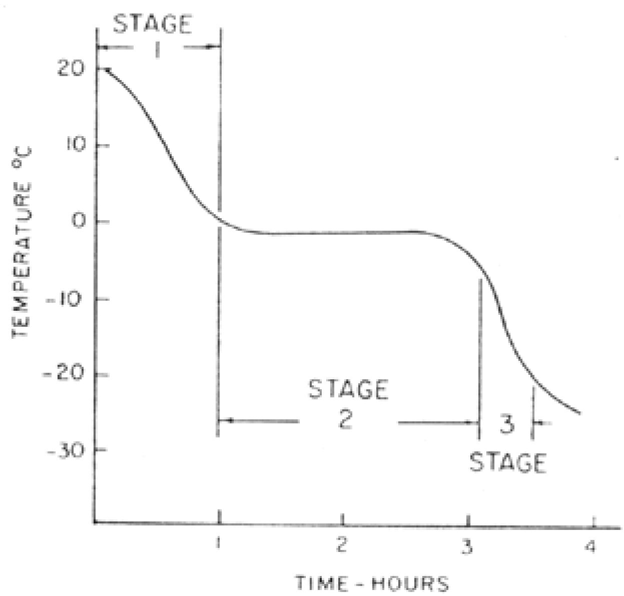

Figure 1 Temperature-time graph for fish during freezing

As the water in fish freezes out as pure crystals of ice, the remaining unfrozen water contains an ever increasing concentration of salts and other compounds which are naturally present in fish flesh. The effect of this ever increasing concentration is to depress the freezing point of the unfrozen water. The result is that, unlike pure water, the complete change to ice is not accomplished at a fixed temperature of 0°C, but proceeds over a range of temperature. The variation of the proportion of water (which is converted to ice) in the muscle tissue of fish against temperature is shown in Figure 2. The figure shows that by the time the fish temperature is reduced to -5°C about 70% of the water is frozen. It also shows that even at temperatures as low at -30°C, a proportion of the water in the fish muscle still remains in the unfrozen state.

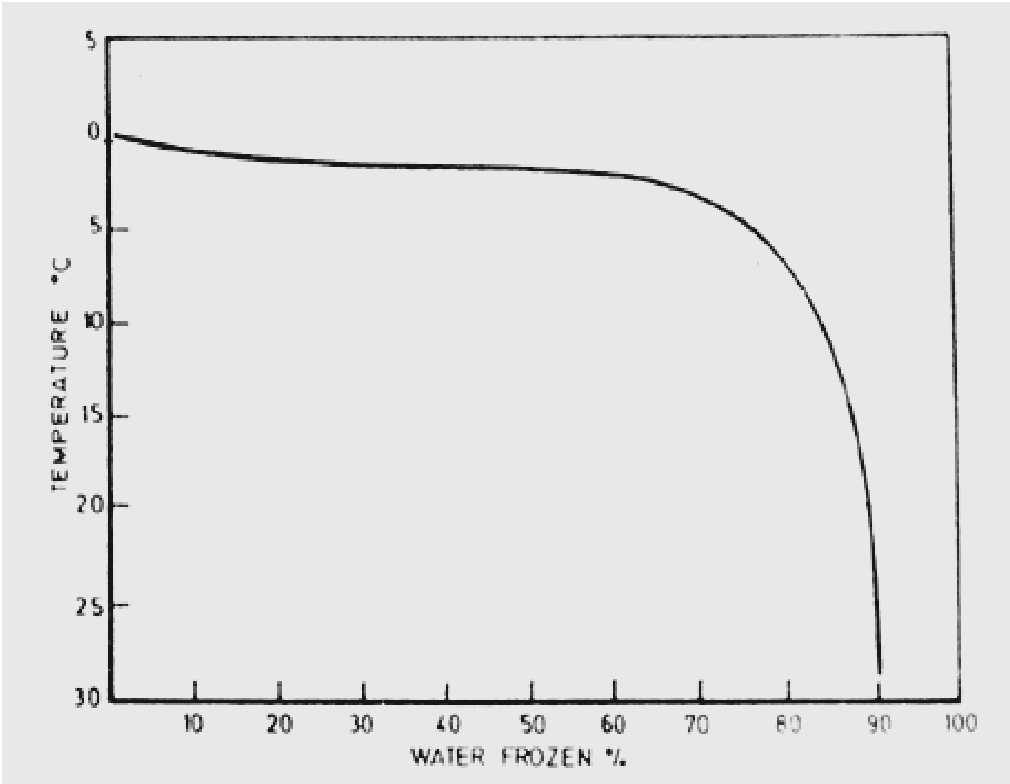

Figure 2. Freezing of fish muscle. The percentage of water frozen at different temperatures

Literature on the freezing of fish is confusing and often contradictory about what happens to fish as it freezes. This is particularly the case when reference is made to the difference between slow and quick freezing. One of the main reasons for this apparent confusion is that only in recent years has knowledge of the freezing process advanced sufficiently to explain these differences in freezing rates. The result is that much of the literature still in circulation is now outdated.

At first it was thought that rapid freezing was unsatisfactory since sudden cooling could disrupt and tear the muscle tissue. It was also thought that, since water expands on freezing, it might be reasonable to expect the cell walls to burst under the induced pressure. There is some justification for both of these theories but they do not fully explain the differences between slow and quick freezing.

For some time a widely held view was that slow freezing resulted in the formation of large ice crystals which damaged the walls of the cells. This would then result in a considerable loss of fluid when the fish was thawed. The smaller ice crystals formed, when fish is frozen quickly, were thought to do little damage to the cell walls and, as a result, little fluid was lost on thawing. Difference in size of ice crystal probably accounts for some of the differences between slow and quick freezing, but is has been shown that this still does not provide a full explanation. The walls of fish muscle cells are sufficiently elastic to accommodate the larger ice crystals without excessive damage. Also, most of the water in fish muscle is bound to the protein in the form of a gel, and little fluid would be lost even if damage of the above nature did occur.

Slow freezing, however, does result in an inferior quality product and this is now thought to be due mainly to denaturation of the protein. Changes take place in some fractions of the protein as a result of freezing and since they are altered from their "native" state they may be said to be "denaturated", hence the term "protein denaturation". This denaturation depends on temperature and as temperature is reduced the rate of denaturation is reduced. Denaturation also depends on the concentration of enzymes and other compounds present. Thus, as the water is frozen out as pure ice crystals, the higher concentration of compounds in the unfrozen portion will result in an increase in the rate of denaturation. These two factors, which determine the rate of denaturation, act in opposition to each other as temperature is reduced and it has been demonstrated that the temperature of maximum activity is in the region of -1 to -2°C.

Slow freezing means that a longer time is spent in this zone of maximum activity and it is now thought that this factor accounts for the main difference in quality between slow and quick frozen fish.

2.2 What is quick freezing?

There is no widely accepted definition of quick freezing.

It is unlikely that even a trained taste panel could detect the difference between fish frozen in 1h and 8h, but once freezing times begin to extend beyond 12h the difference may well become apparent. Freezing times of up to 24h or even longer, achieved in some badly designed and operated freezers, will almost certainly result in an inferior product. Very long freezing times, for example, due to freezing fish by bulk stacking in a cold store, may even result in spoilage by bacterial action before the middle of the stack is sufficiently reduced in temperature.

Since the temperature just below 0°C is the critical zone for spoilage by protein denaturation, an early UK definition of quick freezing recommended that all the fish should be reduced from a temperature of 0°C to -5°C in 2h or less. The fish should then be further reduced in temperature so that its average temperature at the end of the freezing process is equivalent to the recommended storage temperature of -30°C. With normal freezing practice in the UK, this latter requirement is defined by stating that the warmest part of the fish is reduced to -20°C at the completion of freezing. When this temperature is reached, the coldest parts of the fish will be at, or near, the refrigerant temperature of say -35°C and the average temperature will then be near -30°C. This is a rather elaborate definition of quick freezing and it is probably more strict than is necessary to ensure a good quality product.

The more widely used definitions of quick freezing do not specify a freezing time or even a freezing rate but merely state that the fish should be frozen quickly and reduced in the freezer to the intended storage temperature.

<u>Regulations and Guides to Good Practice</u>

In the EC directives apply to the frozen food chain from initial manufacture to retailing and these directives may be used as a guide. They relate to the quality of foods labelled as "quick frozen" and require that foods labelled in this way should be brought through their zone of maximum ice crystallisation as quickly as possible. Thereafter, they must be maintained at -18°C or below. There are exemptions for local deliveries and frozen foods held in retail display cabinets. They also concern the monitoring of temperatures of quick frozen foods during transport, and storage and the sampling procedures and temperature measurement methodology to be used by enforcement authorities.

Complying with these Directives requires an understanding of how different foods freeze, the effects of different freezing processes, and the ability to correctly measure the temperature of frozen foods.

The recommendation that the fish should be reduced to the intended storage temperature is important and this should be included in all good codes of practice for quick freezing. These two basic requirements for freezing, that the fish be frozen quickly and be reduced to storage temperature, go together since it is likely that a freezer which can quick freeze fish also operates at a sufficiently low temperature to ensure that the recommended product storage temperature can be achieved.

Some freezing codes and recommendations define freezing rate in terms of the thickness frozen in unit time. The freezing rate, however, is always quicker near the surface of the fish, where it is in contact with the cooling medium, and slower at the centre. Freezing rates are therefore, only average rates and they do not represent what happens in practice. Average freezing rates vary between 2 and 1000 mm/h and, to give the reader some idea what these rates represent in practice, the range can be sub-divided as shown in Table 1.

Table 1 Freezing rates

2 mm/h	Slow bulk freezing in a blast room.
5 to 30mm/h	Quick freezing in a tunnel air blast or plate freezer.
50 to 100 mm/h	Rapid freezing of small products.
100 to 1000 mm/h	Ultrarapid freezing in liquefied gases such as nitrogen and carbon dioxide

One exception to the general requirements tor quick freezing of fish requires special mention. Frozen tuna, which will eventually be eaten in its raw state as the Japanese product "Shasimi" seemingly requires to be reduced to a lower temperature than other fish products. Japanese fishing vessels catching fish for this product operate with freezers at -50° to -60°C. Tuna is a large fish and when frozen whole by immersion in sodium chloride brine at a temperature of -12 to -15°C takes up to three days to freeze. Air blast freezing has now replaced brine freezing for this purpose and operation with very low freezer temperatures can result in freezing times of about 24h or less. The exceptionally low temperatures used in these freezers of about -50 to -60°C have given rise to conditions which require special precautions to be taken to avoid low temperature brittle fracture of metal structures in the vessels.

The above current requirements for air blast freezing tuna is one special case where general rules for quick freezing are not applied and it should be kept in mind that local requirements for particular products may, in some countries, give rise to others.

2.3 Double freezing

Double freezing means freezing a product, thawing or partly thawing it, and refreezing. This practice is often necessary for the production of some frozen fish products made from fish previously frozen and stored in bulk. What must be remembered is that even quick freezing results in quality changes in the fish and double freezing will therefore result in further changes. Only fish that were initially very fresh could therefore be subjected to double freezing and still conform to good quality standards. Fish frozen quickly at sea immediately after catching, for instance, would be suitable for this purpose.

2.4 Handling of fish before freezing

Freezing and cold storage is an efficient method of fish preservation but it must be emphasised that it does not improve product quality. The final quality depends on the quality of the fish at the time of freezing as well as other factors during freezing, cold storage and distribution. The important requirement is that the fish should at all times be kept in a cool condition before freezing, about 0°C, and the use of ice or other methods of chilling is recommended. The FAO document "Ice in Fisheries" FAO Fisheries Technical Paper No 331 describes in detail the methods of using ice or refrigerated sea water to cool fish.

Apart from keeping the product chilled, it is also essential to adopt a high standard of hygiene during handling and processing to prevent bacterial contamination and spoilage. The FAO/WHO Codex Alimentarius Commission "Recommended International Code of Practice for Fresh Fish", 1983 and "Code of Practice for Frozen Fish" 1984 give guidance on this aspect of quality control. Advice on handling fish before freezing at sea is given in Chapter 13.

In some countries chemicals are currently used to treat fresh fish in order to assist with such things as colour retention and the retention, or even addition, of fluids. The treatment of food with chemicals is usually subject to national and local restrictions and it would be inappropriate to make any general comment on their use in this document.

2.5 Frozen Fish

Freezing and frozen storage of fish can give a storage life of more than one year, if properly carried out. It has enabled fishing vessels to rem ain at sea for long periods, and allowed the stockpiling of fish during periods of good fishing and high catching rates, as well as widened the market for fish products of high quality.

The mechanism by which frozen fish deteriorates is somewhat different from that causing spoilage of chilled fish. Provided the temperature is low enough - below -10°C bacterial action will be stopped by the freezing process. Chemical, biochemical and physical processes leading to irreversible changes will still occur, but at a very slow rate. Deterioration during frozen storage is inevitable, and in order to obtain satisfactory results, fish for freezing must be of good quality.

The proteins changes in fish frozen under poor conditions can be recognised in the thawed fish. The normally bright, firm and elastic product becomes dull and spongy. The flesh will tend to sag and break and there will be substantial losses of fluid, which can be squeezed out easily. When cooked the fish will be dry and fibrous. The rate at which protein denaturation takes place in frozen fish depends largely on the temperature and will slow down as the temperature is reduced.

Changes taking place in the lipids of the frozen fish will also slow down when the temperature is reduced. The oxidation of the fat leads to objectionable flavours and odours. This can be particularly serious in fish of high fat content and probably also accounts for most of the flavour changes in lean fish. Some substances, notably salt, and some processes, such as drying, can aggravate the problem. Smoked fish, for example, has a shorter storage life in frozen condition than the raw, frozen counterpart. The addition of chemicals to prevent oxidation has not been successful, except for some special types of products.

The rate of oxidation can be reduced by reducing the exposure to oxygen. This can be achieved by introducing a barrier at the surface of the fish. Thus fish in a block keep better than fish frozen individually, and the addition of an ice glaze is beneficial. Glazing is carried out after freezing by brushing or spraying chilled water onto the surface of the fish or by dipping in cold water. Packaging materials, impermeable to moisture and oxygen can be effective, especially if vacuum packaging is employed.

Some transfer of moisture from the product is unavoidable during freezing and frozen storage, which leads to dehydration of the fish. Good operating conditions are essential in order to keep dehydration to a minimum. It has been clearly established that fluctuating cold store temperatures are a major cause of dehydration. In practice the more severe cases of drying occur during frozen storage rather than during freezing. In extreme dehydration the frozen fish acquires a dry wrinkled look, tends to become pale or white in colour and the flesh become spongy. This characteristic appearance is called, inappropriately, 'freezerburn'. The weight loss is, of course, serious from an economic point of view and dehydration will accelerate the other important changes - protein denaturation, as well as oxidation. Glaze on the exposed surfaces of the fish before storage will however, evaporate over a period of time and drying of the fish itself will resume. Reglazing is therefore a common need. Paper wrappers can be used as a protection, but depending on the conditions some drying of the fish within the packing will still occur.

2.6 Frozen fish products

The variety of species, processes, methods of presentation and packaging available provide scope for the preparation of numerous frozen fish products. These products, however, can be separated into two main groups; products intended for direct consumption and products intended for further processing.

Products for direct consumption

Individually quick frozen (IQF) products are frozen as single units which need not be thawed for sub-division or perhaps even for cooking purposes. IQF single fillets and shrimp are two products of this type.

The demand for IQF products has increased with the upsurge in the number of low temperature "freezer" cabinets both in catering establishments and in the home. IQF freezing allows for the purchase of a frozen product in bulk and the selection from storage of only sufficient quantities to meet immediate requirements.

Other products such as blocks of fish and fish portions usually packaged in cartons are also produced for direct consumption without the need for reprocessing. The consumer will purchase this type of product from the retailer, still in the frozen state, and either cook it in the frozen state or thaw it for immediate consumption.

The production of products for direct consumption may not yet be appropriate in many developing countries. This type of product requires the provision of an extensive network of refrigerated storage and transport. This facility, which is popularly known as the "cold chain", may not be developed enough to enable this system to operate.

Products for further processing

These products are produced for two purposes:

1. Frozen in bulk and thawed after storing, to be used as newly caught, unfrozen fish.
2. Frozen in bulk and after storage, further processed without thawing so that it may be presented as a retail pack.

Products frozen in bulk can be unprocessed, such as blocks of whole fish frozen in contact freezers. Blocks of frozen fish may weigh up to 50 kg; they are usually glazed or wrapped after freezing and are then stored until required for further processing.

In some cases, fish are bulk frozen, stored and finally thawed all in one place. This is usual when there is a short seasonal fishery and fish are preserved for processing over a longer period. Bulk frozen fish may also be distributed in the frozen state. This enables the fish to be sold to a larger home market and also allows the product to be exported. In this case there are additional requirements for low temperature transport and a more extensive cold chain.

Fish frozen in bulk may also be fully processed before freezing and only the skinless, boneless portion used. One particular process of this type worth special mentioning is the production of frozen fillet blocks. A frozen fillet block is a regular shaped block of fish flesh frozen in a horizontal plate freezer within a treated cardboard carton and a metal retaining frame (Figure 3) The filling process ensures that there are no voids in the block. After freezing, the blocks are stored in bulk and at a later date cut into smaller portions of different shapes. The fish portions may then be packaged and sold in this form or they may be coated with a flour batter and breadcrumbs. Coated fish portions should be returned to the freezer and rehardened before packaging and storing.

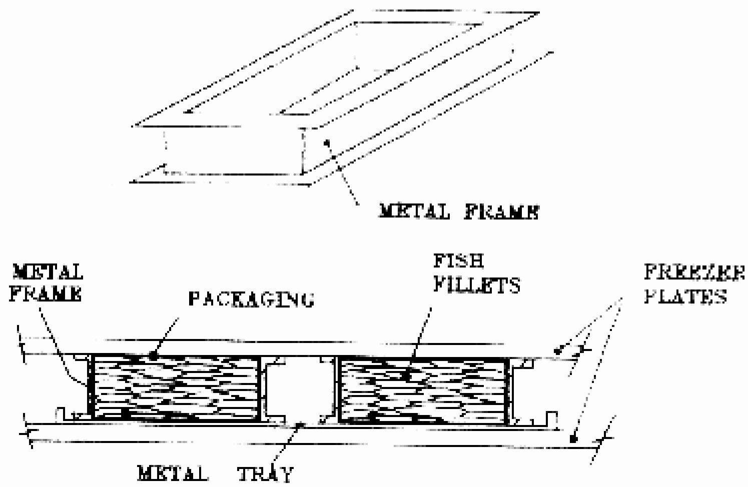

Figure 3 Packaging and loading arrangement for making fillet blocks in a horizontal plate freezer

The type of frozen fish product and the form in which it is produced in a particular country may well depend on the extent of the cold chain as well as on the demands of the consumer. It therefore seems likely that in most developing countries a bulk freezing process will be the initial development. This will enable the industry to cater for seasonal variations and allow a wider distribution of the fish catch. Other frozen products will follow later when the industry develops and the cold chain is extended.

2.7 Time-Temperature Tolerance

As in the case of iced fish the storage life for frozen fish varies considerably. Some typical data are given in Table 2.

Table 2 Practical storage life for fish. From IIR Guide to Refrigerated Storage (Appendix 1)

	Storage life, months		
	-18°C	**-25°C**	**-30°C**
Fatty fish, sardines, salmon,ocean perch	4	8	12
Lean fish, cod, haddock	8	18	24
Flat fish, flounder, plaice, sole	9	18	24
Lobster, crabs	6	12	15
Shrimp	6	12	12

From the table the importance of low temperature storage is clearly illustrated. It is, however, not only the length of storage life which is of importance, but the higher quality at any given moment during storage.

A number of scientific works have shown the importance of low temperature storage and for frozen foods the Time-Temperature Tolerance concept was introduced very early. The corner stones of the TTT theory are:

- There is, for every frozen product, a relationship between storage temperature and the time it takes at this temperature for the product to undergo a certain amount of quality change.
- Changes during storage and distribution at different temperatures are cumulative and irreversible over the entire storage period and sequence is without influence on the size of the accumulated total quality change.

The storage life based on one or more of the chemical, biochemical and physical changes can be defined in many ways. A common definition is High Quality Life - HQL .

HQL is defined as the elapsed time between freezing of High Quality product and the moment when 70 percent of experienced tasters are able to distinguish the product from the control stored at very low temperature.

Other definitions of storage life are also used. Regardless of the definition the accumulated quality loss can be integrated from plots of 1/HQL against time, independent of the order of the exposures to different temperatures.

In Figure 4 quality loss during storage and transport of cod fillets at three different temperatures has been calculated.

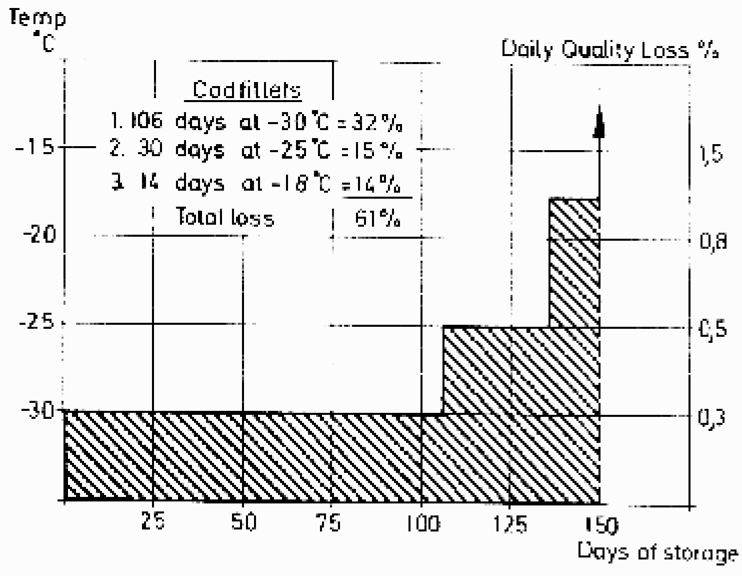

Figure 4 Example of quality loss during storage and transport of cod fillets

The distribution in this case includes 106 days at -30°C, 30 days at -25°C and 14 days at -18°C. The total quality loss during the distribution of this particular fish fillet is 61 percent.

There is, in other words, 39 percent of the original quality left for the consumer. It is important to note that if the, storage and distribution had been carried out at -18°C, the corresponding quality loss would have been obtained in 60 days. By keeping the product at -30°C during the main part of the distribution, it has been possible to more than double the storage life for the same quality level.

As indicated above it must however, be observed that the quality changes in fish products are not only influenced by the storage temperature. Among the factors which are important are the original quality of the raw material, the processing method and the packaging material and method used for the final product. Those three factors are usually defined as the PPP factors - Product-Processing-Packaging.

2.8 Codes of practice

Most countries have legislation which relates to the handling and processing of foods in general and where appropriate, this legislation will apply when handling fish before, during and after freezing. However, additional recommendations are often made, usually in the form of codes of practice which, although not enforceable by law, can be rigidly applied by mutual agreement of all parties involved. Such codes of practice serve as a means of maintaining uniform standards based on good practice and take into consideration all relevant factors. In the absence of legislation, these codes of practice may also be quoted in cases of dispute as the minimum standards to be applied. Adoption of a code of practice is therefore an early step in the development of a freezing and cold storage industry.

For the wider aspects of freezing, codes of practice already exist which cover most of the likely requirements of a developing country with an expanding fish freezing industry. A number of these are listed below with a brief summary of their contents.

Codex Alimentarius Commission Joint FAO/WHO Food Standard Programme

The main aims of the Commission are to recommend product standards for international uniformity and to provide advice on how to meet such standards by issuing codes of practice. Relevant codes and standards should therefore be the starting point for all national and local codes and allowance made, if necessary, for differences that cannot be resolved due to legal or other factors. These codes and standards are often detailed and may refer to only one species or product. Until final acceptance by The Codex Alimentarius Commission, the codes are available as FAO Fisheries Circulars.

Code of Practice for Frozen Fish, FAO Fisheries Circular No. 145 (Revision 2) 1977

General advice in English, French and Spanish on the production, storage and distribution of frozen fish. The code covers the freezing of fish at sea and on shore and also deals with cold storage, packaging, transport and thawing of frozen fish and fish products. The code does not cover all the potential variations in freezing and cold storage practice but the information given can form the basis for more specialised codes which can take into account local and national requirements.

OECD/IIR Draft Code of Practice for Frozen Fish, 1969

Produced in an English-French edition it gives guidance on quality and handling at all stages of the processing of fish into a frozen product. The code covers a wide range without becoming too involved in details. (OECD = Organisation for Economic Co-operation and Development, Paris; IIR = International Institute for Refrigeration, Paris).

Recommendations for the Processing and Handling of Frozen Foods, IIR, 3rd Edition

Produced in a combined English-French edition, the document is concerned with all kinds of frozen foods including fish and fish products. It deals with principles and with basic and applied problems, and is intended as a guide for international and national organisations. In many ways, it is similar in content to this document but since it covers all frozen foods products, it has a wider application.

Guide to Refrigerated Storage IIR, 1976

Produced in a combined English-French edition, the document is a comprehensive and detailed guide covering all aspects of the design, construction and operation of cold stores. It is in a form which may be used for technical and practical study of cold storage and it can also be used commercially to make improvements in one of the most important links of the chain of refrigeration, namely refrigerated storage.

National codes of practice

The majority of developed countries with well established fisheries have codes of practice and guidelines for their own fishermen, processors, retailers and other interested groups involved in the handling and processing of frozen fish and fish products. It would be advisable for the authorities in developing countries to study these. They will give guidance for the formulation of new codes. In addition, a study of the codes will ensure that any new standards will be in accord with the standards of customers for frozen fish exports.

Most codes of this type are formulated and issued by the appropriate agricultural, food or fisheries division of national or state governments.

3.0 QUALITY ASSESSMENT

In trying to assess fish quality, great care must be taken to carefully investigate the many variables that have an impact on this protein source. One must be prepared to examine each species individually, its environment, composition, harvesting and handling. It must be understood that no single index of quality has been standardised and that there are microbiological, chemical, biochemical and physical interactive changes.

A number of different tests can be used for estimating the degree of spoilage in fish. These include total bacterial numbers, total volatile bases, TMA, total volatile reducing substances, indoor sensory analyses, refractive index of the eye fluid, electrical parameters of the fish flesh, volatile acids, volatile ammonia and total volatile nitrogen. All of these however, require considerable judgement, if they are to be interpreted correctly.

Bacteria growing on the surface of the fish tissue produce volatile amines. One such volatile base is trimethylamine (TMA), a reduction product of the component trimethylamine oxide. TMA has been used as an indicator of general fish spoilage. Other volatile amines produced include ammonia and small amounts of monomethylamine and dimethylamine. While the fish is still in *rigor* dimethylamine begins to form and after *rigor* trimethylamine is formed.

Although not universal in acceptance or acceptability the TMA determination has become one of the established procedures for determining fish quality. It has been proposed that TMA levels between 5 and 10 mg/100 g tissue should be considered the maximum allowable levels in international trading. It should be observed that TMA, as would be expected of the bacterial product, is not useful in determining quality deterioration, which occurs during frozen storage. It should also be observed that the TMA value are dependent upon the storage temperature of the fish and will vary accordingly.

Another school of thoughts centres around dimethylamine (DMA) as a basis for quality assessment and in many cases DMA has been successfully used to measure quality of frozen fish. DMA has been shown to be produced autolytically at sub-zero temperatures. While DMA formation has been shown for cod, haddock, husk, hake and Alaskan pollock, no DMA has been found in similar studies of frozen lobsters, scallops or shrimps after extended storage at -5°C.

Chemical tests for dimethylamine are most valuable in the early stage of spoilage and trimethylamine is most sensitive as an indicator in the later stages of spoilage. Determination of bacteria counts, while they are of value to research, requires too much time before results are known for routine testing.

Thiobarbituric acid (TBA) has been used to assess the development of oxidative rancidity. Oxidation of fat-containing foods leads to the formation of malondialdehyde or derivates of this compound. The reaction of malondialdehyde with TBA is an effective means of measuring the extent of auto-oxidation, but unfortunately it seems too unreliable as an index of freshness. Such a wide variation exists between species and within species and so many other additional factors effect the development of rancidity that this determination seems not to be the answer of how to judge rancidity.

All the above-mentioned quality assessment methods must be carried out by specially trained experts, which means that the storeperson can use only sensory evaluation of appearance, odour and texture. Very few specifications exist, as there are obviously differences from species to species and therefore a general specification cannot be very detailed. Torry Research Station, Aberdeen, UK, has developed specifications for cod, herring, flat fish and red fish and the specification on cod is given as an example in Appendix 2. It must, however, be observed that this sensory judgement also requires a specialist taste panel.

4.0 FREEZERS

There are now many different types of freezer available for freezing fish, and freezer operators are often uncertain about which type is best suited to their needs. Three factors may be initially considered when selecting a freezer; financial, functional and feasibility.

Financial considerations will take into account both the capital and running cost of the equipment and also projected losses such as product damage and dehydration. Expensive freezers should therefore justify their purchase by giving special benefits and if these benefits are not worthwhile, they need not be considered.

Functional considerations will take into account such things as whether the freezer is required for continuous or batch operation and also whether the freezer is physically able to freeze the product. For instance, a horizontal plate freezer would be inappropriate for freezing large whole tuna.

Feasibility will take into account whether it is possible to operate the freezer in tile plant location. A liquid nitrogen freezer (LNF), for instance, may be suitable in every respect for freezing the product and the high costs of using this method of freezing may be justified. However, if the location of the plant is such that there can be no guaranteed supply of liquid nitrogen, the freezer should not be considered.

Initial considerations such as those mentioned above will eliminate many freezers from the final choice but still leave many options open to the freezer operator. In order to give the reader some guidance in both selection and use of freezers, descriptions of the various types now available for freezing fish are described. The types of freezer likely to be used in developing countries, especially where freezing is a relatively new process, are those that have already been widely used for freezing fish and have therefore been well tried and tested. Freezers in this category are described more fully than others.

4.1 Types of freezer

The three basic methods of freezing fish are:

1. Blowing a continuous stream of cold air over the fish - air blast freezers.
2. Direct contact between the fish and a refrigerated surface - contact or plate freezers.
3. Immersion in or spraying with a refrigerated liquid - immersion or spray freezers.

4.1.1 Air blast freezers

The advantage of the blast freezer is its versatility. It can cope with a variety of irregularly shaped products and whenever there is a wide range of shapes and sizes to be frozen, the blast freezer is the best choice. However, because of this versatility it is often difficult for the buyer to specify precisely what he expects it to achieve and, once it is installed, it is all too easy to use it incorrectly and inefficiently.

Before going on to describe the various types of air blast freezer, it is necessary to deal with some of the basic principles of air blast freezer design and operation.

<u>Designing air blast freezers</u>

The use of air to transfer heat from the product being frozen to the refrigeration system is probably the most common method used in commercial refrigeration. The natural convection of the air alone would not give a good heat transfer rate, therefore, forced convection by means of fans has to be introduced. To enable the product to be frozen in a reasonable time the air flow rate should be fairly high. Also, in order to obtain uniform freezing rates throughout the freezer, the air flow requires to be consistent over each fish or package.

Examination of Figure 5 shows that at very low air flow rates the freezing time is long. A single fillet for instance will take 4 times as long to freeze in the relatively still air in a cold store as it would in a properly designed air blast freezer. Figure 5 also shows that a high air speed, which also means high fan power, freezing times will change very little with further increases in air speed. A design air speed of 5 m/s has been found to be a good compromise between slow freezing rates and high fan costs and this air speed is recommended for most air blast freezers.

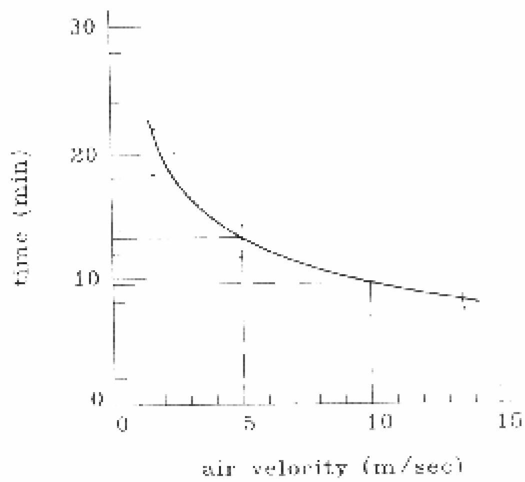

Figure 5 Variation of freezing time with air velocity for 14 mm thick fillets

Continuous air blast freezers may economically justify air speeds in excess of the above-recommended value. Continuous freezers are expensive and require a good deal of floor space. If the air speed is increased and the freezing time reduced, a smaller freezer will be required for a given freezing capacity. The savings in freezer costs may therefore justify the use of higher air speeds. Air speeds as high at 10 to 15 m/s may therefore be economically justifiable for continuous freezers. Higher airspeeds can also be justified when products have freezing times of less than about 30 mins.

The air flow over the surface of a product being frozen cannot be measured simply. In reality the air immediately adjacent to the surface of the product is stagnant due to the friction between the air and the surface of the product. This stagnant air forms a boundary layer which acts as a resistance to heat transfer. The layer thickness depends on air velocity, degree of turbulence and other factors. The air speeds quoted for air blast freezers are therefore only average speeds for the spaces between the fish or packages of product being frozen. A simple calculation which shows how this average air speed is derived is shown diagrammatically in Figure 6.

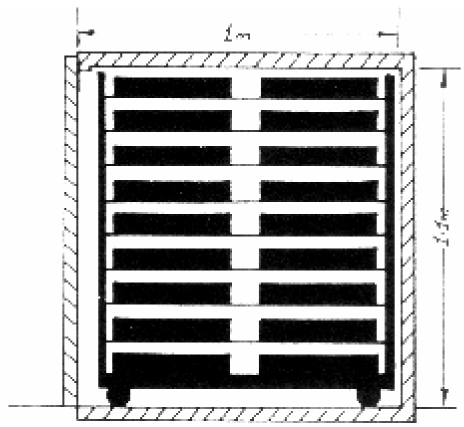

Figure 6 Calculation of average air speed in an air blast freezer

Calculated cross sectional area of tunnel,1.1m x 1.0m = 1.1 m2
Calculated cross sectional area of produce and trolley (shaded areas) = 0.7 m2
Air flow (obtained from fan rating or measured in open part of tunnel) = 2.0 m3/S
Calculated average air velocity, 2.0 ÷ (1.1-0.7) = 5 m/s

Another aspect of air flow rate that has to be considered in the design of a freezer the permitted temperature rise over the product. If the temperature rise is too great, the will be differences between the freezing times of products placed upstream and downstream in the freezer space. The differences in freezing time can be calculated by the method shown in Chapter 5. If the air temperature rise in the freezer is too small then it is possible that t freezer design is poor, the quantity of air being circulated is too high and more powerful fans than necessary are being used to maintain the recommended air speed.

Table 3 Fan power requirement for a continuous air blast freezer

Air velocity over product (M/S)	Freezing section pressure drop (mm water gauge)	Fan static pressure (mm water gauge)	Fan power (kW)
5.5	1.8	17.3	6.26
11.0	9.5	25.0	7.16

However, from Table 3 it can be seen that (in a well designed blast freezer) the increase in fan power required to double the air velocity over the product is no more than 15%.

Even in a good air blast freezer, the fan load can account for 25 to 30 percent of the refrigeration requirement and in a poor design it has even been known for the fan load to exceed the product load. No firm recommendation can be made about the permissible rise in temperature but an average air temperature rise of 1 to 3 degC is reasonable and may be used as a guide. This temperature rise will depend on the heat load; therefore it will be higher at the start of a freeze than at the end. The average temperature rise is therefore calculated from the total heat extracted from the fish and the weight of air circulated during the freezing period. The following sample calculation is used by way of illustration:

Weight of fish frozen	100 kg
Heat content of 1 kg of fish (+ 8°C to -30°C)	80 kcal/kg
Total heat to be extracted 90 x 100 =	8000 kcal
Freezing time	2 h
Fan circulation rate	2.5 m3/s
Density of air	1.45 kg/m3
Weight of air circulated during freezing	
2.5 x 3600 x 2 x 1.45 =	26 100 kg
Specific heat of air	0.24 cal/kg °C
Average rise in air temperature 8000 ÷ (26100 x 0.24) =	1.28°C

Many of the faults of air blast freezers can be attributed to insufficient or non-uniform air flow over the product. Air must be directed to flow uniformly over the product and not merely be blow into the freezer space to find its own way to where it is required. Air will normally take the path of least resistance. Many of the faults of air blast freezers are due to the low resistance paths which allow air to be diverted from its main work - transfer of heat from the surface of the product.

Given a free choice, the designer should position the fan before the cooler. The cooler provides a relatively high resistance to air flow and this helps to even out the flow. Air leaving an axial fan is also imparted with a whirling motion and the fins of the cooler act as a flow- straightener.

However, if proprietary unit coolers are used the designer may have no choice. Unit coolers generally have lower capital costs then separate fans and coolers.

When air changes direction in the freezer, there are difficulties in maintaining uniform distribution, and air flow over the product may be variable (Figure 7). There are a number of ways of solving this problem by using vanes, baffles and plenum chambers. In Figure 7 the air is shown to be correctly distributed by using suitably designed and properly spaced turning vanes. The air may also be redistributed by means of baffles which are spaced so that the pressure resistance across the section results in an even flow. It is difficult to predict the exact pattern required for correct redistribution of the air, and to compensate for this the baffles are often made adjustable. This method adds to the total resistance of the system and may mean higher fan power and additional costs. The method however is very simple, allows for readjustment on site and therefore is well worth considering.

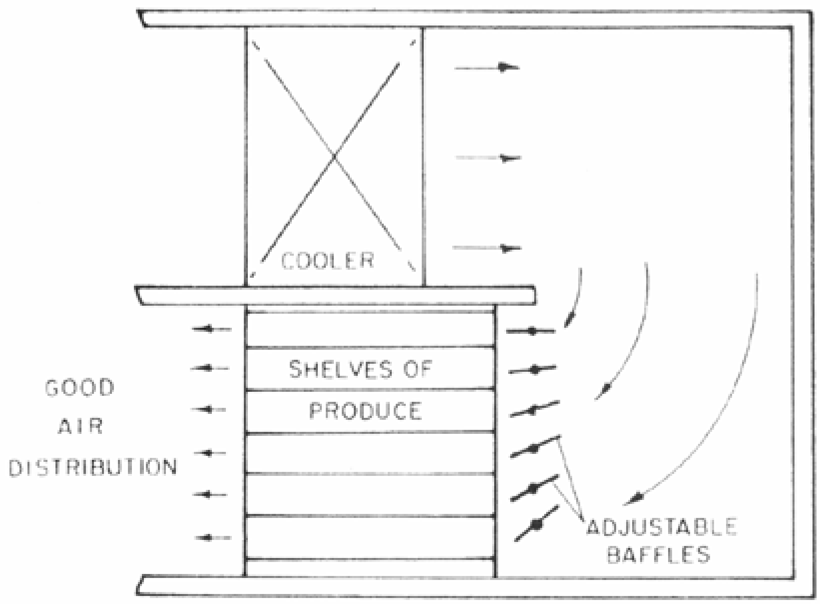

Figure 7 Good air distribution in a tunnel air blast freezer using adjustable baffles.

Nearly all air blast freezers operate with finned tube coolers. The fins greatly extend the surface for heat exchange, and the closer the fins the greater will be the surface area and the smaller the cooler unit. Moisture lost from fish during freezing and from air infiltrating into the cooler will eventually be deposited as frost on the cooler surface. If this frost eventually bridges the space between the fins, the effective cooler surface is then reduced, the rate of heat transfer will be reduced and the freezer temperature will rise. There will also be a greater resistance to air flow through the cooler and the air flow rate may be reduced.

Most of the water lost from the fish is lost during the early stages of freezing and in some freezer designs, this will mean a higher degree of frosting on some parts of the cooler than on others. This will effectively reduce the period of operation before a defrost is necessary. Frost build-up on the cooler is also more prolific on the front, upstream coils; therefore a cooler with a large frontal area will be able to operate longer before a defrost is necessary. The specified fin spacing may also be increased where there is likely to be a quick build-up of frost. A good freezer design should be able to operate for at least 8h before a defrost is required but a poor design may require defrosting every 2h.

Types of air blast freezer

There are many different designs of air blast freezer both for batch and continuous operation. Details are given of a number of types of air blast freezer in common use, with comment on their suitability for various products and methods of processing and also on their limitations.

Continuous air blast freezers

In this type of air blast freezer, the fish are conveyed through the freezer (on trucks or trolleys or they may be loaded on a continuously moving belt or conveyor) usually entering at one end and leaving at the other.

When trucks or trolleys are used, they are loaded at one end of the freezer and progressively moved along the freezer as additional trucks are loaded. Once the freezer is full, a truck has to be removed from the exit end before a fresh truck can be loaded. This batch-continuous operation must always allow the coldest air to flow over the coldest fish; otherwise fish which are well frozen will be subject to warmer air as new trucks are loaded. The movement of the trucks in Figure 8 is therefore in the opposite direction to the air flow in the freezing section. One difficulty with this type of freezer is that when the freezer is fully loaded, a whole row of trucks has to be moved at one time. This is particularly difficult at very low temperatures since special bearings and lubricants are required for the truck wheels and it is difficult to keep the trucks free of frost and ice. Trolleys have been suspended from overhead rails to overcome some of these difficulties but this equipment is cumbersome and still not easy to operate.

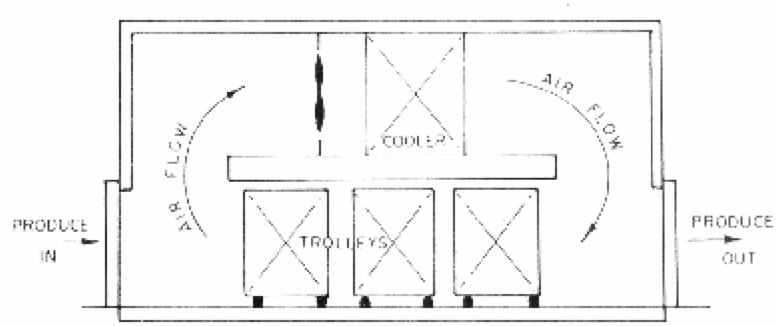

Figure 8 Batch-continuous air blast freezer with counterflow air circulation

To avoid moving trucks within the freezer, a batch-continuous freezer can be designed with a cross flow air arrangement and the freezers may then be loaded from the side as shown in Figure 9. Again in this freezer, once it has been fully loaded, a truck is removed before a fresh one is added. It is a simple matter to keep account of the loading sequence of the freezers by having hand-set clock dials above each entrance which will indicate the time the truck or trolley will be ready for unloading. This cross-flow arrangement allows a cooler with a large frontal area to be built, and frost is also deposited uniformly.

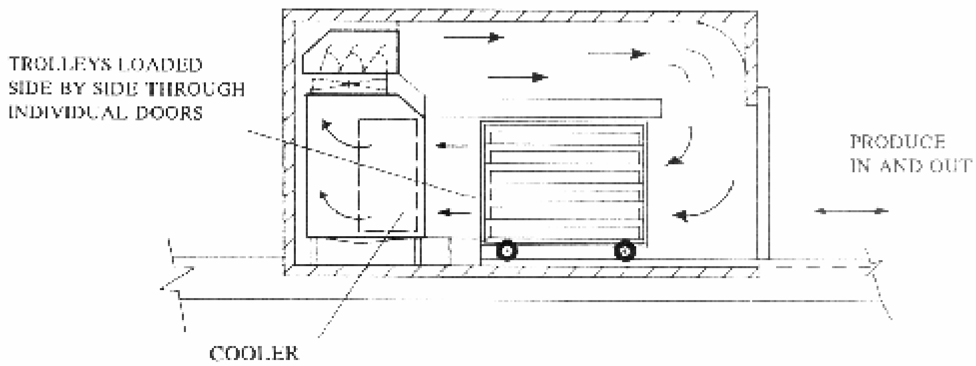

Figure 9 Batch-continuous air blast freezer with crossflow air circulation

Continuous air blast freezers using belts or conveyors for moving the product through the freezer can only be used if the product can be frozen quickly (Figure 10). It is unlikely that a product with a freezing time of more than 30 min would be suitable for this freezer. The reason for the limitation on freezing time is that the freezer will become too long and cumbersome if a long freezing time is required. The freezing time, the freezing requirement in kg/h and the loading density of the product on the belt determine the freezer dimensions.

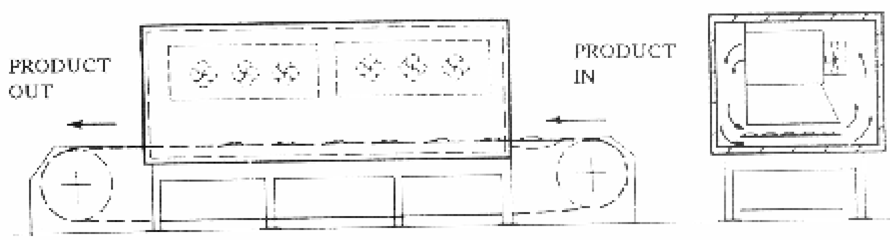

Figure 10 Continuous belt air blast freezer with crossflow air circulation (also constructed with counter current series flow air circulation)

The following example shows how this calculation is made:

Freezing requirement	200 kg/h
Freezing time	18 min
Load on belt 200 x 18 ÷ 60	= 60 kg
Belt loading density	6 kg/m^2
Belt width	1.2 m
Belt loading per unit length 6 x 1.2	= 7.2 kg/m
Belt length 60 ÷ 7.2	= 8.4 m

Allowing for loading and unloading of the fish outside the freezing space, the length of the freezer required for the above requirement would be about 11.4m.

The space required for a continuous belt freezer can be reduced if a double or triple belt is used (Figure 11), or if the belt is arranged in the form of a spiral (Figure 12).

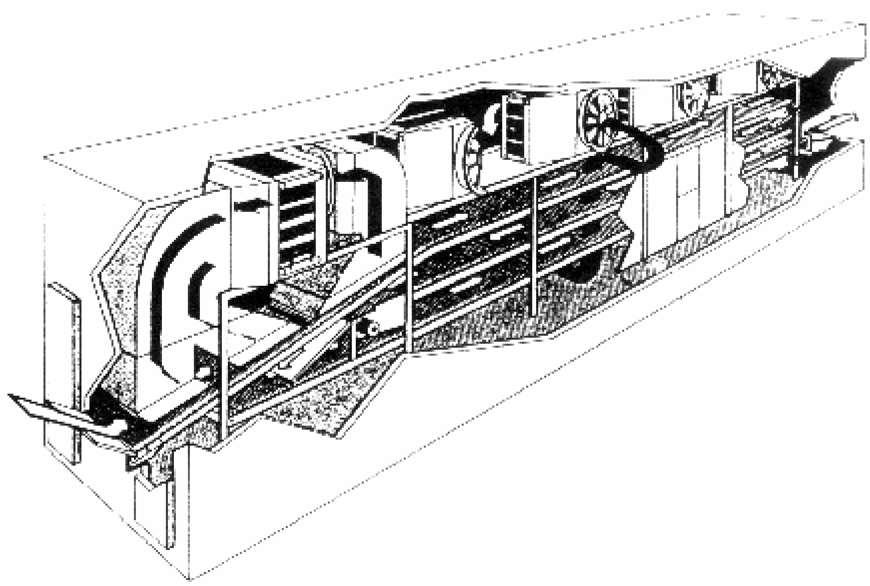

Figure 11 A triple belt air blast freezer

Partially frozen fish tend to adhere to open metal mesh belts and so do not transfer easily to another belt. Double belt and triple belt freezers are therefore more suitable for products such as battered and breaded fish portions, unless certain features are built into the design of the freezer. The semi-fludized freezer described later is a freezer specially designed for this method of operation. Spiral belt freezers are made in a variety of designs and are widely used for IQF products. Continuous belt freezers, Fig 12, generally have their own special problems. The belt has to be flexible, easily cleaned, non corroding, suitable for use in direct contact with food and should not interfere unduly with either the freezing time or adversely affect product quality. Stainless steel mesh link belts or chain link belts are mainly used for this purpose but they have certain disadvantages. Apart from being expensive, they affect the appearance of the product. If fish are loaded directly on the belt, the crinkled or indented appearance of the frozen product is not always acceptable. Open mesh belts can also give rise to difficulty when removing the product after freezing, and some weight loss may be incurred due to slight physical damage. Skin-on fillets call usually be removed quite easily but skinless fillets and fish portions can stick to the belt and cause unacceptable weight losses.

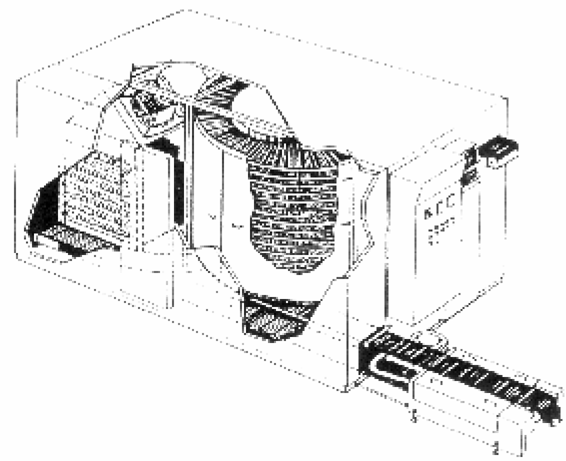

Figure 12 Continuous air blast freezer with the belt arranged in a spiral

Plastic belts made in the form of interlocking links have been used in some continuous freezers. These belts, add about 10 percent to the freezing time. They suffer from the same indentation problems as metal mesh belts but transfer is generally easier. However, their larger mesh makes them unsuitable for small products. If they are only used for the initial part of the freezer, the fish can be surface-hardened and then be transferred to a stainless steel belt. This would allow a two-belt operation in the freezer. In spite of these often minor difficulties in obtaining an ideal belt for continuous belt freezers, many are successfully operated for freezing a variety of products.

Continuous belt freezers can be constructed with either cross-flow or series-flow air circulation. In the series-flow arrangement, the direction of air flow must be such that the coldest fish meet the coldest air. The design of the belt entry and exit must keep the rate of air infiltration to a minimum.

In a continuous freezer, there is no scope for rearranging the volume or space for different products. The belt speed, however, is usually variable and this can be adjusted to accommodate different product freezing times. The capacity of a continuous freezer can therefore vary considerable depending on the product being frozen and its freezing time Table 4 is a freezer capacity list supplied by the manufacturer of one type of continuous freezer and it clearly shows there is a wide variation depending on the type of product being frozen.

Table 4 Variations in the capacity of a continuous freezer

Product	**Product thickness (mm)**	**Capacity (kg/h)**
Plaice fillets	10	100
Cod fillets	18	85
Shrimp (whole)	9	55
Shrimp (meats)	8	150

Another important consideration when using a continuous air blast freezer is whether the freezer will be used continuously. A continuous freezer left in operation but not fully loaded could give rise to higher freezing costs per kg of product frozen.

<u>Batch air blast freezers.</u> Batch air blast freezers use pallets, trolleys or shelf arrangements for loading the product. The freezer is fully loaded, and when freezing is complete, the freezer is emptied and reloaded for a further batch freeze. Apart from this difference in mode of operation, the batch freezer gives rise to bigger fluctuations in the refrigeration load than continuous or batch-continuous freezers (Figure 13).

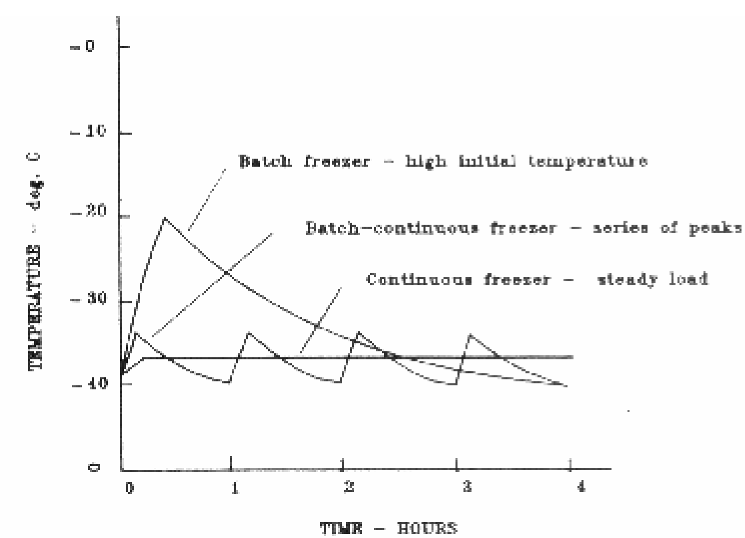

Figure 13 Freezer operating temperatures for different types of air blast freezer

This large fluctuation in refrigeration load means that the refrigeration system will require special control arrangements to cater for the variations. Capacity control or a multiunit system can be used or a competent engineer can manually control the system to match the load. Some refrigeration systems are also better suited to this type of variable load application than others.

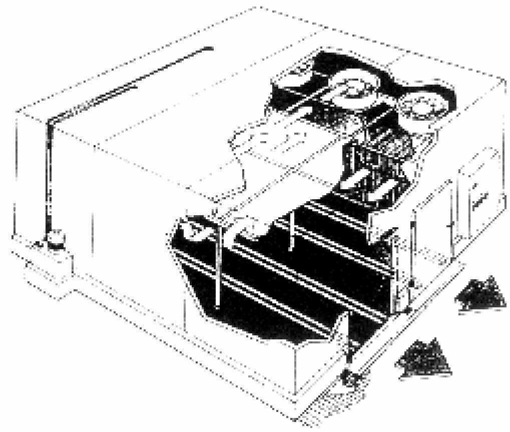

Figure 14 Factory assembled air blast freezer with push through tunnel for two rows of trucks

It is seldom that fish processing can be arranged so that all the fish can be loaded into a batch freezer at the same time. Therefore, if each trolley or pallet is loaded as and when it is ready, the refrigeration peak load will be considerably reduced. This will make the operation similar to a batch-continuous process, but again, care should be taken not to place warm fish upstream of a partly frozen product.

The freezer shown in Figure 14 is a batch tunnel freezer with a push-through arrangement for two lines of trucks. If this design of freezer was used with a batch-continuous operation, warm fish might loaded upstream of partly frozen fish. This freezer should therefore only be fully loaded and operated as a batch freezer.

Another batch freezer arrangement is shown in Figure 15. In this model, the trolleys are loaded from the side of the freezer and the air flows across the three trolleys in line.

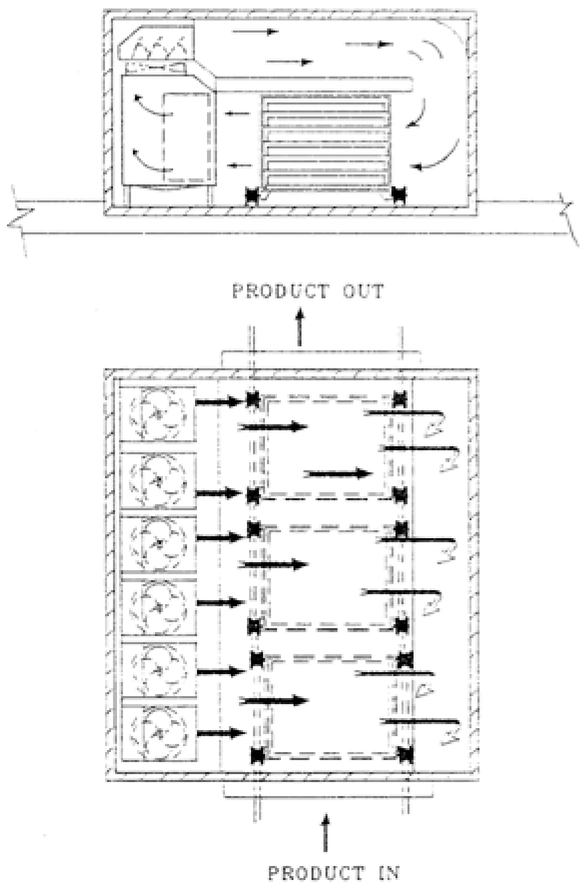

Figure 15 Batch air blast freezer with side loading and unloading

In some air blast freezers, the cooling coil can be at the same level as the working section (Figure 16). This is a fairly good arrangement since the cooler acts as a diffuser and evens out the air flow immediately before it is directed over the fish.

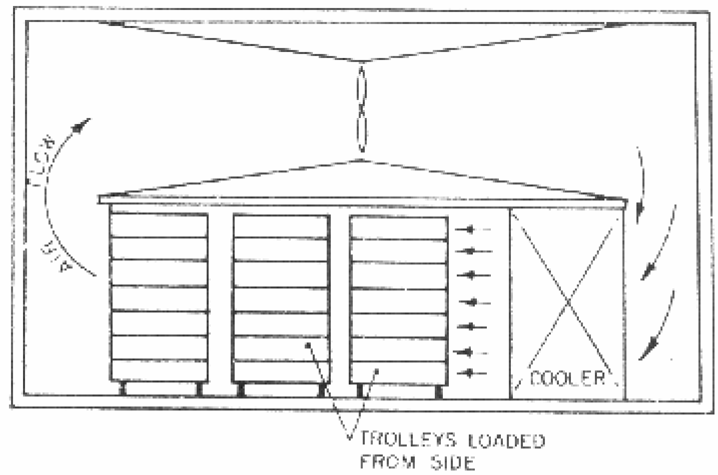

Figure 16 Air blast freezer arrangement showing the cooler acting as an air diffuser

It can be seen that there is a wide variety of air blast freezer arrangements to suit the requirements of different layouts, operating methods and freezing systems. Some air blast freezer designs are not suitable and some of the faults that give rise to long freezing times are shown in the series of diagrams (Figures 17 to 19).

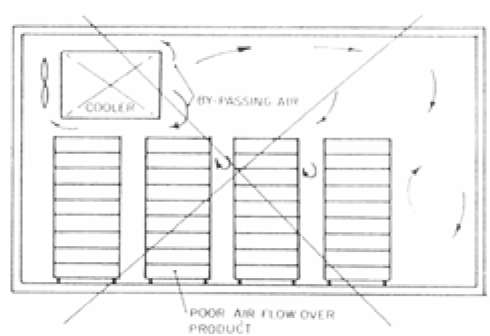

Figure 17 Room freezer with poor air flow over the surface of the product

The freezer arrangement show in Figure 17 is typical of many room freezers that are built. The cooler unit may be mounted at roof level, as shown, or may be a floor-mounted unit. There is no special means of directing the air over the fish and therefore it generally tends to swirl about in the empty spaces in the room and not flow between the shelves or trays loaded on the pallets. The reason for this is that the air takes the path of least resistance and does not readily flow through the comparatively narrow spaces between the product. The air must be ducted so that it has no alternative but to flow over the fish. This is an extremely important feature of a tunnel air blast freezer. Many of the diagrams shown earlier have good layouts which show this.

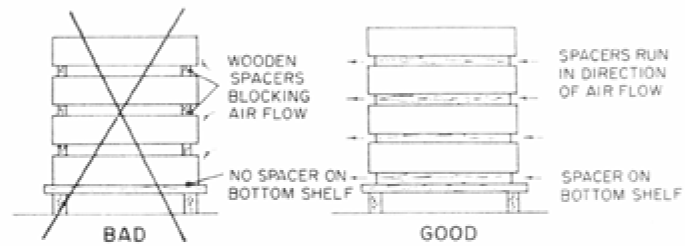

Figure 18 Bad and good use of spacers when stacking produce for freezing

The incorrect method of loading the pallet shown in Figure 18 seems hardly credible but is often used in commercial practice. The mistake can easily be made by an operator who does not observe the direction in which the battens on the base of the pallet are running. Some directional marking on the top of the pallet base may be advisable. The effect of omitting spacers totally is to increase the effective thickness of the product resulting in an unacceptable increase in freezing time.

Poor air flow over the fish but good air flow through the cooler will result in a freezer operating at a temperature below the design value. Poor freezing conditions therefore often mean a low product loading and the air temperature will fall below the design value.

Fluidized and semi-fluidized freezers. One type of air blast freezer fluidizes the product with a strong blast of air from below (Figure 19). The product then behaves like a fluid and when poured into the trough at the input, it moves along the length of the freezer without mechanical assistance and over-flows at the output. This type of freezer has been used successfully for such products as garden peas which are readily separated and kept apart but, as yet, the freezer has not had a wide application for fish or fishery products. Small cooked and shelled shrimp is one of the few fish products that has been successfully frozen by this method.

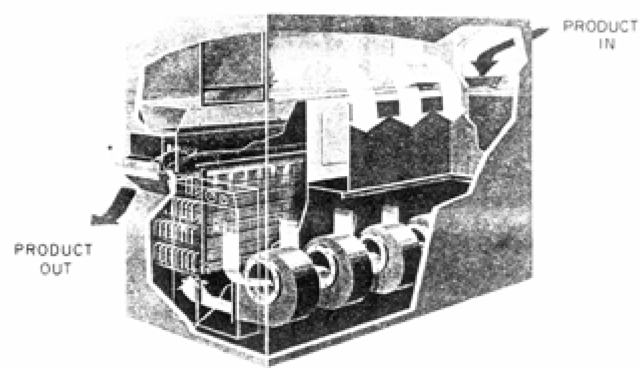

Figure 19 A fluidized flow air blast freezer

A modified fluidized freezer which may be termed a semi-fluidized freezer has also been used for fish-freezing applications (Figure 20). A conventional conveyor is used but at the early stages of freezing, sufficient air is blown from below the belt to agitate the product and ensure that individual portions remain separate until the outer surface has been hardened. This type of freezer can be used with a double belt, with transfer from one to the other midway through the freezing process.

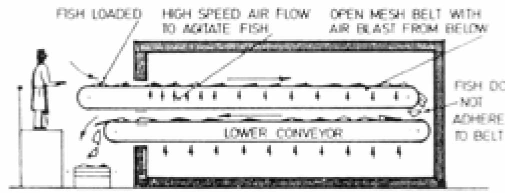

Figure 20 Semi-fluidized flow freezer with double belt

There is however some difficulty in judging the correct air flow to produce the slight agitation required and a fixed flow rate is not suitable if a variety of products are to be frozen. Also, with many products there still remains some difficulty in making the transfer from one belt to the other.

Loading a batch air blast freezer. Because of their versatility, batch air blast freezers are often misused by operators who do not realise their freezing limitations.

The size of the refrigeration plant is fixed to match a given freezing requirement at the designed freezer operating condition. However, if the freezer is used for freezing other products which have different space requirements and freezing times, the freezer operating condition will change. Depending on the original design specification, the freezer may therefore be overloaded or underloaded by a change in product.

The examples in Table 5 show what happens when products of different freezing time are loaded in a batch freezer.

Table 5 Optimum loading of a batch air blast freezer

Product	Plant Capacity (t/h)	Load per freeze (t)	Freezing time (h)	Loading frequency	Freezing rate (t/h)
A	1	2	2	Every 2 h	1
B	1	1	1	Every 1 h	1

In both examples in Table 5, the freezer is correctly loaded since the product load matches the plant capacity in the weight of fish that can be frozen in 1 h.

The above freezer would therefore be designed to hold 2 t of product A and when product B is frozen, only 1 t will be loaded and the product distributed to give uniform air flow. If however, 2 t of product B are loaded into the freezer at one time, the refrigeration plant will be overloaded.

This is probably one of the most difficult aspects of freezer operation to explain clearly but in simple terms it means no matter how spacious your freezer and how much product can be loaded, you cannot freeze more fish than the refrigeration plant will allow.

Good performance in batch air blast freezers is obtained by freezing the product in open trays without wrapping. Trays used in air blast freezers should transfer heat readily, be easily emptied and also be robust. Normally they are required to produce a pack that is of regular shape but when the product allows their use, trays with a taper on the sides of about one in eight can be emptied by applying a cold water spray on the underside for a few seconds and then giving a gentle tap on the edge. Trays used in this manner should never be filled above the tray edge or the product will be damaged during release.

Cleaning and drying of trays before re-use is necessary to maintain a high standard of hygiene. Where the rate of production justifies the cost, an automatic tray washer may be installed.

The reader will no doubt find other types of freezer available on the market which have not been mentioned. The design of many of these is based on combinations of two or more of the basic methods described. For instance, a variety of freezers make use of both contact and air blast freezing techniques. Other freezers may be identical in every respect with one of the methods described, but may use some other liquid, gas or contact method for heat transfer. These freezers will be seen to be similar to one of the types described and will therefore have the same advantages and disadvantages.

4.1.2 Plate freezers

Plate freezers and air blast freezers are the types of freezer most commonly used for freezing fish in industrial countries. Plate freezers do not have the versatility of air blast freezers and can only be used to freeze regularly shaped blocks and packages.

Plate freezers can be arranged with the plates horizontal to form a series of shelves and, as the arrangement suggests, they are called horizontal plate freezers (HPF) (Figure 2 1). When the plates are arranged in a vertical plane they form a series of bins and in this form they are called vertical plate freezers (VPF) (Figure 22).

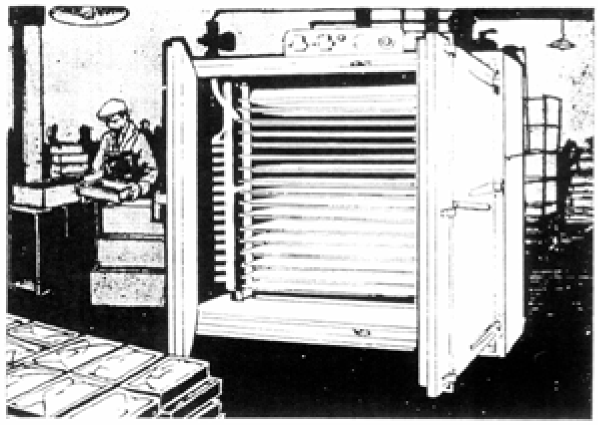

Figure 21 Horizontal plate freezer

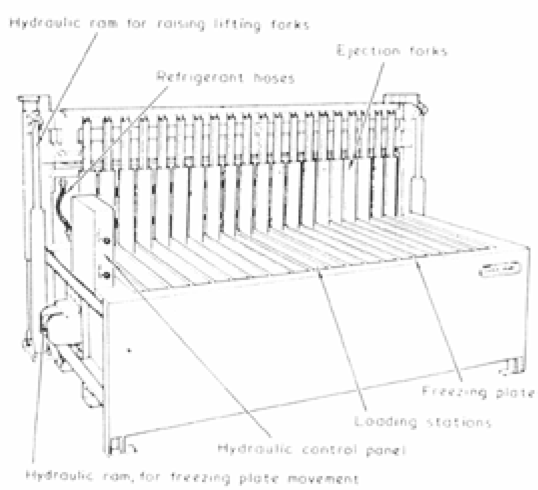

Figure 22 Twenty-station vertical plate freezer with top unloading arrangement

Modern plate freezers have their plates constructed from extruded sections of aluminium alloy arranged in such a manner as to allow the refrigerant to flow through the plate and thus provide heat transfer surfaces on both sides (Figure 23). Plate freezers are fitted with hydraulic systems which move the plates together and apart.

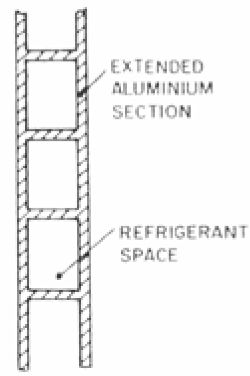

Figure 23 Construction of plates used in contact plate freezers.

<u>Horizontal plate freezers.</u> The two main uses for this type of freezer are the freezing of prepacked cartons of fish and fish products for retail sale and the formation of homogeneous rectangular blocks of fish fillets, called laminated blocks, for the preparation of fish portions. The thickness of package or block frozen is 32 to 100 mm and the freezer can readily adapt from the thicker to the thinner package provided the range required is made known to the supplier at the time of purchase. There is no direct contact between the fish and the freezer plates when freezing by this method since the fish is always packaged before freezing. If the operator is also careful not to spill water on the plates during loading and unloading, the freezer may be operated with only a light brush between each freeze to remove surface frost. The door may be left open overnight to allow the plates to defrost fully after being hosed down with warm water. A hot gas defrost arrangement is the quickest method to defrost an HPF, but even with this method, it may take 30 min or more. The defrosted plates must be completely free from frost or ice and dried before the freezer is used again.

Horizontal plate freezers intended to be operated with a hot gas defrost are fitted with additional pipework which allow the cold refrigerant to be discharged from the bottom of the freezer as the defrost proceeds. Without this special pipework and operating valves, a hot defrost would clear the top plates only and leave the cold refrigerant in the plates at the lower levels. As in all hot gas defrost systems, the refrigeration system must have an adequate load to provide sufficient hot gas for an effective defrost. This system would therefore be better applied when there are two or more freezers operated from a common refrigeration system and each freezer will then be defrosted in turn while the others are in operation.

An HPF will only operate correctly if good contact is made on both the top and bottom surfaces of the pack or tray to be frozen. The faults shown in Figure 24 are some of those which make freezing times longer than necessary. If the product is frozen from one side only due to poor contact on the upper surface, the freezing time could be three or four times as long as the time achieved with good contact on upper and lower surfaces. The plates of the HFP are closed by means of a hydraulically operated piston to make contact with the upper surface of the product. The plate pressure applied to the product can easily be varied between 70 x 280 mbar to suit the product and is increased by a factor of two as the fish expands during freezing.

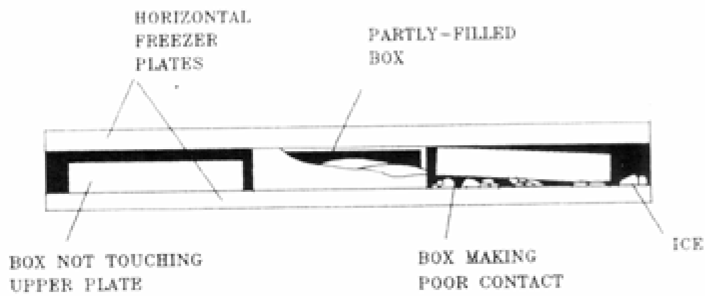

Figure 24 Some reasons for poor performance in a horizontal plate freezer

<u>Vertical plate freezers</u>. The main advantage of this type of freezer is that fish can be frozen in bulk without the requirement to package or arrange on trays. The plates form what is in effect a bin with an open top and fish are loaded directly into this space. This type of freezer is therefore particularly suitable for bulk freezing and it has also been extensively used for freezing whole fish at sea. The maximum size of block made by this method is usually 1 070 mm x 535 mm. Other dimensions however, can be produced in which the thickness can vary from 25 to 130 mm, but will depend on the fish to be frozen. The maximum weight and dimensions are also limited by the physical effort required from the operator to lift the block, and by the ease with which it can be handled so that damage to the fish is kept to a minimum.

In most cases, fish can be loaded between the plates without wrappers and water need not be added either to strengthen the frozen block or improve the contact with the plates. Fish such as cod and haddock produce compact blocks with a block density of approximately 800 kg/m^3.

With fatty fish such as herring, it has been found advantageous to use wrappers and add some water to fill the voids in the block. Fatty fish do not form blocks which are as firm and strong as blocks made from lean fish especially during seasons when the oil content of the fish is high. Water added helps to strengthen the block, protects the fish during subsequent handling and reduces the effects of dehydration and oxidation during cold storage. Well formed, rigid blocks are particularly important when freezing at sea. The product may be handled under particularly adverse operating conditions and poorly formed blocks, prone to breakage, would result in a high percentage of loose fish. Machine filleting or splitting of the fish for instance, may be difficult if fins and tails are broken. Wrappers have been used when freezing fatty fish in VPFs to protect the exposed fish on the outside of the block. A wrapper that has been found suitable for this purpose is a single layer paper bag, coated internally with polyethylene, and shaped to fit the space between the freezer plates. Wrappers made from polyethylene with a specially roughened outer surface to reduce slippage have also been used.

Fish frozen in wrappers require a longer freezing time due to the insulating properties of the wrapping material. Some types of wrapper would have a considerable effect on freezing time but in sea trials the material described did not increase the freezing time by a significant amount.

Vertical plate freezers are defrosted to release the blocks of fish after each freeze. Fish are in direct contact with the plates and the force required to release the blocks without a defrost could be excessive and result in plate damage. The defrost time need not exceed 3 or 4 min if a suitable supply of defrost gas or hot liquid is available. If a primary refrigerant is used in the plates, a hot gas defrost is generally used. Where there is a multiple installation, the freezers are defrosted in turn with the other units in operation providing the necessary refrigeration load for the compressor. When a secondary refrigerant is used, a reservoir of hot liquid has to be maintained and pumped through the plates to displace the cold liquid present. With this arrangement, it is possible to return the bulk of the cold liquid to the low temperature reservoir at the start of defrost, and also return the warm defrost liquid to the hot liquid reservoir for reheating at the start of the next freeze. This arrangement reduces the quantity of liquid interchanged at each defrost but provision must be made to maintain the liquid charges in both the cold and hot systems at the correct level.

Defrost arrangements such as those described lead to more complicated and expensive refrigeration pipework. Attempts have been made to assist the release of the blocks by coating the plates with a low friction plastic material so that a defrost was unnecessary. Although this worked reasonably well, a defrost was found to be essential to prevent fish sticking to the plates which are at a temperature below 0°C, and thus failing to form a compact block. Freezing times are longer due to the poor contact being made with the plates and because of the lower block density, more storage space is required for a given quantity of fish. The results of some tests that clearly show this difference in loading fish between warm plates and plates at refrigerated temperatures are given in Table 6. The first two results in the table were obtained when the fish were loaded between defrosted plates. The last results, which gave low density blocks and longer freezing times, were obtained when fish were loaded between cold plates.

Table 6 Variation of freezing time with density and contact area

Block density (kg/m³)	Contact area (%)	Freezing time (h)
800	48	3.0
780	45	3.0
650	29	3.8
650	21	4.0

Vertical plate freezers can be made with top, side or bottom unloading of the blocks. Generally, top unloading models are preferred since the block is lifted clear of the plates and presented at a suitable height for handling by the freezer operator.

Vertical plate freezers may be supplied in units with up to 30 stations and some thought has to be given to the selection of the correct unit size for each particular requirement. An installation may consist of a number of freezer units which are loaded in rotation. If 12 units are used, and the freezing cycle takes 4h, 1 unit will be defrosted, unloaded and reloaded every 20 min. If this frequency of operation fits in with a suitable work rate and the fish can be handled in and out of the freezers in this time, then the 12 units are suitable for this particular application. Individual units should not be partially loaded, freezing commenced and the rest of the unit loaded later. A further defrost would be necessary and this would reheat the partially frozen fish. The freezer unit size should therefore be matched to the rate at which fish becomes available for freezing. This will ensure that fish are not kept waiting for the unit to be fully loaded and that the freezers are not operated with partial loads for a good deal of the time. If, however, the fish supply rate and the freezer capacity are not matched, it is better to freeze a partial load of fish rather than wait for a full load. Fish can deteriorate quickly at this stage of processing, particularly if it is not chilled and also remains ungutted.

<u>Automatic plate freezers</u>. This type of freezer freezes fish in cartons and is a continuous form of the HPF. Automatic plate freezers are specially designed for a processing line; and units with capacities of up to 2 t/h are available. Their main advantage is that they save the labour required for the loading and unloading of batch plate freezers. However, when this labour saving is related to the total labour requirement for packing and other operations, the saving is often not significant.

4.1.3 Liquid nitrogen freezer.

In this freezer, the product is brought into direct contact with the refrigerant (Figure 26).

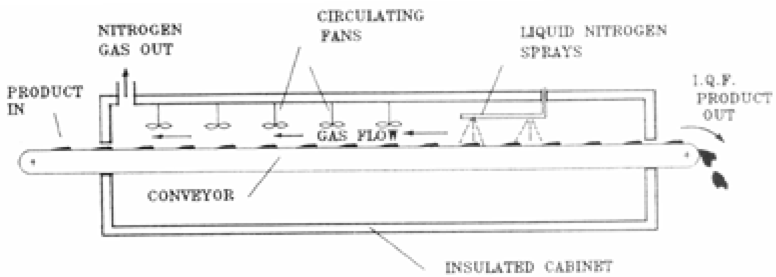

Figure 25 Liquid nitrogen freezer

The fish on the stainless steel conveyor belt initially come into contact with the counter current flow of nitrogen gas at a temperature of about -50°C. As the fish. progress through the precooling stage of the freezer, the gaseous nitrogen partially freezes the fish and up to 50 percent of the product heat is extracted. The product then passes below the liquid spray where freezing is completed by the boiling liquid. The last stage in the freezer provides a few minutes for the fish temperature to reach equilibrium before the fish are discharged.

The main advantage of the liquid nitrogen freezer LNF is that freezing is very quick and the physical size of the freezer is correspondingly small. The freezer is operated without the need for compressors, condensers or coolers; therefore maintenance requirements are minimal and the power required to operate the freezer is very low. Liquid nitrogen must be retained in a vacuum insulated pressure vessel with continuous venting to keep the contents cool and the internal pressure down. One estimate given is that 0.5 percent of the stored contents is lost each day by this method. In addition, about 10 percent has been estimated to be lost during the transfer of liquid from the tanker to the storage vessel although the customer is not charged directly for this loss. This method of freezing is more expensive than most others, being up to four times more costly than conventional air blast freezing. Although the freezer is small and there is no refrigeration machinery requirement, storage space and access is required for the liquid nitrogen tank. The main disadvantage of this type of freezer in most developing countries is that delivery of nitrogen could be expensive and there may be no guarantee of regular supplies.

Carbon dioxide freezer. This type of freezer has been known for a long time and uses liquefied carbon dioxide which is usually a by-product of another industrial process.

The liquefied carbon dioxide is injected into the freezer and comes into direct contact with the product. In this respect, it is similar in operation to an LNF. With large units, it is economically feasible to recover the carbon dioxide and about 80 percent of the refrigerant used can be reliquefied. Carbon dioxide can be contained in insulated vessels at a moderate pressure and losses during storage are therefore negligible. High levels of carbon dioxide in the factory air are dangerous, therefore a freezer using this refrigerant must be vented and the gas discharged outside the building. Again, as is the case with other types of freezer which rely on regular supplies of refrigerant, carbon dioxide freezers would not be suitable for use in remote areas.

Immersion freezers. By using a liquid for the removal of heat from a product, favourable freezing rates can be achieved. Liquid can remove more heat per unit volume than gas (eg. air) but, like gas, a stagnant boundary layer is formed which slows the transfer of the heat. Liquids used for heat transfer must therefore be circulated over the product. Difficulties due to high viscosity often arise when a low temperature liquid is used.

Many liquids that have suitable refrigeration and heat transfer properties are not allowed to be used in direct contact with food. Those that are available are limited in their use because they may cause changes in texture and taste in the food with which they are in direct contact. Immersion in sodium chloride brine was one of the very first methods used to freeze fish since it was a logical progression from the method used to freeze block ice. Brine immersion freezing may still be used for such fish as tuna which are intended to be marketed as a canned product. The fish are large and have a thick skin; therefore the uptake of salt is not great. The little salt that is absorbed is not detrimental to the canned product since salt is usually added to the product before canning in any case. For many other fish freezing applications, adverse effects on texture and taste of the fish due to the absorption of brine have proved to be unacceptable. Even without excessive brine uptake, the surface of the fish will be coated and handling the product after freezing is difficult and messy. Some fish products such as shrimp have been frozen in syrup and salt solutions, and sugar and salt solutions but again there is some degree of absorption with changes in flavour.

4.2 Freezing operating temperatures

Bearing in mind that the freezer must reduce the temperature of the product to the intended temperatures of storage, freezers should operate at temperatures which allow this to be accomplished under the most favourable economic conditions (Table 7). When selecting the appropriate freezer operating temperatures, account should also be taken of cost of equipment, operating costs, space requirements, quality considerations and other factors. In some types of freezer, the temperature is fixed by the method of operation, whereas in others, such as air blast and plate freezers, there is scope for varying the temperature to suit any particular requirement.

The following table gives some typical operating temperatures for various freezers:

Table 7 Freezer operating temperature

Type of freezer	**Operating temperature (°C)**
Batch air blast	-35 to -37 air
Continuous air blast	-35 to -40 air
Batch plate	-40 refrigerant
Continuous plate	-40 refrigerant
Liquid nitrogen	-50 to -196 refrigerant
Liquid carbon dioxide	-50 to -70
Sodium chloride brine	-21 refrigerant

4.3 Space requirements for freezing

The space required for a freezer obviously depends on the capacity and type of freezer. Some factors affecting total freezer space required are given below.

It can generally be assumed that, for a given capacity requirement, the quicker a freezer can freeze the product the smaller will be the physical space required. Freezer space, including that required for loading and unloading the product, is only one factor to be taken into account when calculating the total area requirement. Distinction should be made between floor space required within a building and that required in an open yard outside the covered factory area. Space is required for refrigeration machinery and access for maintenance but for small units, the machinery may be located above or below the freezer unit and will not add to the floor area. With liquid nitrogen and carbon dioxide freezers, no mechanical refrigeration is required, but storage must be made available for the refrigerant. In addition, an area has to be made available for manoeuvring the tanker supplying the refrigerant.

A working area is also required for handling and possibly packaging the product before and after freezing. Trolleys and pallets also require space and if they are doubled up to allow for a rotation system to be used, the floor area occupied by this equipment can be considerable. Packaged products also require a dry area for storing the packaging material which is often printed or marked to identify the product and the company, and this often means ordering in larger quantities.

Total area can therefore be far in excess of the actual freezer space and comparisons made on the basis of this total requirement are often completely different from those made when the freezer unit only is considered.

4.4 Labour requirement for freezing

Low labour requirements for loading and unloading freezers are often quoted by manufacturers to impress potential customers. These requirements, however, can be misleading. Freezers which process packaged fish products without the need for physically handling the fish in and out of the freezer unit can rightly be said to require the minimum of labour. Much of the labour may have been transferred to another part of the process. Requirements should therefore be assessed as a whole and savings in the freezer operation may only be identified by studying what has to be done before, during and after freezing.

Few fish products, when dumped on a conveyor belt, can sort themselves out and be loaded into a freezer. Claims for freezers that can be operated in this way are usually based on experiences gained with other food products, such as fruit and vegetables.

4.5 Calculation of freezer refrigeration load

The individual items to be taken into account in a refrigeration load calculation depend on the type of freezer. It would be impossible to include all the eventualities in one sample calculation; therefore, a relatively simple one is given below for a HPF and some notes have been added to help with other freezer calculations.

Specification

- 50 mm thick trays of fish each weighting 7.5 kg (6 trays per plate)
- Capacity (32.4 t/day)
- Secondary refrigerant temperature (-40°C)
- Evaporating temperature (47°C)
- Fish initial temperature (10°C)
- Freezing time (1 3/4 h)
- Total cycle time including load/ unload/ defrost (2h)

Load calculation

I Number of freezers

32.4 t/day = 32 400 kg/day
32400 ÷ 7.5 = 4320 blocks/day
24 ÷ 2 = 12 cycles/day
4320 ÷ 12 = 360 blocks/cycle

II Fish load

32400 ÷ 24 = 1 350 kg/h
Enthalpy at 10°C = 85.9 kcal/kg
Enthalpy at -30°C = 4.6 kcal/kg
Change in enthalpy = 81.3 kcal/kg
Heat to be removed = 1 350 x 81.3 = 109 755 kcal/h

The change in enthalpy value (the heat to be removed from the fish during freezing) used in the calculation is obtained from Table 29 or Figure 49 and this is a true measured value for cod.

An approximate figure can also be calculated by using the following values:

a. Specific heat of fish above freezing, 0.9 kcal/kg °C
b. Latent heat of the fish, 60 kcal/k
c. Specific heat of fish below 0°C, 0.4 kcal/ kg °C

Using these values, the above calculation for fish refrigeration load would be:

Heat to remove on cooling to 0°C	
1 350 x 0.9 x 10	=12 150 kcal/h
Latent heat to remove 1 350 x 60	=81 000 kcal/h
Heat to remove on cooling to -30°C	
1 350 x 0.4 x 30	=16 200 kcal/h
Total heat to remove from fish	**109 350 kcal/h**
Total refrigeration requirement with allowances:	
Method I - Add 30% = 109 744 x 1.3	=142 681 kcal/h
Method II - Assume 18 h/day running	
109 755 x 24 ÷ 18	=**146 340 kcal/h**

These methods give nearly the same allowance and both calculations are only used here to show the reader how these refrigeration allowances can be applied by different designers.

In the above example, it is the freezing cycle time that is used in the calculation, not the actual freezing time of the block of fish. Account has therefore been taken of the time it takes to load and unload the fish and any minor delays. This time is therefore more realistic when calculating freezer size.

The calculation of fish load gives the refrigeration requirement to freeze the fish only. Depending on the type of freezer used, other heat loads have to be taken into account and added to this value to determine the total refrigeration requirement. Some of these additional heat loads are:

- Fan heat
- Pump heat from circulating pump
- Heat leak through freezer insulation
- Heat load due to pallets, trays, trolleys, etc.
- Head load due to a defrost procedure
- Heat load due to air infiltration
- Heat load due to internal lighting

Once the total load has been calculated, a factor is added which will take care of peak loading, and eventual deteriorating of the freezer and refrigeration equipment. There are no fixed rules for applying this operating factor since it will vary with the equipment and type of operation. Only experience can be used to make a fair judgement but, if no expert guidance is available, applying the factor of only 18h running time in every 24h, shown in the calculation, should make adequate provision in most cases.

A generous allowance for refrigeration machinery for freezers need not, in the end, be an expensive addition. Even short delays due to plant breakdown or reduced performance of equipment can be expensive, especially when freezing at sea.

4.6 Ordering freezers

Buyers specification. The buyer should supply in writing all the information he has about the products, the proposed freezer, the site and facilities available. The more facts the buyer gives, the easier it will be for the contractors to submit tenders that the buyer can compare on a common basis.

Ideally, the buyer should provide as much of the following information as possible when ordering a blast freezer:

- The kinds of fish product to be frozen
- The shape, size and packing of each product
- The freezing time of each product
- The product initial temperature
- The intended cold storage temperature
- Required daily output of each product in metric tons or kilograms
- Normal freezer working day in hours
- The average air temperature required in the freezer section
- The average design air speed required in the freezer section
- Type of air blast freezer required with sketch plan
- The position of freezer in factory premises with a sketch plan showing its location in relation to others parts of the process.
- Maximum headroom available at the freezer location
- Availability and specification of present electricity and water supplies
- Reliability of electric supply and quality of water
- Maximum ambient temperature
- Spare parts required
- Availability of maintenance facilities and skilled labour for plant operation.

The above list is by no means exhaustive and may be added to; for instance, reference should be made to any local laws that may affect the siting or operation of the freezer. Most of the information above will require to be supplied for other types of freezer together with additional information that may be considered relevant.

No detail is too small to assist the supplier to provide the exact equipment to meet the buyer's requirements.

The contractor should also supply a complete written specification of the equipment being offered and also a detailed sketch plan showing the layout and space requirements of the freezer refrigeration plant and other ancillary equipment.

The following notes and lists will give some guidance on what information may be supplied so that the customer is quite clear about all details of the plant being offered.

Refrigeration capacity is sometimes quoted in terms of the power of the condensing unit's electric motor. There is such a loose relationship between them, that motor power is at best only a very rough guide. Refrigeration capacity is sometimes quoted in terms of kcal/day or quantity of fish frozen per day without specifying what is meant by a day; is it 24h or is it a working day of 8h? In order to avoid confusion, capacity should be quoted as an hourly rate in kcal/h and it should be made clear whether this is the gross capacity of the condensing unit for all duties or the net heat extraction rate available for freezing the fish only. If there is likely to be confusion, both the gross and net values should be given.

Another common error is to ignore the intended operating conditions when quoting the refrigeration capacity. It is important that compressor capacities should not be quoted at standard rating conditions or any other unrelated condition. The following additional information should also be specified by the contractor:

Refrigeration machinery:

- Number and type of compressors
- Compressor operating conditions
- Total refrigeration capacity
- Refrigeration capacity of each compressor in kilo calories per hour at design condition
- Power of compressor motors in Watts or kilowatts
- Maximum electrical power requirement in Watts or kilowatts
- Compressor safety arrangements
- Condensers, number and type
- Water consumption in cubic metres per hour
- Circulating pumps for condenser
- Fan power requirements for condenser
- Sketch of machinery layout showing total space required

Refrigeration system:

- Refrigerant used
- Type of system
- Initial refrigerant charge in kilograms
- Power of circulating pumps for refrigerant
- Standby arrangements, if any
- Method of temperature control, if any
- Temperature control limits

Freezer:

- Sketch of freezer layout showing total space requirement
- Weight of load for each product specified
- Output in metric tons per hour or kilograms per hour for each product specified
- Output in metric tons or kilograms for normal working day including allowance for loading
- Recommended loading procedure
- Air temperature in freezing section Number and capacity for fans
- Air speed in empty freezer in metres per second Air speed over the product in metres per second Air temperature rise over the product
- Method of defrosting
- Instrumentation supplied Type of insulation
- Thickness of insulation in millimetres Method of erection of insulation
- Type of vapour sealing
- External finish
- Internal finish
- Door arrangement
- Door heaters
- Frost heave precaution, if any
- Lights

5.0 FREEZING TIME

The freezing time is the time taken to lower the temperature of the product from its initial temperature to a given temperature at its thermal centre. Most freezing codes of practice require that the average or equilibrium temperature of the fish be reduced in the freezer to the intended storage temperature. The final temperature at the thermal centre is therefore selected to ensure that the average fish temperature has been reduced to this storage value. The recommended storage temperature for frozen fish in the UK for a period of 1 year is -30°C and, to ensure that the fish are frozen quickly, the temperature of the freezer must be lower than this.

The surface of the fish in a freezer will be quickly reduced to near the freezer temperature of say -36°C. Thus when the warmest part at the thermal centre is reduced to 20°C, the average temperature of the fish will be close to the required storage temperature of -30°C. The freezing time, in this particular case, will therefore be defined as the time taken for the warmest part of the fish, at the thermal centre, to be reduced to -20°C.

5.1 Variables which affect freezing time

- Freezer type
- Freezer operating temperature
- Refrigeration system and operating condition
- Air speed in an air blast freezer
- Product temperature
- Product thickness
- Product shape
- Product contact area and density
- Product packaging
- Species of fish

The above factors will determine the overall heat transfer coefficient and hence the freezing time.

Freezer type. The type of freezer will greatly influence the freezing time. For example, due to improved surface heat transfer, a product will normally freeze faster in an immersion freezer than in an air blast freezer operating at the same temperature.

Operating temperature. The colder the freezer, the faster the fish will freeze. However, the cost of freezing increases as the freezer temperature is reduced, and in practice, most freezers are designed to operate only a few degrees below the required storage temperature of the product. For example, plate freezers usually operate at about -40°C and blast freezers at about -35°C when the storage temperature is -30°C.

Air speed in blast freezers. The general relationship between air speed and freezing time is shown in Figure 5 and this shows that freezing time is reduced as the air speed is increased. This, however, is a rather complicated relationship and it depends on a number of factors. If the resistance to heat transfer of the stagnant boundary layer of air is important, changes in air speed will make a significant difference to the freezing time. If, however, the package is large and the resistance of the fish itself is the important factor then changes in air speed will be less significant. Air temperature, air density, air humidity and air turbulence are other factors that have to be taken into account when the effect of air condition on freezing time is considered. Some of these factors however, may only have a minor effect.

Product temperature before freezing. The warmer the product, the longer it will take to freeze. Fish should therefore be kept chilled before freezing both to maintain quality and reduce freezing time and refrigeration requirement. For example, a single tuna 150 mm in diameter frozen in an air blast freezer will take 7h to freeze when the initial temperature is 35°C but, only 5h when the temperature is 5°C.

The initial temperature of the product must therefore be given when quoting a freezing time.

Product thickness. The thicker the product, the longer is the freezing time. For products less than 50 mm thick, doubling the thickness may more than double the freezing time whereas doubling a thickness of 100 mm or more may increase the freezing time fourfold. The rate of change of freezing time with thickness therefore, depends on the relative importance of the resistance of the fish to heat transfer.

Product shape. The shape of a fish or package can have a considerable effect on its freezing time and this is dependent on the ratio of surface area to volume.

Product contact area and density. In a plate freezer, poor contact between product and plate results in increased freezing time. Poor contact may be due to ice on the plates, packs of unequal thickness, partially filled packs or voids at the surface of the block. Surface voids are often accompanied by internal voids and this also results in poor heat transfer. Apart from increasing freezing time, internal voids also reduce the density of the block. The relationship between time, block density and contact area for 100 mm blocks of white fish is shown in Table 6.

Product packaging. The method of wrapping and the type and thickness of the wrapping material can greatly influence the freezing time of a product. Air trapped between wrapper and product has often a greater influence on the freezing time than the resistance of the wrapping material itself. The following example illustrates the point. Smoked fish in a cardboard box with the lid on take 15h to freeze in an air blast freezer. Smoked fish in an aluminium box of the same shape and size and with the lid on take 12h, but if the lid is taken off the cardboard box, the freezing time is only 8h because there is no trapped air acting as an insulation.

Species of fish. The higher the oil content of the fish the lower is the water content. Most of the heat extracted during freezing is to change the water to ice; therefore, if there is less water, then less heat will require to be extracted to freeze the fish. Since the fat content of oily fish is subject to seasonal variations, it is safer to assume the same heat content figure used for lean fish in any calculation. This also ensures that the freezer capacity is adequate whatever the species of fish being frozen.

5.2 Calculation of freezing times

Freezing times can be calculated, but there is usually insufficient information available to make this calculation accurate. Calculated freezing times can be fairly accurate for uniformly shaped products such as blocks of fillets but, for other products with irregular shapes, calculation can only give a rough guide. The presence of wrappers and many other factors can make calculation of the freezing time difficult and unreliable.

Formulae that have been used for quick calculations in the past had to be simplified to make them practical. They also assume that the fish has been chilled before freezing and that all of the heat is extracted at the initial freezing temperature. Calculated freezing times should therefore only be used to give an approximation of the true figure and should not be used for designing freezing equipment. Modern computer techniques have now made it possible to calculate freezing times more precisely.

Plank's formula for calculating the freezing time of fish has been widely used in a variety of forms. It has proved to be particularly valuable in extending the results from experimental studies to cover a wide range of variables. Thus, if an accurately measured freezing time is known, others can be calculated if most of the freezing conditions are similar.

The most general form of Plank's equation for calculing freezing time is:

$$Freezing \cdot time = \frac{L}{V\Delta}\left(\frac{PD}{f} + \frac{RD^2}{k}\right)$$

Where

L = Heat to be extracted between the initial freezing point and final temperature (kcal/kg)

V = Specific volume of fish (m3/kg)

D = temperature difference between the initial freezing point of the fish and the refrigeration medium (°C)

D = Thickness of product in direction of prevailing heat transfer (m)

k = Thermal conductivity of frozen fish (kcal/h m °C)

P and R = Constants which depend on shape

From the above formula, it can be seen that freezing time is inversely proportional to the temperature difference and, depending on other conditions, it may also be nearly proportional to the square of the product thickness. This knowledge can be used to calculate other freezing times as shown in the examples shown in Table 8.

Table 8 Values for shape constants P and R

Shape	P	R
Sphere	0.167	0.042
Infinite Cylinder	0.167	0.042
Infinite Slab	0.500	0.250

Measured freezing time. A measured freezing time of 3h 20m (200 min) is known for a 100 mm thick block of whole herring frozen in a VPF with a refrigerant temperature of 35°C.

Calculated freezing time - Example 1. What is the freezing time if all other conditions remain the same but the operating temperature is -25°C?

Fish freezes at about -1°C, therefore in the measured freezing time the effective temperature difference is 34 degC (the difference between -35°C and - 1°C). The effective temperature difference for the freezing time required is 24 degC(the difference between -25°C and -1°C). Freezing time is inversely proportional to the temperature difference, therefore the freezing time with an operating temperature of -25°C will be longer than for a temperature of -35°C and can be calculated as follows:

200 × 34 ÷ 24 = 283 min or 4h 43min

Table 10 Freezing times for fish products

Product	Freezing method	Product initial temperature (°C)	Operating temperature (°C)	Freezing time	
				(h)	(min)
Whole cod block 100 mm thick	Vertical plate	5	-40	3	20
Whole round fish 125 mm, e.g. cod, salmon, frozen singly	Air blast 5 m/s	5	-35	5	00
Cod fillets laminated block 57 mm thick in waxed carton	Horizontal plate	6	-40	1	20
Haddock fillets 50 mm thick on metal tray	Air blast 4 m/s	5	-35	2	05
Whole lobster 500 g	Liquid nitrogen spray	8	-80/ Variable	0	12
Scampi meat 18 mm thick	Air blast 3 m/s	5	-35	0	26
Shrimp meat	Liquid nitrogen spray	6	-80/Variable	0	5
Single haddock fillets	Air blast	5	-35	0	13
Packaged fillets 50 mm thick	Sharp freezer	8	-12 to -30	15	00
Packages fillets 50 mm thick	Air blast 2.5 to 5 m/s	5	-35	5	15
Single tuna, 50 kg	Sodium chloride immersion	20 to -18°C at centre	-12 to -15	72	00
Single tuna, 90 kg	Air blast	20 to -45°C at centre	-50 to -60	26	00

Notes:

1. All freezing times are to -20°C at the fish centre unless otherwise stated. Other temperatures are given within the brackets after the freezing time.
2. The times given are measured freezing times. In commercial practice, these times should be increased by a factor to allow for operating discrepancies.

Calculated freezing time - Example 2. What is the approximate freezing time if all other conditions remain the same and the block thickness is reduced to 75 mm?

Freezing time is directly proportional to the square of the thickness since in this case the surface heat transfer coefficient is high and the factor relating to the thickness of the block, PD/f, will be small. The new freezing time will therefore be calculated as follows:

$200 \times 75^2 \div 100^2 = 200 \times 5625 \div 10000 = 112$ min (1h 52 min)

5.3 Sample freezing times

The freezing times in Table 9 are observed times for a number of fish products and will give designers and operators some idea of what to expect in practice.

It should be noted that the initial fish temperature for all the examples given in Table 10 is about 5 to 8°C. This temperature is typical if fish are chilled before freezing and makes allowance for the fish warming up during handling prior to freezing.

6.0 TREATMENT OF FISH AFTER FREEZING

As soon as fish are removed from a freezer, they should be glazed or wrapped (unless they have been packaged before freezing) and immediately transferred to a low temperature store. When it is known that storage will be for a short period only, glazing or wrapping may not be necessary or practical. Blocks of whole cod, frozen at sea, are usually transferred to the ship's cold store without a protective wrapper or glaze but this may be added later, prior to long term storage on shore. During relatively short terms of storage, fish without a protective wrapper or glaze can be severely dehydrated in a poorly designed or operated store.

6.1 Glazing

The application of a layer of ice to the surface of a frozen product by spraying, brushing on water or by dipping, is widely used to protect the product from the effects of dehydration and oxidation during cold storage. The ice layer sublimes rather than the fish below and it also excludes air from the surface of the fish and thereby reduces the rate of oxidation. Heat added by the glazing process is often considerable and the fish may require to be recooled in a freezer before being transferred to the cold store.

In order to form a complete and uniform glaze on the surface of the fish, the glazing process requires to be closely controlled. The amount of glaze applied depends on the following factors:

- Glazing time
- Fish temperature
- Water temperature
- Product size
- Product shape

Glazing by dipping in a container of water is not recommended. The initial temperature of the water may be relatively high; this is reduced as glazing proceeds and the thickness of glaze will therefore vary. The glaze on IQF fillets has been shown to vary between 2 and 20 percent using this method, even when the immersion time was kept constant. In practice, the time will not be constant and this will give rise to even greater inconsistency. The water will also become contaminated after some time; therefore, this method is not recommended. If a dipping method is used to apply a glaze, the container should be continuously supplied with chilled water and fitted with an overflow.

Spray glazing methods are suitable, but again it is difficult to obtain a completely uniform glaze and it may be necessary to invert the fish to ensure that all surfaces are treated.

The glazer shown in Figure 26 has a number of features which enable a complete uniform glaze to be applied.

1. A constant speed belt will ensure a fixed time in the glazing zone;
2. The overhead and underside spray provide a constant supply of chilled make-up water and glazes both the upper and lower surface of the product;
3. The double belt arrangement forces fish to invert providing an even glaze.
4. The adjustable baffle may be used to rearrange overlapping fish on the belt so that each fish is totally exposed;

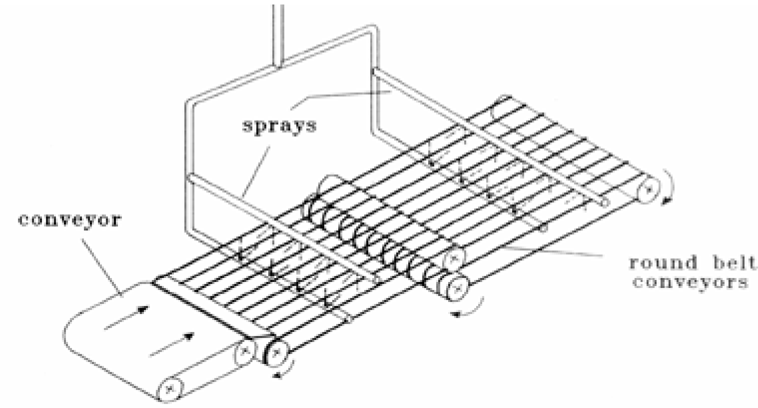

Figure 26 A dip-spray glazer for glazing fish

Glazing when the fish surface temperature is at -70°C or lower, e.g. immediately after cryogenic freezing, results in a glaze which is fractured and broken due to thermal stress during the formation of the ice. This glaze is easily dislodged during subsequent handling. If the fish are immersed in the glaze water for too long, a thick glaze is formed but the equilibrium temperature of fish and ice is high and only slightly below 0°C. This glaze will be soft and easily dislodged during subsequent handling.

Good glazing practice can be beneficial, particularly when other aspects of storage and transport are far from ideal, but poor glazing involving partial thawing of the fish and slow refreezing in cold storage may do more harm than good.

6.2 Packaging of frozen fish

6.2.1 Need for Packaging

After fish has been frozen, it can be subjected to many forms of deterioration between production and eventual consumption. Contamination from humans, animals, insect and atmospheric sources is possible. Physical damage can be caused by bad handling during stacking, transit and storage or display in freezer cabinets. The sensory properties can be adversely affected by tainting and textural and flavour changes can be caused by dehydration and chemical changes which can take place under poor cold storage conditions. To prevent or reduce losses in product quality, it is essential that the frozen product is packaged in such a way as to provide an effective barrier with sufficient impact and compression strength to prevent mechanical damage. The packaging material must have adequate barrier properties to reduce losses due to dehydration and pick-up of taints. Further considerations are the printability of the material, so that a well designed attractive illustrated package can be produced. The package should give the consumer information on the nutritional properties of the product and instructions on how the product should be prepared, stored and give the 'use by' or 'best before' date.

A final consideration which is becoming increasingly important is the environmental issue. Considerations should include the impact of the packaging material on the environment, whether or not the package is re-usable or recyclable, whether the package is made from renewable resources and if the package produces pollution when it is being destroyed.

6.2.2 Types of Packaging Material for Frozen Fish

The range of packaging material for frozen fish is very wide and is dependant on the form of the product being packed. Whole fish frozen in a vertical plate freezer, for example, may require little packaging, other than an ice glaze, to prevent dehydration. Small pelagic fish frozen in vertical plate freezers may benefit from being frozen in water blocks where the freezer plate is lined with a robust plastic paper lined bag. This can be filled with water after the fish have been placed between the freezer plates. A processed fish product, for example fish sticks, may be wrapped in a primary package which is in direct contact with the frozen food and then stored in an outer carton. A number of primary packages may be collected together and packaged in a master carton (secondary package) for delivery or display in a freezer cabinet. The secondary packages can be bought together in a tertiary package, for example a wrapped pallet, and used for bulk transportation.

6.2.3 Primary Packaging Material

6.2.3.1 Plastics

The primary package in contact with the frozen product is generally a plastic derived from a natural hydrocarbon source. The choice of which plastic wrapper is dependant on the type of barrier required, and if the product is to be cooked or heated in the container. Migration of the plasticisers from the wrapping is a potential health hazard and the type of wrapping which can be in contact with food is covered by national legislation. The non-biodegradability of plastic wrapping material is an environmental issue and toxic compounds eg dioxins can be produced when, for example polyvinylidene chloride (PVDC) or polyvinyl chloride (PVC) plastics are incinerated at low temperatures.

Many different types of packaging materials are used for fish, and it would be unrealistic to try to list them all. Tables 10 and 11 list various films and laminates, their barrier properties and Table 12 lists various packaging methods and their applications . Table 13 summarises the properties of the basic material in comparison with nylon and (Polyacetol, PA) and polythene (Polyethylene, PE), and Table 14 summarises the properties of laminate with polyethylene and nylon. Plastics with good moisture vapour barriers and stability at low temperatures are required for the storage of frozen fish, and a good vapour barrier is required to prevent oxidation of fats in frozen fatty fish. The group of plastics called polyolefins, which include polyethylene, polypropylene and its co-polymers are most widely used. Generally, the higher the density of the polyethylene the better the barrier properties, with polypropylene being the best. Polypropylene is able to withstand temperatures up to around 100°C and is therefore suitable for boil in the bag products. To package ovenable products, a modified polyethylene CPET (Crystaline Polyethylene Tetraphthalate) is used, which maintains low temperature flexibility.

Polypropylene or polyethylene laminated with polyamide or polyester are frequently used for boil in the bag type products, and laminated plastic aluminium foil may be used when good vapour and moisture barriers are required, particularly with fatty fish to prevent fatty acid oxidation.

Plastic and paper based packaging is transparent to microwaves (passive packaging) and therefore can be used to contain foods which are to be microwaved. Thin polyester films can be metalised with aluminium and then laminated to a supporting board. When microwaved the aluminium absorbs a certain amount of radiation, generating heat and cooking the product.

Other considerations concerning primary packaging materials are the sealability of the material by heat and also its printability properties.

6.2.3.2 Cartons

Cartons can also be regarded as primary packages when used as a protective sleeve to the product. The boards for the cartons can be made of :

1. Kraft boards. These are frequently used for packaging frozen foods and are usually made from fully bleached materials. They are strong, of good appearance and are suitable for direct contact with food.
2. Folding box boards. These usually have one fully bleached side which is suitable for direct contact with food.
3. Recycled fibre boards. These are usually used for secondary and tertiary packaging.

6.2.4 Secondary Packaging

Secondary packaging is usually a carton which holds a number of primary packages. The secondary package is usually made from boards but can be bands of paper or plastic.

6.2.5 Tertiary Packaging

Tertiary packaging is used to hold a number of secondary packages. Tertiary packaging may be palletised for easy handling and wrapped with shrink, stretch wrap or corrugated outers or may be packed in re-usable containers. Wooden pallets are in regular use, but can become a source of contamination. Plastic pallets, which can be colour coded, are more easily cleaned but will support the growth of mould in frozen fish factories.

6.2.6 Packaging Machinery

Packaging equipment may vary between a simple hand operated tool to an extremely complex machine and examples are listed in Table 15. For primary packaging of frozen fish two types of carbon, top load and end loads are generally used.

6.2.6.1 Top Load Cartons

Top load cartons (Fig 27) which are formed immediately prior to packaging, are supplied flat and unglued. The cartons are erected by a machine at speeds of between 20 and 320 cartons per minute and glued with hot melt adhesives which can tolerate cold store conditions. Top load cartons are used for some forms of fish sticks, the product being loaded in through the widest opening. A top load processing line normally consists of three machines for carton erecting, filling and closing respectively. Closing is usually effected by heat seal or adhesive to make the container tamper proof.

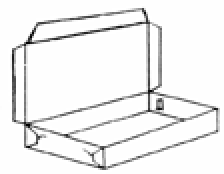

Figure 27 Top-load lock-formed carton

6.2.6.2 End Load Machines

End load cartons (Fig 28) are used for products which are sufficiently robust to allow the product to be pushed in at the end of the carton. These are frequently used as a primary package for frozen fish portions or fish sticks. The process is slightly more expensive than top load processing, but has the advantage that the process is carried out by a single machine.

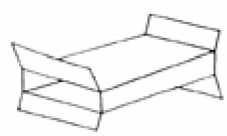

Figure 28 End-load carton

6.2.6.3 Auto Loading

Many machines have intelligent product - transfer units (IPTU's) which will automatically monitor and load the frozen product into the container and can be set to accept different tolerances. This technology is widely used in packaging frozen fish products to ensure that the weight of the product within the packet is with the designated tolerance.

6.2.6.4 Bags

Frozen fillets can be packed directly into bags made from materials with good gas vapour and moisture barrier properties. The level of sophistication can range from manual weighing and loading to a highly sophisticated form-fill-seal technology where a specified weight, volume or count of product is filled into a formed bag which is heat sealed. Such equipment can be used for packing IQF cooked, peeled shrimp.

6.2.6.5 In-Line Pouch Forming Equipment

In-line pouch forming equipment was developed in the mid 1960s to reduce the labour required to product the package, fill and seal the container. Such machines (Figure 29) are widely used in the frozen fish industry, particularly in situations where sauces are added to the product. The material for the package is formed from a roll of packaging laminate (bottom web) which is heat formed in a dye, either by compressed air or vacuum to form the pouch. The product is then loaded, either by machine or hand into the pouch and any added liquid will be added by an automatic depositor. The package then has the top sealing web brought into contact with the bottom web, evacuated and then heat sealed. Some products may have an inert gas injected into the package as an alternative to evacuation, to prevent the packaging coming into contact with the product. The packages are then separated by cutters which cut both along and across the webs which join the packages together.

Typical films for this type of packages are:

Bottom web - nylon 75 microns + polyethylene 50 microns = 125 microns

Top web - nylon 20 microns + polyethylene 50 microns = 75 microns

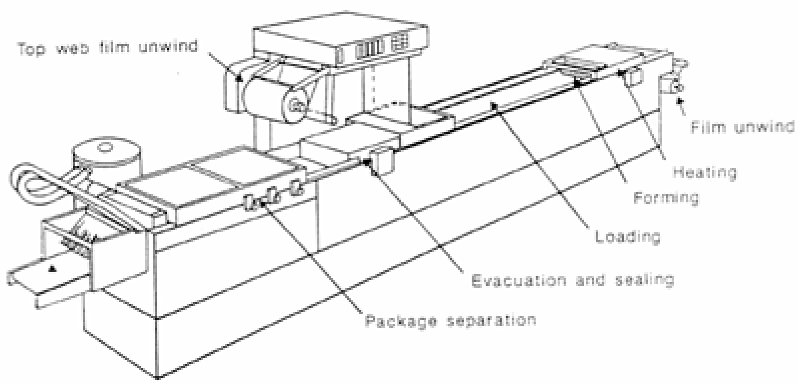

Figure 29 Horizontal in-line pouch former

6.2.7 Machinery For Tertiary Wrapping

Tertiary packaging is the final stage of the packaging procedures and machinery is available which will collate, package and palletise the secondary packages. Tertiary packaging normally takes place after the product has been frozen. A typical operation would involve the orientation and collation of a number of secondary packages which would be automatically loosely wrapped in shrink wrap. The shrink wrap would then be heat sealed before the wrap packs are conveyed through a heated tunnel, where the wrapping shrinks to assume the geometry of the pack. Alternatively, the secondary packages can be packaged in cases, which may be formed round the product (wrap around) or the case may be preformed and glued before the packages are loaded.

The tertiary packs are then frequently palletised for storage or distribution. The pallet and contents themselves may be wrapped in stretch wrap or similar materials for further protection. This may be done by hand, but is increasingly carried out by mechanical pallet wrappers.

Table 10 Characteristics of some film used for the packaging of solid foods

	Gas transmission $cm^3\ m^{-2}\ day^{-1}$(dry gas)			Water vapour transmission $g\ m^{-2}\ day^{-1}$	
Film (thickness 25 mm)	**Oxygen (at 23 °C)**	**Carbon dioxide (at 23 °C)**	**Nitrogen (at 23 °C)**	**RH 90.0% (at 38 °C)**	**RH 90.0% (at 25 °C)**
LPDE (0.917)	7400.00	40000.00	2800.00	12.50	4.00
HDPE (0.960)	1600.00	11400.00	440.00	3.70	1.45
PP cast	3040.00	9760.00	690.00	8.20	3.30
OPP coextruded	1550.00	5280.00	320.00	5.00	1.35
OPP coated	15.00	88.55	4.50	5.00	2.00
OPP acrylic coated	1200.00	4500.00	250.00	4.60	1.80
OPP metallized	35.00	108.00	6.50	1.00	
PVC rigid	120.00	320.00	20.00	32.00	12.00
PVC oriented	27.00	68.00	20.00	17.50	7.00
PVC plasticized	190-3100	430-19000	53-810	85.00	32.70
PVDC	1.25-14.5	5.0-50.0	0.4-2.5	0.6-3.20	0.25
PS cast	4500.00	11000.00	640.00	170.00	70.00
SAN	900.00	2800.00	120.00		
Polycarbonate	3200.00	17500.00	450.00	178.00	72.50
PET	55.00	240.00	12.40	20.00	7.00
PET PVDC coated	8.00	32.00	2.00	8.50	3.40
PET metallized	0.65	3.4 -10.0	0.20	1.00	0.40
PA6	40.00	200.00		280.00	80-110.00
OPA 6	18.00	120.00	9.00	130.00	28.30
PA 6.6	35.00	140.00	11.00	90.00	15.0-30.0
EVAL (32% ethhylene)	0.16	0.45		80.00	32.00
Cellulosic film 445MXXT A	8.75	80.00	3.65	8.60	3.40

LDPE, low-density polyethylene; HDPE, high density polyethylene; PP, polypropylene; OPP, oriented polypropylene; PVC, polyvinyl chloride; PVDC, polyvinylidene chloride; PS. polystyrene; SAN, styreneacrylonitrile; PET, polyester; PA, polyamide; OPA, oriented polyamide; EVAL, ethylene-vinyl alcohol; MXXT, a PVDC coating.

Table 11 Characteristics of some laminates used for the packaging of solid foods

	Gas transmission $cm^3\ m^{-2}\ day^{-1}$ (dry gas)			Water vapour transmission $g\ m^{-2}\ day^{-1}$	
Laminate	**Oxygen (at 23 °C)**	**Carbon dioxide (at 23 °C)**	**Nitrogen (at 23 °C)**	**RH 90.0% (at 38 °C)**	**RH 90.0% (at 25 °C)**
Cellulose film 280XS +PE 40m	12.00			4.50	1.10
OPP coextruded 25m +OP coextruded 25m	650.00			2.60	0.95
PET coated PVDC 12m PE 40m	5.00	15.00	1.00	3.70	1.40
M PET 12m + PE 80m	1.00	4.00	0.20	0.50	0.20
M PET 12m + M PET 12+ PE80m	< 0.10	< 0.10	0.00	0.15	0.06
OPA 15m end. PVDC +PE 60m	10.00	30.00	2.50	5.00	
OPA 6 20m + PE 80m	40.30				
M OPA 5 15m + PE 80m	2.00			2.50	
Kraft 45 g m^{-2} + PE 20 g					
m^{-2}	34.00			1.70	0.60
+ end. PVDC 20 g m^{-2}					
Kraft 60 g m^{-2} + end.					
PVDC 30 g m^{-2}	15.00			1.90	0.65
PET 12 m + 119 m+					
monomer 20m	< 0. 20			< 0.10	
Cellulosic film 320 DM					
+A 19m + PE 35m	7.25			0.15	0.10
Kraft 70 g m^{-2} + PE 15 g					
m^{-2}	4.30			0.10	0.08
+ A 19 m					
A 19 m + Kraft 70 g m^{-2}	25.40			0.25	0.15
A 19m + TPP 20 g m^{-2}	28.00			0.40	0.15
wax					
30 g m^{-2} TPP 20g m^{-2}	< 8. 00	< 35.00	< 3. 00		

M, Metallized; Kraft, paper; DM. one side nitrocellulose coated; A, aluminium foil; TPP, this porous paper; XS. cellulosic film coated with PVDC

Table 12 Packaging methods and applications

Method	Details	Process	Function/use
Coated paper bags	Polythene-lined sacks	Hand	Water-filled blocks 20-50 kg, whole fatty fish
"	Metalized Laminate	Hand/M/c	Bulk pack - fish sticks, etc., (2.5 kg) reclose by folding
Plastic film bags	Polythene - laminated (preferable) generally transparent-somentimes over printed- can be metalized or opaque	Hand	Whole fish blocks 20 - 50 kg. Can be unstable unless friction film used. Cover for pallet of blocks or boxes
"	Heat-sealed	Hand/M/c	Bulk packs (up to 2 kg) of IQF products
"		Usually M/c	Outer seal on small cartons
"	Film pulled tight by vacuum	M/c	IQF fillets, etc good appearance
"	Vacuum-packed and suitable for boil-in-bag cooking	M/c	IQF-smoked fish. Fish-in-sauce and prepared dishes
Shrink/stretch film	Shrink applied as sheet or tube. Shrunk by heating	Hand/M/c	(a) Used to stabilise and cover pallets
			(b) IQF portions, enrobed products with tray (where enrobing might damage vacuum pack film)
	Stretch elastic film. Both can be heat sealed	Hand/M/c	as (b) above
Cartons	Waxed or laminated board	Hand	For fillet blocks
		Hand/M/c	For IQF products
		Hand/M/c	Outer cover for products in film bags
	Corrugated paper	Hand/M/c	Master cartons for smaller packages
Trays			Used with shrink or stretch film for IQF products Used with inserted or heat-sealed lids for prepared dishes
	Plastic Foil		
	Plain		
	Foam		
	Overnable		
Boxes	Polystyrene foam		Used as an outer cover for packs of whole shellfish, e.g. Nephrops
Pallets (Not strictly packaging, but used as the basis for collection of blocks and cartons in to tertiary packaging)			

Table 13 Properties of basic materials

			Strength (higher = better)		Permeability (lower = better)			Process			
Material	**Uses**	**Type thickness (mm)**	**Tensile**	**Tear**	**WV**	**Gas (Oxygen)**	**Grease/Oil**	**Heat seal (C)**	**Stretch**	**Shrink**	**High temperature**
Waxed or polycoated	Cartons	0.30 to 0.70	-	-	-	-	Impervious	-			
White bleached board or chip board											
Cellophane	Bags etc		9	0.02	0.4	0.8	Impervious	90-180	No	No	No
Polythene (PE) low density	"		1	1	1.0	100	Fair	120-180		Some	No
Polythene medium density	"		2	0.5	0.4	60	Good	130-150		Some	No
Polythene high density	"	varies usually	3	0.15	0.3	15	Good	135-150		Some	Yes
Nylon (PA)	"	laminated to give 0.03 to 0.30	7	0.20	20	1	Impervious	180-260		No	Yes
Polypropylene (PP) (oriented')	"		25	0.04	0.3	40	Good	No		Some	Yes
PVC	"		2 upwards	Varies	> 3.3	2 to 500	Good	120-180	Yes	Some	No
PVdC (Saran)	"		8	0.1	0.1	0.2	Good	120-150	Yes	Some	No
Polyester (PET)	"		25	1.13	1.13	2	Good	No		Some	No
Aluminium Foil	"	0.009 to 0.012	-	-	0.1	3	Good	No			Yes

Notes: 1. Tensile, tear and water vapour (WV) qualities are relative to PE which has unit value

2. Gas permeability is related to PA which has unit value

Table 14 Typical laminates compared with PE (Polyethylene) and PA (Nylon)

	Thickness	Permeability		Seal Temperature	Form depth Maximum
Material (mm)	**(mm)**	**Water Vapour**	**O_2**	**(°C)**	**(mm)**
PE	0.10	1	100	130-150	
PA	0.10	20	1	180-260	
PE	0.20	0.5	50	130-150	
PA/PE 30/70	0.10	1.8	5	120-200	
PE/PVdC/PE	0.10	0.4	0.1	130-200	
PA/PVdC/PE	0.10	1.4	0.3	120-200	40
PA/PVdC/PE	0.25	0.8	0.1	120-200	150
Alum foil/PE 16/84	0.034	0	0	120-200	

Table 15 Packaging machinery

Method	**Manpower**	**Throughput**	**Typical space (M/C only) Length × depth × height**	**Energy**	**Cost $**	**Remarks**
Heat sealing	Manual (1)	-	Bench	70-300W	75-300	Static. Intermittent use
	Manual (1)	-	Bench	500W	900	Rotary Band. 5-h day
	Semi Auto (1)	Up to 200 mm/s	0.85 × 0/70 × 1.77 m	900W	2000	Rotary Band. 12-h day
	Semi Auto (1)	150/200 mm/s	1.25 × 0.90 × 1.68 m	1400W	7000 to 10000 Higher price for optional coding and bag trimming	Rotary Band. Continuous
	Semi Auto (1)	-	0.89 × 0.69 × 1.45 m	500W	1900	'L' sealer for film
Vacuum packing bag fed	Manual (1)	15-20 s cycle + filling time Chamber 370 × 380 × 140 mm	0.46 × 0.56 x 0.43 m Table model	550W	2700 to 3200	'L' sealer for film
	Manual (1-2)	20-24 s cycle + filling time Chamber 1000 × 700 × 200 mm	1.18 × 1.17 × 1.05 m	4.0W		Single chamber machines
	Semi auto (1-2)	20-24 s cycle Each chamber 440 × 540 × 160 mm,	1.27 × 0.95 × 0.98 m	1.5kW		
	Semi auto (1-2)	20-24 s cycle Each chamber 610 × 815 × 160 mm	1.62 × 1.24 × 1.10 m	4.0 kW		Twin chamber machines
	Automatic (1)	- Chamber 825 × 745 × 180 mm	1.79 × 1.09 × 1.45 m	1.5 kW		
	Automatic (1)	25-30 s cycle Chamber 950 × 1110 × 200 mm	2.31 × 1.37 × 2.62 m	0.9 kW		Belt loaded machines

Vacuum packing reel fed	Automatic (2-6) (hand loading)	4 s cycle Varying chamber areas 285 x 320 x to 620 x 800 mm	4 × 0.65 × 1.63 to 6.54 x 0.82 x 1.70 m	6 to 7.5 kW + compressed air and water	30000 to 66000	
Tray scaled lid	Semi Auto (1)	2-4 packs/min	0.77 x 0.45 x 0.45 m	1 kW	Up to 10000	
Tray stretch wrap	Semi Auto (1 + tray filling)	Up to 35 packs/min	2.98 x 1.02 x 1.46 m	1.5 kW	8000 upwards	
	Automatic (1 + tray filling)	50-60 packs/min Tray min 120 × 90 × 10 mm Max. 270 × 230 × 130 mm	(2.77 to 7.37) ×1.36 × 1.31 m	2 kW	32000 to 45000	
Tray shrink wrap	Automatic (1 + tray filling)	Up to 60 packs/min	(4 to 8) × 1.5 × 1.8 m	12 kW upwards	30000 upwards	
Tray overwrap Automatic (1 + tray filling)		max. 120 packs/min Tray min. 80 × 30 × 1 mm max. 700 × 220 × 100 mm	3.25 × 0.95 × 1.62 m	2.5 kW	18 to 45000	
Foil tray lidder	Automatic (1 + tray filling)	Max. 120 packs/min	5.65 × 0.76 × 1.83 m	2.5 kW	37500 upwards depending on options	
Carton scaling	Semi Auto (1)	Up to 60 packs/min (depends on operator) Tray min. 100 × 44 × 22 mm max. 355 × 266 × 100 mm	(1,83 to 2.97) × 1.14 × 1.10	3.5 kW	9000 to 13500	operator forms cartons
Carton forming	Automatic (+ product loading)	60 to 120 packs/min Tray min. 100 × 44 × 22 mm max. 355 × 266 × 100 mm	(3.60 to 4.40) × 1. 14 to 2.09 × 1.60 m + infeed conveyors	5 kW	30 to 45000	
	Semi Auto (1) (operator loads product)	Up to 100 packs/min Tray min. 100 × 44 × 22 mm max. 355 × 266 × 100 mm	4.34 × 1.14 × 1.60 m + infeed conveyor	5 kW	from 27000	
Master carton taping	Manual (1)	Varies	Bench	-	12-20	
	Semi Auto (1)	Operates at up to 18 m/min Box 75 × 115 mm sq up to any length × 508 mm sq	0.9 × 0.7 × 1.3 m	0.1	2500 to 3000	
	Automatic (1)	Operates at up to 18 m/min box 150 × 114 mm sq up to any length × 508 mm sq	1.07 × 1.09 × 1.42 to 2.24 × 1.04 × 2.06 m	Up to 0.8 + air in some cases	6000 to 30000	

Master carton strapping - polypropylene straps	Manual (1)	Varies	Bench	Hand operated Also air/ electric at higher prices 0.8	150 to 300	Strap fed by hand
	Semi Auto (1)	17/min, size limited by table	0.90 × 0.56 × 0.78 m		1800 to 3000	Box on table
	Automatic	17/min, size limited by arch 500 mm sq up to 1000 mm sq	0.6 × 1.4 × 1.6 to 0.6 × 1.6 × 1.6 m	1.2 to 1.6	6000 to 9000	Box passes through arch
Master carton string tying	Semi Auto (1)	40/min, size limited by arm swing	0.9 × 0.9 × 1.15 m	0.55	3500	
Heat shrinking	Manual (1)	-	Bench	Gas	600	Hand held shrink gun
Heat shrinking	Automatic	Varies	Usually incorporated in machines	Varies	1200 upwards	
Stretch wrap	Manual (1 + pallet truck operator)	Varies	Bench	-	50	Dispenser for 400-mm wide film
	Semi Auto 1 + pallet truck operator	About 30 pallets/h	2.80 × 1.83 × 2.44 m	2.5 kW	7600 to 14700	

Note: Data for typical machines. Local prices and availability may vary.

7.0 COLD STORES

A cold store is any building or part of a building used for storage at temperatures controlled by refrigeration at -1WIC or lower.

7.1 Recommended storage temperature

The spoilage of fish due to protein denaturation, fat changes and dehydration can all be slowed down by reducing the storage temperature. The FAO Code of Practice for Frozen Fish recommends that frozen fish products should be stored at temperatures appropriate for the species, type of product and intended time of storage.

The recommended storage temperature for all fishery products in the UK is -30°C and this temperature has also been adopted throughout Europe. Spoilage by bacterial action in any practical sense is completely arrested at this temperature and the rate at which other undesirable changes proceed is greatly reduced. Some products can be stored safely at higher temperatures than the -30°C recommended providing storage is only for a short period. Since it is not always possible to guarantee that a product will stay in storage no longer than originally intended, it is generally safer to use the lower recommended temperature.

The International Institute of Refrigeration recommends a storage temperature of -18°C for lean fish such as cod and haddock and -24°C for fatty species such as herring and mackerel. The code also recommends that for lean fish intended to be kept in cold storage for over a year, the storage temperature should be -30°C.

Cold store operators can seldom be sure to store only one species or type of fish, or to store it for a limited period only. Cold stores built for storage of fish should preferably be able to operate at -30°C but can be operated at a higher temperature if circumstances and relevant codes or recommendations allow.

It has been calculated by an eminent authority on cold store design that under specific conditions, the total cost of operating a cold store at -30°C is only 4 percent higher than when operating at -20°C although the corresponding percentage increase in running costs will be higher.

The difference between total cost and running or operational cost will be made clear to the reader by examining the cold store costing detailed in Chapter 10. The total cost is the more realistic figure to use in making comparisons. It can be seen from Table 16 that there is a distinct storage life advantage in keeping fish at -30°C. It is possible that the advantage of improved quality can more than offset the additional cost of storage at the lower temperature. These times are for practical storage life which is defined as the time the product remains suitable for consumption or for the process intended.

Table 16 Practical storage lives (PLS) of fish products

Product	**Storage life in months**		
	- 18°C	**- 24°C**	**- 30°C**
Fatty fish (glazed)	5	9	> 12
Lean fish (fillet)	9	12	24
Flatfish	10	18	> 24
Shrimp (cooked/peeled)	5	9	12

A number of codes of practice for fish and fishery products, elaborated by Codex Alimentarius Commission, Joint FAO/WHO Food Standard Programme, also make recommendations for storage conditions and these are listed elsewhere in this document. Reference should also be made to the International Institute of Refrigeration third edition of their book 'Recommendations for the processing and handling of frozen food 1986'.

7.2 Factors limiting storage life

Protein changes. Fish proteins become permanently changed during freezing and cold storage and the speed at which this denaturation occurs depends very largely upon temperature. At temperatures not very far below freezing point, -2°C for example, serious changes occur rapidly; even at -10°C, the changes are so rapid than an initially good quality product can be spoilt within a few weeks. The rate of deterioration due to protein denaturation, however, can be slowed by ensuring that storage is at as low a temperature as possible.

Fat changes. Fatty fish may become unpleasantly altered during cold storage but they can be protected to some extent either by glazing or by packaging in plastic bags sealed under vacuum. These oxidation changes take place more rapidly at higher temperatures and storage at a low temperature is an effective means of slowing the rate of spoilage by this method.

Colour changes. The quality of fish is often judged by appearance, and colour changes which are not otherwise significant can result in fish being downgraded. The changes in the fish flesh which bring about these colour changes are also retarded at lower temperatures.

Dehydration changes. Dehydration of the product is probably the major concern of the cold store operator and the rate of drying can be linked with a number of factors in cold store design and operation.

When fish get badly dehydrated in cold storage, the surface becomes dry, opaque and spongy. As time progresses, these conditions penetrate deeper into the fish until it becomes a fibrous, very light material. Visible effects of severe dehydration on the surface of the fish are known by the term "freezer burn". This is an unfortunate choice of term since the effect is unlikely to result from freezing in a properly designed freezer, and appears only after periods of storage in a cold store.

Frozen fish may dry slowly in cold storage even under good operating conditions. This is undesirable for reasons other than the obvious one that the product will lose weight. Drying also accelerates denaturation of the protein and oxidation of the fat in the fish. Even totally impervious wrappers used to protect the product do not give full protection if the cold store operating conditions are favourable for desiccation within the pack. In-pack desiccation prevails when there is some free space within the wrapper and the temperature of the store fluctuates. When this occurs, there will be times when the wrapper is colder than the fish and moisture will then leave the product and appear as frost on the inner surface of the wrapper. The total weight of the product and package will not change but if the in-pack dehydration is severe, the fish will have the quality defects of excessive drying.

7.3 Choice of Planners and Designers

When considering the construction of a cold store, one of the very first steps is to decide on specialists to be responsible for planning, design and project management. The construction of cold stores involves a number of factors besides the actual building. The use of specialists enables the organisation responsible for the project to:

- Share the responsibility for the project with an outside body.
- Avoid building up a department of costly specialists who may not have adequate knowledge in the field of activities and who eventually will not be fully occupied with the project.
- Benefit from the practical experience of the specialist group.
- Save time as initial training and research will not be required.
- Ensure that latest techniques are used.

It is recommended that specialists handle a project all the way from a feasibility study to commissioning, including supervision and training of the local management responsible for the future operation of the cold store.

7.4 Shape and Size

Cold stores can be divided according to construction into single-storey and multi-storey buildings. They can be used as production stores, bulk stores, distribution stores or retail stores. For a long time, the most appropriate shape was a cube for which the ratio of surface to volume is a minimum. Besides this, the cost of land was a major consideration, especially when stores were located in urban areas. This resulted in multi-storey buildings, with a number of disadvantages, e.g., costly foundations, heavy framework, congested handling areas.

The main considerations which have resulted in the appearance and success of single storey buildings are cost reduction together with mechanised handling techniques. Today multi-storey buildings are built only in congested or costly harbour areas, where cranes can be used externally to mezzanine floors. Those buildings are normally not more than two storeys high.

A single-storey cold store can be easily designed to meet the specific requirements of stacking and handling equipment. Wall and roof constructions can be made lighter as they do not have to support the weight of the product stored, as in a multi-storey building. The main disadvantages are the relatively large ground area covered and the high ratio of surface to volume. The advantages however, normally override the disadvantages. Most European and United States cold stores built in the course of the last 20 years are single-storey buildings.

A production cold store is usually a part of one or several food businesses, storing frozen raw materials and semi-finished, as well as finished products. Bulk stores normally give the same service as production cold stores, but are often located at some distance from the actual processing industries and are normally much larger than the production stores. The storage time at a bulk store is also normally longer. Distribution stores, generally located in urban areas, receive products from the production or bulk store in large lots, which are broken down - order assembled - before delivery to the retail stores. The storage time is short, one week up to two months.

There is a general tendency to build larger installations than those in the past. Capacities of new cold stores are now between 5,000m^3 and 250,000m^3 where, depending on local conditions, the optimum investment/running cost relationship is generally found. It should, however, be noted that the size of the distribution warehouse depends on a number of factors like amount of traffic, average storage period, number of articles, as well as the number of clients. Bulk and distribution cold stores are often combined at the same location, the main difference between them being stacking arrangements and equipment used.

7.5 General Layout

A single-storey building can have a relatively simple layout. Depending on size, it can either have one single room or it can be divided into a number of rooms. Normally all the rooms are operated at the same temperature, for fish preferably in the range of -24° to -30°C. Most stores, with the exception of small prefabricated ones, are built at a higher level

than the surrounding yard with a special loading ramp at one or more sides. The loading ramp level corresponds to the height of the most commonly used vehicles. Sometimes the stores are also built with a loading ramp for railway wagons, often placed on the opposite side to that used for loading road vehicles.

The engine room should be as close as possible to the position of the air cooling equipment within the store. This sometimes poses a problem in the planning of future extensions and it may therefore be placed at the end of the cold store in such a position that it will easily serve future expansion. Alternatively, the engine room can be placed away from the cold store complex and serves the air cooler via a pipe bridge so that extensions can take place in any direction. Freezing tunnels can either be arranged so that their entrance doors communicate with the loading platform or alternatively they can be arranged with the discharge doors within a cold room so as to minimise the amount of heat losses.

7.6 Construction Methods

Modern large or medium cold stores are built as one-storey buildings designed for mechanical handling, e.g., forklift trucks and automatic stacker cranes. Manual handling is, however, still used for most small-sized stores.

A cold store can be built as an ordinary building using conventional building material, such as bricks, concrete or concrete process sections to which a vapour barrier and insulation is fitted internally. Modern insulation material, in particular polyurethane, has a strength that can be utilised structurally. Today, this is used for panel designs suitable for all sizes of cold rooms from (20m 3 to 250 000m 3) . Factory made insulation panels are delivered to the site complete with a vapour barrier and internal cladding, thus reducing the site work to a minimum. There are two basic principles for panel-built cold stores. A common system has an external structure and cladding with a wall insulation on the inside of the columns and the insulated ceiling hanging from the outer roof structure as shown in Figure 30.

The panels normally used in these systems are either polyurethane or polystyrene insulated panels with or without frames. They are manufactured as sandwich panels, one face being the vapour barrier of light-gauge galvanised steel sheet and the other face being the internal finish of plastic-coated galvanised sheet or aluminium sheet. A decorative external cladding is erected on the outside of the columns.

The roof insulation is constructed as a suspended ceiling. The roof panels are, in principle, the same as the wall panels, but are sometimes equipped with wooden frames.

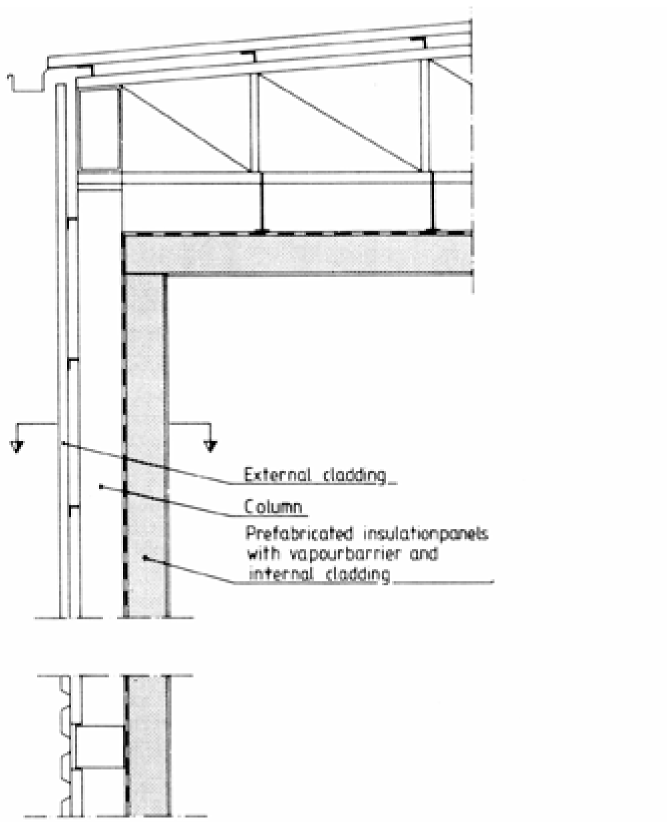

Figure 30 Example of panel built cold store. External structure.

The wall panels are fixed to the columns or horizontal rails between the columns with special bolts. The joints are sealed with tape or sealant mastic and the internal joints are finished with a cover strip. The roof panels are hung from the outer roof construction with hanger rods and locked together with sealed, tongued and grooved joints or similar. For the roof panels, special care must be taken where the hanger rods pass through the vapour barrier. In humid climates, ventilation might not be sufficient to avoid condensation in the attic space above the insulated ceiling. This problem can be overcome by closing the space and drying the air with some form of air drier.

The other system shown in Figure 31 has an internal structure, i.e., columns and roof trusses are placed in the cold room. The panels used for this system can be of the same types as in the other system but the vapour barrier is also the external weather protection and decorative finish. Therefore the metal sheet itself and the jointing between the panels must be of very high quality. The roof insulation can either be carried out with panels or built oil site.

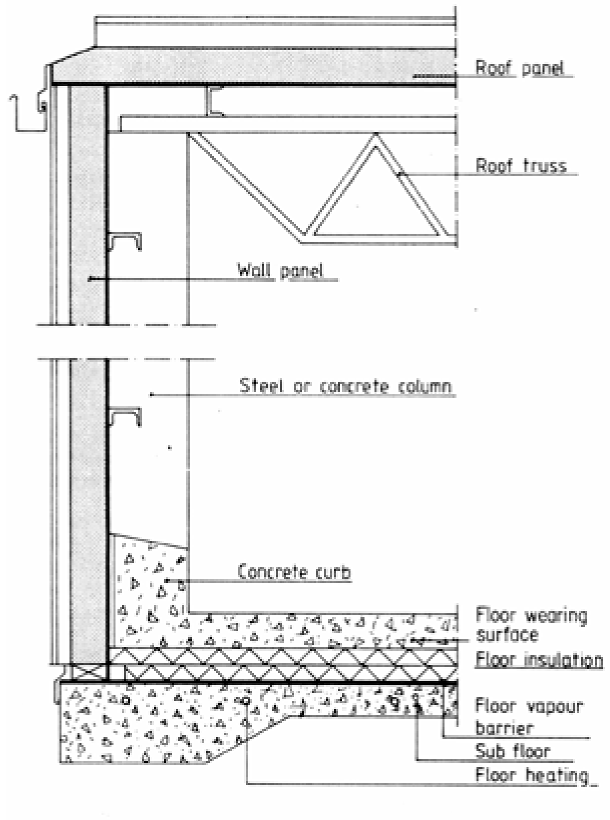

Figure 31 Panel-built cold store with internal structure

The latest development are panels with a rib profile on the external face of aluminium which is also the total external cladding - with polyurethane foam insulation and an internal face of low profile corrugated aluminium. The panels are generally of large size and erected with small mobile cranes. Thus the erection time is reduced to a minimum, the panels are pulled together with Camlocs or other special devices giving positive pressure between the joints. The joints are filled with flexible compounds and covered with a metal strip. The walls are attached to horizontal rails fixed at 3 m vertical intervals with clamps, which admit sufficient movement of the construction. These panels are also used for roofing, being place on beams at 3 m intervals.

The external cladding joints are made with a special seaming machine, which automatically moves along the joints, mechanically closing the rib profile of one sheet around that of another. The space between the panels is filled with a one component polyurethane foam. The internal cladding is sealed with a PVC strip. One component foam is also used to join wall panels to roof panels and seal around doors, etc, maintaining good insulation properties throughout the building. With this design both the insulation and external vapour barrier are entirely sealed units enveloping the whole building. This means that losses via heat bridges or air leakage are completely eliminated, which gives practical insulation properties closer to theoretical values than normally expected.

In the case of single-storey cold stores, two types of frame work are commonly employed. Metal frameworks, can span distances up to 60m without the need for internal columns. They are prefabricated in the factory and transported to the site in sections for quick and easy erection. The minimum span is approximately 15m. Minimum load is involved as the roof frame is carrying only the waterproof covering and the insulation. In some designs it also carries the weight of the air coolers within the room. Then it is desirable to concentrate these loads near the columns rather than at mid spans. An outside metal framework can be used for electrical earthing connections.

Reinforced concrete frameworks can incorporate concrete beams spanning the room, or can be a combination of concrete columns supporting metal trusses. Overhead rail systems can be supported from the main structure or a separate steel frame can be incorporated inside the cold store with separate columns transferring the load onto the main structural floor.

7.7 Insulation

The choice of insulation is very important as it accounts for a large proportion of the total construction cost. The insulation material and thickness is also important from an energy point of view. Besides a satisfactory thermal conductivity coefficient the insulation material should also be odour-free, anti-rot, vermin and fire-resistant and impermeable to water vapour. Some of the most common materials are shown in Table 17. The table also gives examples of typical insulation thickness for the different materials.

Table 17 Typical insulation thickness for chill and cold stores utilising different insulation materials

Insulation	Calculated thermal conductivity (kcal/m h °C)	Thickness (mm)
Polystyrene	0.033	220
Styrofoam FR	0.030	200
Polyurethane	0.025	170

Currently, with existing energy costs, the thermal conductance should not exceed 0. 15 kcal/m^2h°C for cold stores. However in the future with ever increasing energy costs this figure may have to be improved.

The final quality of any insulation is not only a matter of the properties of the material itself, but of the way it is erected or fitted to the external building. Heat bridges should be avoided, e.g., those normally created by pipes, cable joints, etc. Piping which carries low pressure refrigerant or other liquids at low temperature must be insulated. The provision of an efficient vapour barrier on the outside of the finished insulation with joints properly sealed is of utmost importance, as moisture vapour penetrating the insulation will form ice and gradually destroy the insulation material. The thickness of insulation depends upon the internal temperature, heat conductivity of the insulation material and the dew point of the ambient air, in order to avoid condensation. The insulation material should be protected against moisture and mechanical damage. Where uncovered insulation material is used, the internal walls and ceiling can be protected by sheets of aluminium, galvanised steel, reinforced plastic, etc., or with materials such as plaster and cement. The choice of material should be related to the use of the store, e.g., need for washing down. Painting of plastered walls are not recommended unless special paint is used as it will quickly peel off.

The insulation of the cold store doors should be the same standard on the store wall. The most common insulation material for doors is polyurethane and door heaters should be fitted to prevent ice forming at the seal thus jamming, and ultimately causing damage to the door.

7.8 Vapour barriers

The air within a cold store holds a good deal less water vapour than the air outside. Water vapour in the air gives rise to a pressure and together with the other gases present, such as oxygen and nitrogen, account for the atmospheric pressure that we are all familiar with. The partial pressure exerted by the water vapour is proportional to the quantity of vapour present and the vapour in the air will tend to migrate from areas of high partial pressure to areas of low partial pressure. Hence, there is a tendency for moisture in the ambient air to pass through the insulation of a cold store to the area of low partial pressure within (Figure 32). When this vapour is cooled, it condenses and at the point where the temperature is 0°C, it freezes to form ice. This process will continue over a long period of time and the build-up of ice will eventually affect the insulation properties of the cold store wall and also weaken the structure of the wall or building. Unfortunately, the outward effects of this build-up of ice may not show for some time, long after the builder's guarantees have become invalid.

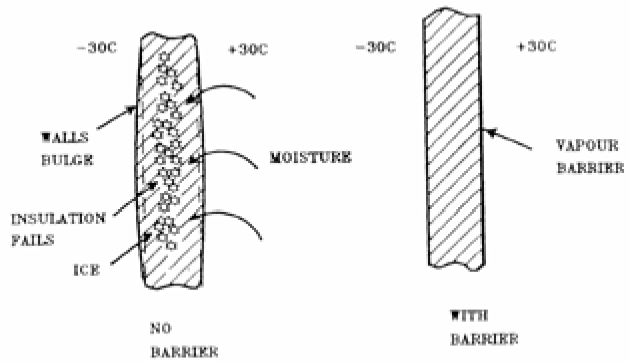

Figure 32 Diagram illustrating the function of a cold store vapour barrier.

To prevent this type of destruction to the store insulation, a vapour barrier has to be provided on the warm side of the insulation. This vapour barrier must be complete and cover all walls, the roof, ceiling and the floors. For stores constructed against a building wall, this may be formed by applying at least two coats of a suitable bituminous sealing compound. With prefabricated stores, a vapour barrier is already provided with the individual sections, usually an outer facing of sheet metal, and only the joints require sealing. It must be remembered that water vapour is a gas and it is not sufficient merely to make the outer surface waterproof; overlapped joints, for instance, must be sealed.

Foundations and frost heave. Low temperature stores built directly on the ground may require special precautions to prevent the build-up of ice below the cold store floor. The ice formation causes distortion known as "frost heave" and in particularly bad cases, it can lead to the complete destruction of the store and structure of the building (Figure 33).

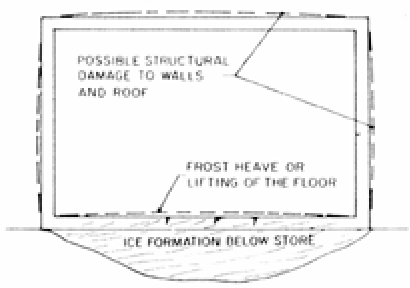

Figure 33 Ice formation resulting in the frost heave of a cold store

The conditions that give rise to frost heave are rather complex, since they are related to the type and texture of the soil, the insulation properties, the availability of moisture, the dimensions of the store, seasonal climatic variations and other factors.

Two methods of preventing frost heave are commonly used. The ground below the store can be heated either by a low voltage electrical mat in the cold store foundation or by circulating a heated liquid such as glycol through a pipe grid built into the foundation (Figure 34). The heat for the glycol is usually obtained from the compressor hot gas through a heat exchanger.

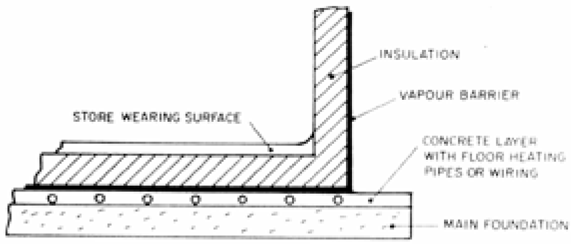

Figure 34 Frost heave prevention using floor heating

Another method of preventing frost heave is to leave a space below the store for ventilation (Figure 35). The level of the floor of a cold store is usually arranged to suit the unloading and loading of vehicles. The additional height required for this facility leaves plenty of height for an air ventilation space below the insulation. If there is any danger of flooding, cold store floors will be built above the likely water level and again there will be an opportunity to leave an air space for ventilation. This ventilation arrangement should be clearly defined and not blocked at a later date when the main function of the air space has long been forgotten.

The provision of a vapour barrier and the prevention of frost heave are probably the two most important requirements in the construction of a cold store.

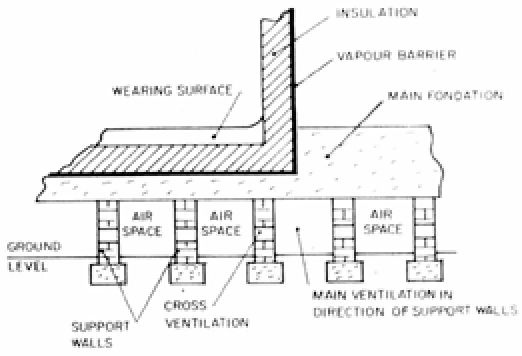

Figure 35 Frost heave prevention using underfloor ventilation

Air ingress .Outside air entering the store adds heat and moisture. This moisture will be deposited as frost on any cold surface and will eventually finish up on the surface of the cooler. Excessive air exchange should be prevented to keep the cold store temperature steady and reduce the frequency of defrosting. Small air locks have been used to prevent the free flow of air in and out of the store but they are not popular with cold store operators (Figure 36). The air-lock space often does not allow complete mobility and unless this condition can be met, both doors are left open. The air lock will therefore serve no useful purpose and merely occupies valuable space.

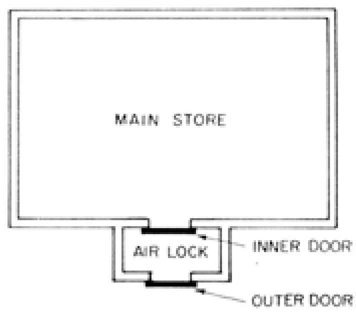

Figure 36 Illustration of a cold store air lock

A curtain of air blown downward or from the side of the doorway can reduce the exchange of air when the door is open. These air curtains, as they are called, can be a useful aid when the door is opened for short intervals. However, they are often abused and doors are often left open for long periods.

Hatches can be used to reduce air ingress when a product is being loaded or unloaded. Hatch openings should be as high up in the store wall as possible to prevent excessive loss of cold air. Portable conveyors can also be used to speed up the transfer of produce.

Store door openings can be fitted with an inner curtain made from overlapping strips of synthetic material suitable for use at low temperatures (Figure 37). This reduces the air exchange considerably without interfering too much with traffic but the curtain must be maintained in good order and, as with the air curtain, not abused by leaving the outer main door open.

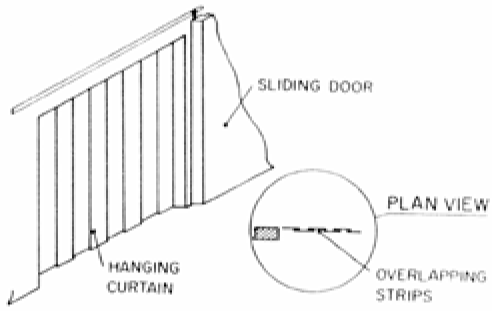

Figure 37 Inner curtain of flexible strips used to reduce air exchange

Large stores are fitted with power-operated doors which can be quickly opened and closed, usually by automatic vehicle sensor or pendant switches outside and inside the doorway. Because this system is easy to operate even from a moving fork lift truck, door opening times are kept to a minimum.

7.9 Floors

The ground loads from a cold store are in the order of 5500-8000 kg/m^2. This consists of static loads due to merchandise, structure and concentrated rolling loads transmitted by e.g., forklift trucks and other handling equipment. It is of importance that those loads are investigated in detail for each special project.

In the case of a single-storey building, a reinforced raft is usual, including ground beams at the edges or bases for the structural frame. This can rest directly on the existing ground or a supported slab.

The floor wearing surface requires particular care. In addition to the wear other industrial floors have to stand, it is exposed to low temperature. All other parts of the cold store can be repaired whilst most of the space is still used for storage, but not the floor. Most commonly the floor wearing surface is a concrete slab cast on the floor insulation with a thickness of 100-150mm. In cases where intensive traffic is foreseen a special hard wearing top-finish is recommended. Before casting the wearing surface, the floor insulation should be protected by bituminous paper or plastic sheeting, the function of which is twofold. Firstly, to prevent the water from the fresh concrete penetrating into the floor insulation and secondly, to provide a slip-sheet, which will reduce the friction when the concrete when contracts. It is of great importance that the floor wearing surface be level to enable high stacking and easy traffic. The top-finish should provide a reasonable anti-slip surface.

Special attention must be given to floor joints. It is recommended that a device which allows horizontal displacement, but not vertical movement, is used between the joints. If the joints open too much after lowering of the temperature, they must be filled with a suitable jointing compound.

If the pallet layout is painted on the floor (the conventional way for easy location) a special hard-wearing, alcohol-based paint should be used.

7.10 Types of cold stores

Stores with unit coolers. The most widely used method of cooling modern cold stores is by means of unit coolers with fan designed with good air flow characteristics (or good circulation of the air). This type of cooler is generally the cheapest to install; it contains a relatively small charge of refrigerant, it can be readily defrosted without interfering too much with the store conditions and it does not require a heavy structure for support. The main disadvantage is that many designs using this type of cooling unit do not allow for uniform distribution of the air within the store. This gives rise to poor storage conditions where the air circulation is either too high or too low (Figure 38). By suspending the unit cooler from the ceiling (Figure 39) or installing the unit outside the store (Figure 40) and ensuring that pallets are stacked with suitable head space and floor spacing, uniform air distribution can be achieved.

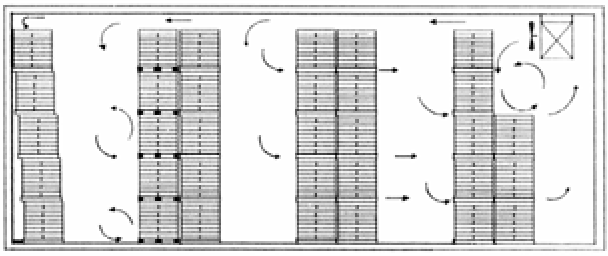

Figure 38 **Uneven air distribution in a store with a unit-cooler with fan circulation**

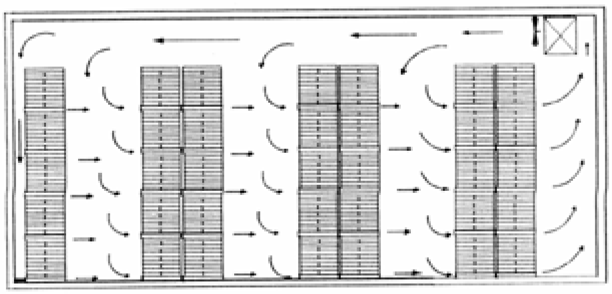

Figure 39 **Cold store with suspended unit cooler and head space above pallet stacks**

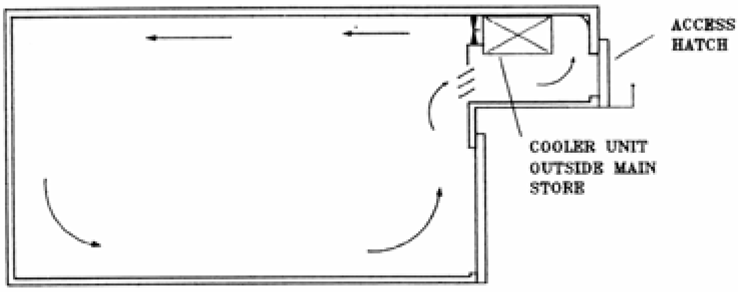

Figure 40 **Cold store with cooler unit outside the main store.**

Multiple units are usually better than large single units for a number of reasons. A multi-unit system gives some insurance in case of breakdown. The store can usually be maintained at its design value without the need for all units to be in operation provided there is not a high additional refrigeration load due to product and heavy traffic in and out of the store. Multiple units also allow each unit to be defrosted in sequence and this arrangement has the least effect on storage conditions. If a hot gas defrost system is used, then a multiple unit system is essential so that the units in use provide the necessary refrigeration load for the refrigeration compressor.

With small units, electrical defrosting is more common. The defrosting of unit coolers in small cold stores is usually automatic and operated by a time clock. With this mode of operation, the timing of defrosts should be arranged to coincide with times when the refrigeration load is low, usually during the night.

Prefabricated Cold Stores

Besides prefabricated panels and the structural components used in the construction of cold stores, there are "building kits" available on the market today for small modular cold stores. The most complete "kits" include wall and roof panels, loading ramp, canopy as well as refrigeration plant. A typical example is a cold store with a nominal storage capacity of some 200t measuring 12 x 12 x 6m built with self-supporting polyurethane insulated panels faced inside and out with galvanised and plastic coated steel sheeting, as well as a prefabricated floor. The only local requirement is a concrete floor slab on which the building is erected. Normally the assembly is carried out by specialists and the erection time varies between 4 and 8 weeks depending on local conditions. The material for the store is shipped in three ordinary containers one of which contains the engine room which can be contained in a weatherproof building adjacent to the cold store.

A possible cross-section of such a prefabricated cold store with a simple overhead crane is shown in Figure 41.

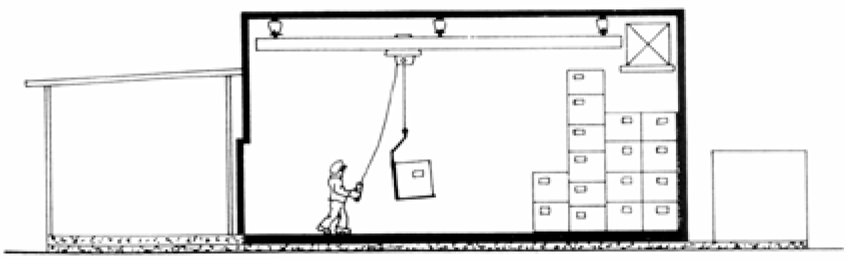

Figure 41 Cross-section of prefabricated cold store.

Reference to handling equipment viz. pallets etc. handling costs, administrative routines, stock records and engine room logs are all referred to in the FAO Fisheries Circular No,771 Planning and Engineering Data 3.Fish Freezing.

7.11 Cold-Air Distribution

Heat transfer is effected by radiation or convection. The air in a cold room essentially transfers heat by convection. Convection is often referred to as natural when air movement is activated only by a density difference created by the temperature difference. It is called forced when air movement is activated by a fan. The actual cooling is effected by two main types of heat exchangers, natural convection coils and forced-air coolers. Natural convection coils have the advantages of maintaining high relative humidity and low air velocities, but these advantages are offset by disadvantages like difficulties of defrosting, which also could be dangerous to carry out. Furthermore, they are not suited to run with high product loadings since the refrigeration capacity is low and are therefore rarely installed today.

Forced air coolers can be mounted inside the cold store space or placed in an external compartment with air circulation by means of fans through a delivery duct (Figure 40). Such a duct sometimes taking the form of a double ceiling or double floor. The defrosting of air coolers situated externally is convenient since it is possible to isolate the air cooler from the interior of the room for this operation. The normal placement is, however, inside the room for larger cold stores, whereas outside placement is normally used for smaller ones. Forced-air circulation enables greater refrigeration capacities because of high rate of heat transfer. It also gives a more even temperature distribution within the room.

Forced-air coolers are usually built as a single small unit, including the fan which is easily mounted within the room itself. The equipment is often combined with special air ducts for even air distribution in the room. The advantages of this type of equipment are reduced installation costs and easy maintenance.

7.12 Defrosting

When the refrigerant temperature is lower than -3°C, frost will deposit on the coils and this results in a reduction in the heat exchange. The frost thickness built up is however, of less importance than ensuring the free passage of air through the coil battery as indicated above. Regular defrosting is of great importance in the operation of a cold store. There are a number of methods available, such as hot-gas defrosting for direct expansion systems, water defrosting and electric defrosting. Sometimes combinations of these methods are employed, e.g., hot-gas defrosting followed by water spraying or hot-gas defrosting of coils with electric tray heating. The latter is now the most used in new installations. It should be noted that labour costs for manual defrosting operations can be high and they are often complicated. In order to increase the operation periods of air coolers between defrost, a wide fin spacing of coils at the inlet side is used in order to act as frost catchers without obstructing the airflow.

Other developments include sensors which measure the frost deposit at specific locations on the cooler fins, the air flow reduction due to frost build up or the refrigerant temperature differential across the cooler. They may be linked to a timer to ensure that auto defrosts do not occur during high refrigeration load period.

7.13 Factors affecting storage conditions

The rate of product dehydration can be related to the size and shape of a cold store. A small cold store has a greater heat leak in proportion to the quantity of product in the store since the volume of a store increases at a greater rate than the surface area. This means that one large store is likely to provide better storage conditions than two smaller stores with the same capacity.

7.14 Product handling and storage

Large stores are provided with a loading platform which can be adjusted to accommodate varying vehicle heights. This platform must also provide adequate space for quick sorting and manoeuvring of goods in and out of storage. A platform width of 8 to 10m may be necessary for this purpose. The unloading area should also be roofed over so that goods being transferred in and out of the store are protected from direct sunlight and rain. This cover also protects the doorway, which may ice up if it is exposed to rainfall.

In hot countries, handling frozen fish outside the low temperature storage space can quickly result in exposed fish being warmed and even thawed. The provision of a refrigerated working area and loading dock is therefore recommended for prestorage sorting and the assembly of loads for shipment. This loading dock should be totally enclosed, insulated and refrigerated to a temperature of about MC. The area of this dock will depend on the amount of traffic and the type of store operation. In a public store where a good deal of sorting is required, this area may be much as 25 percent of the store floor area as shown in Figure 42.

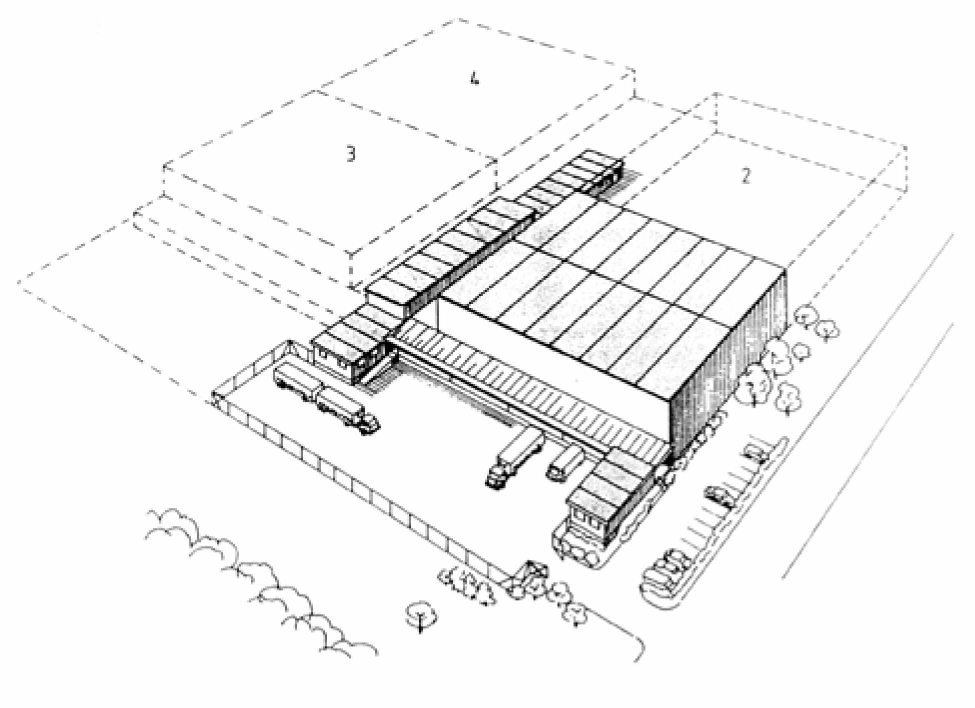

Figure 42 Example of layout for a 20000m^3 cold store

In addition to providing a chilled working space, this refrigerated dock will act as a large air lock between the outside air and the low temperature air within the store. As much as 80 percent of the moisture in the ambient air will be removed by the cooler in this space and a good deal of precooling will be done before this air enters the main store. This will reduce the defrost requirement for the store coolers and generally result in a more stable and lower storage temperature.

The means of transporting goods in and out of the store and within the store depends on the goods being handled, the type of cold store, the height of store, the need to reduce labour costs and many other factors that may only have a local significance.

A list of some of the equipment that may be considered is given below:

a. Transport on the level

Two-wheeled trolleys
Manual platform trolleys
Self-propelled platform trolleys
Manual or self-propelled pallet trucks
Belt, chain or roller conveyors, either gravity or self-propelled.

b. Equipment for vertical handling

Continuous elevators of various types
Platform elevators
Cranes
Gantries
Hand-stacking equipment
Various types of mechanised stacking equipment

c. Equipment for both horizontal and vertical movements

Fork lift trucks, hand or power operated
Adjustable mechanised conveyors

Whenever possible, pallets should be used for storage of product. These divide the goods into unit loads which can be transported, stacked and retrieved with a minimum of effort. Regular-shaped packages or blocks can be readily palletised. Loose fish, such as those broken from blocks and other irregular- shaped products, can also be stored in pallet cages. In public stores where it is often necessary to remove a pallet from the bottom of a stack, the individual pallets do not rest on the pallets below but are supported on a framework. This allows any individual pallet to be added or taken away without the need to break down the stack.

Pallets should not be stacked so that the base of one pallet rests on the produce below except in the case of frozen blocks of fish or where the product cannot be crushed. Framed pallets can be stacked five high with safety, but only if they are correctly stacked. In large distribution stores, pallet racks have been motorised so that there is no need to provide so many passages within the store. The racks are moved as required to allow access to individual rows. This degree of mechanisation would only be employed when store utilisation and quick handling are critical factors.

Attempts have been made to standardise pallet sizes but this has not yet become world-wide. Pallet dimensions of 800 x 1200mm and 1000 x 1200mm have been widely used but the final choice will depend on local circumstances depending on such factors as the degree of interchange of pallets outside the store, vehicle and package dimensions, and other transport and storage considerations.

When a fully accessible palletised system is not used, the product should be loaded in the store so that a first-in first-out system can be operated. This ensures that there is a correct product rotation, and storage times are not unnecessarily long.

The width of passageways will depend on the equipment used for transporting and stacking the product. Details of the space requirements of this equipment must therefore be obtained before a decision is made on the size of store required.

When products are placed in the cold room it is important that an air space is left between the product and the ceiling, the floor and the external walls otherwise heat entering the store through the insulation will pass through the produce before being transferred to the cooler. In the case of internal walls an exception can be made only when the same temperature exists on opposite sides of the wall.

With normal storage of palletised products the required air space is usually obtained through the small irregularities which occur when assembling the product on the pallet. However, in the case of solid block storage or where the pallet sides are completely flat, special care should be taken to ensure that the air space is adequate. Between the product and the floor the air space is automatically provided by the construction of the pallet. The question of air space above the uppermost pallet is, as a rule, no problem since the height of the chamber is designed for a certain number of standardised pallet units and thus allowance is made at the design stage.

Cold store layout . The layout of a store is determined by the type of product, packaging, method of palletization, accessibility required and the equipment used for handling.

Passageways should be clearly defined and in the interests of safety and quick handling, these should be kept free from obstruction at all times.

The floors of large stores are often marked off with a grid and the grid spaces numbered so that the location of goods can be recorded thus enabling quick retrieval.

Products stored near the doorways will come into frequent contact with warm moist air entering the store when the door is open. Some form of partition may be used to reduce the effect of this warm air on products stacked in this area.

7.15 Refrigeration

The capacity of the refrigeration plant must be based on a thorough heat load calculation for each individual project. Refrigeration load can vary widely for stores of the same capacity depending on design, local conditions, product mix, etc. Therefore no rule of thumb can be applied. In past practice, a safety margin of some 50 percent of the theoretical calculation has been used. Today with a more thorough knowledge of practical cold store operation, combined with theoretical knowledge, the safety margin can be reduced to a more realistic level.

The refrigeration equipment should conform to requirements laid down in national codes of practice, insurance companies, as well as international recommendations (ISO R1662) (BS4434 1989/).

The following discussion is limited to general considerations serving as guidance and introduction to more detailed studies of the factors influencing the purchase and installation of refrigeration plants.

Heat leakage or transmission load can be calculated fairly closely using the known over-all heat transfer coefficient of various portions on the insulated enclosure, the area of each portion and the temperature difference between the cold room temperature and the highest average air temperature likely to be experienced over a few consecutive days.

Heat infiltration load varies greatly with the size of the room, number of door openings, protection of door openings, traffic through the doors, cold and warm air temperatures and humidities. The best basis for this calculation is experience. The type of store has a marked influence on the heat load, as has the average storage time. In comparing long-term storage, short-term storage and distribution operation it can be found that there is a 15 percent increase in refrigeration load for the short-term storage as compared to the long-term storage, whereas the refrigeration load in the distribution operations is in the order of 40 percent higher than for long-term storage, due mainly to additional air exchanges.

Section 8 gives an example on a heat-load calculation of a small cold store.

Most large cold stores are equipped with 2-stage ammonia refrigeration installations. For smaller plants, usually less than 6 000 kcal/h refrigeration capacity, approved refrigerant will probably be used in single stage systems operating with thermostatic expansion valves. Such systems are thermodynamically less efficient, but in areas where only staff with relevant refrigerant experience are available the system may be preferred for service reasons.

The refrigeration system should be designed for high reliability, and easy and proper maintenance. Once a cold store plant has been pulled down in temperature, it is expected to maintain this temperature, literally, forever. Even maintenance jobs that need carrying out only every 5-10 years must be taken into consideration.

8.0 CALCULATION OF COLD STORE REFRIGERATION LOAD

8.1 Cold store capacity

A good deal of experience is required to make a correct calculation of a cold store's refrigeration requirement and this should therefore only be done by a qualified person. The following calculation is not complete but it serves two purposes. It allows the reader to make a similar calculation for his own store and thereby obtain an approximate refrigeration requirement. It also helps the reader to appreciate the number of factors that have to be taken into account in calculating the heat load and also gives him some idea of their relative importance.

One important heat load that has been omitted in the calculation is the heat gain due to solar radiation. This factor depends on a number of conditions which are related to both the location of the store and its method of construction. In some cases, solar heat load may not be significant but in other instances, precautions may be necessary to reduce its effect.

Cold store refrigeration load

Specification

Dimensions 20 m x 10 m × 5 m = 1 000m3
Insulation thickness (0.25 m)
External store surface area (771.5m 2)
Maximum ambient temperature (35C)
Store temperature (-30C)

Load calculation

(1) Insulation heat leak through walls, roof and floor

Conductivity of polystyrene 0.033 0.033 kcal/h mC
Temperature difference between ambient and store 35°C and -30°C = 65 degC
Thickness of polystyrene = 0.25 m
Surface area of store = 771.5 m 2
Heat leak = 771.5 x 65 × 0.033 ÷ 0.033 = 7422 kcal/h

(2) Air changes

Average of 2.7 air changes in 24 h
Store volume = 1000m ^{3}
Heat gain (35C and 60% R.H. air) 40 kcal/m^3
Air change heat gain = 1000 × 2.7 × 40 ÷ 24 = 4500 kcal/h

(3) Lights (left on during working day)

1000W = 860 kcal/h

(4) Men working

1 man working at -30C gives off 378 kcal/h
2 men working is equivalent to 756 kcal/h

(5) Product load

5.5 kcal/kg for fish load at an average temperature of -20C
Fish loaded per day 35 000 kg
Product load = 3500 × 5.5 ÷ 24 = 8020 kcal/h

(6) Fan load

3 × 250W = 644 kcal/h

(7) Defrost heat

1 defrost of 8440 W for 1 h (recovered over 6 h) = 1 209 kcal/h
Total calculated refrigeration load (sum of Items 1 to 7) = 23411 kcal/h
Total refrigeration requirement with allowances 23411 × 24 ÷ 18 = **31215** kcal/h

If a pump is used to circulate refrigerant, the heat equivalent must be added to the capacity of the refrigeration condensing unit but not to the capacity of the room cooler.

The minimum refrigeration requirement will be when there is only an insulation heat load and the fans are in operation. In this example, the minimum load corresponds to only about 25 percent of the capacity of the installed refrigeration plant. This minimum load factor will vary considerably with the type of store and mode of operation but some account may have to be taken of this difference between the maximum and minimum refrigeration requirements. Large cold stores should be operated with a number of compressors, which can be switched on and off as required. Large compressors may be fitted with off-loading equipment which allows them to work efficiently on partial loads. The reliance on one large compressor for a large cold store could be catastrophic in the event of its failure. In the case of smaller stores it may be that only one compressor is viable. Other arrangements can be made to cater for the variation in refrigeration demand. What must not happen is that a large compressor should operate with a low load and hence operate with a very low suction pressure or stop and start too frequently. The first condition is bad for the compressor and the second for the electrical equipment.

8.1 Cold store capacity

There is no method of defining cold store capacity that satisfies the requirements of everyone concerned with cold storage. Storage capacity based on the weight of produce that can be stored will depend on the storage density of the products and the method of storage.

Therefore, unless only one product is stored under closely defined conditions, this definition is obviously unsuitable. It is generally agreed that it is more appropriate to define storage capacity in terms of the store volume but there are a number of ways in expressing this value.

<u>Gross volume</u> is the volume of the refrigerated space.

<u>Net volume</u> is the volume that can potentially be used for storage and is the gross volume less the volume required for coolers, structural requirements, doorways and other permanent features of the store.

<u>Effective volume</u> is the store space that can actually be utilised for storage and it takes into account the requirements for passageways, stacking equipment etc.

Gross volume and net volume can easily be defined by devising a simple set of rules for making these calculations. These store volumes, however, can only give a rough estimate of storage capacity and their main use may before statistical purposes. The effective volume can only be calculated for each particular case and to achieve any degree of accuracy, a drawing of the store layout would be required together with full details of the storage conditions. Store operators should therefore use general statements of store capacity with care and when placing an order they would give full details of the products and the storage operation to enable the supplier to provide a store to suit the operating requirements with the maximum utilisation of the gross storage volume.

9.0 WEIGHT LOSS FROM FISH DURING FREEZING AND COLD STORAGE

9.1 Freezer weight loss

Weight may be lost by dehydration or due to physical damage of the fish during the freezing process.

Physical damage may be due to damage during freezing which results in small pieces being broken off; this is likely, for instance, in freezers where the product is fluidized by the cooling air.

The other form of physical damage encountered during the freezing process is due to fish adhering to trays or conveyor belts. If the weight loss on releasing fish from trays is excessive, the trays may be sprayed on the underside with water to assist release. Fish frozen in continuous freezers with stainless steel link or mesh belts may stiffer weight losses due to small particles being trapped in the belt. Losses due to physical damage in a freezer should be small and need not be more than about 1 percent if the freezer and freezing process is suitable for the product.

Weight loss due to dehydration in a freezer depends on a number of factors, and the weight losses in air blast freezers give rise to the greatest controversy.

Weight loss due to dehydration will depend on:

- Type of freezer
- Freezing time
- Type of product
- Air velocity
- Freezer operating conditions

Freezers such as plate freezers where the fish is frozen by contact and released by defrosting will have a negligible weight loss during freezing. Any measured change in weight will probably be due to loss of drip before the freezing started.

Dehydration losses occur mainly in air blast freezers and in other freezers which use a gas such as nitrogen or carbon dioxide in direct contact with the product.

The loss of weight in nitrogen, carbon dioxide and other cryogenic freezers will be low by virtue of the fact that freezing times are short. A direct contrast made between a carbon dioxide freezer and an air blast freezer showed that the weight lost from haddock fillets in carbon dioxide freezer was about half of the weight lost in the air blast freezer, 0.6 percent compared with 1.2 percent. Other cryogenic freezers are likely to give rise to weight losses which are about the same as that of the carbon dioxide freezer.

Time in a freezer, however, cannot be directly related to the weight loss since the rate of weight loss shown in Figure 43 is not directly proportional to time. More weight is lost at the start of a freeze than at the end.

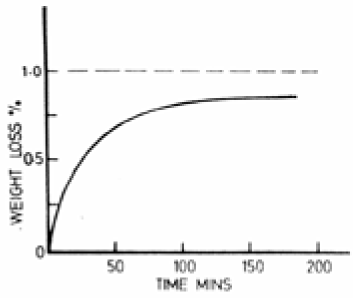

Figure 43 Dehydration weight loss from fish during freezing.

Some weight losses are given in Table 18. The differences between different types of freezer are not great and not as high as some commercial literature would imply. It should also be remembered that some of the weight loss is due to the evaporation of surface water probably left from washing the fish, and this would have eventually been lost as a drip if the fish had remained unfrozen.

One fact that is seldom considered is that fish kept in ice for a number of days will generally lose more weight than is ever likely in a freezer.

Table 18 Weight lost from fish during freezing

Product	**Method of freezing**	Percentage weight loss
IQF shrimp	Air blast	2 to 2.5
IQF haddock	Air blast	1.2
IQF haddock	Carbon dioxide freezer	0.6
IQF products	Liquid nitrogen freezer	0.3 to 0.8
Tray of fillets	Air blast	1.0
Large fish or blocks	Air blast	0.5
Blocks of fish	Contact freezer metal to fish contact	0
Cartons of fish	Contact freezer	0.5 within pack

In view of the weight losses quoted above, claims that fish may show signs of "freezer burn" or severe dehydration as the result of the freezing process would appear to be unfounded. The shape of the weight loss curve shown in Figure 43 would imply that freezing times would have to extend to many hours or even days for "freezer burn" to become apparent.

9.2 Cold store weight loss

Much has yet to be done to correlate the rate of weight loss with differences between storage conditions but the rate of weight loss has been shown to vary with the following:

- Temperature
- Temperature fluctuation
- Humidity
- Heat transfer
- Air flow over the product
- Radiation effects of lighting
- The product
- Shape and size of the product
- Type of wrapper

Most codes of practice only state the temperature for storage. Variations in the other factors that control the rate of dehydration can therefore result in cold stores having widely different storage conditions. The rate at which the product loses weight by dehydration can therefore vary considerably.

Table 19 shows rates of weight loss measured in a variety of stores. The losses are expressed as the weight changes per square metre of exposed fish surface. These results clearly show that there are great differences between the quality of cold stores which may be attributed both to their design and mode of operation as well as to the operating temperature. Apart from the physical loss in weight, excessive dehydration results in "freezer burn". The overall weight loss, however, cannot be used to define the point when "freezer burn" becomes apparent. Dehydration only occurs from exposed surfaces and the rate of dehydration is greater where the surface area to volume ratio is high. The edge of fish fillets and the corners of slabs of fish will therefore show signs of excessive dehydration or "freezer burn" long before the other exposed surfaces of the product. For this reason, "freezer burn" can even become apparent on glazed fish long before the overall weight loss is equal to the weight of glaze applied.

The rate of weight loss within a store can vary considerably with location. Fish stored near fan coolers, where they are subjected to high air velocities, will quickly show signs of dehydration. Fish stored against walls remote from the cooler may be subject to poor air distribution and heat gains from the store walls. This can cause temperature fluctuations in the product which inevitably results in high dehydration losses.

Table 19 Rate of weight loss from fish in cold storage

Type of store	Average temperature (C)	Rate of weight loss from exposed surfaces per day (g/m2)
Unit cooler	-29.3	4.96
Jacketed	-15.0	4.06
Pipe grid	-27.9	0.25
Unit cooler	-27.9	9.34
Finned pipe grid	-25.4	2.30
Unit cooler	-30.0	5.0 to 50.0

Note: The last store was a large store and the very high results were obtained at points where unfrozen fish were placed in the store.

Fish adjacent to roof coolers may also dehydrate more quickly since the path of moisture migration is considerably shorter. Fish near the roof or walls of stores which are affected by a high incidence of solar radiation may also be subjected to higher losses. Finally, fish in storage which have unfrozen or partially frozen fish frequently stacked alongside show the highest dehydration rates of all.

10.0 FINANCE OF FREEZING AND COLD STORAGE

10.1 Cost of freezing

An accurate cost can only be determined for each individual case since so many factors have to be considered which depend on local conditions and economics.

This document can therefore only give the reader a guide to what differences in cost are likely to be between different systems. The information given will also help the reader by letting him know what costs must be considered to obtain the total cost of a project. Actual prices are given in the examples shown but they should not be used except as a very crude guide (Table 20).

The prices quoted are only valid for 1993 and are related to UK prices at that time and should be used for guidance only. It is essential that actual costs are sought as differences between localities and widely changing values of currencies due to inflation and other factors may completely change the cost for individuals.

Small-scale operation usually means higher costs per kilogram of product frozen. One manufacturer quotes a decrease in freezing cost per kilogram of 40 percent in a plant with a capacity of 4500 kg/h compared with one of 1800 kg/h. Tables 21 to 24 also show how the capital cost related to the capacity decreases as the freezer size increases.

Table 20 Freezing cost for different freezing methods (plant capacity 1000 kg/h from +5 to -30C)

Freezing method	Capital cost (US $)	Total freezing cost (US cents/kg)
Batch air blast freezer	315000	8.0 to 10.0
Continuous air blast freezer	458000	8.0 to 10.0
Horizontal plate freezer	260000	6.0 to 9.0
Vertical plate freezer	273000	6.0 to 9.0
Liquid nitrogen freezer	195000	30 to 35

Table 21 Cost of air blast freezers (Blast freezer tunnel with trolleys)

Weight of fish frozen +5 to -30C (kg/h)	Capital (US $)	Capital cost (US $/kg per h capacity)
25.0	16000	640
45.0	21000	470
90.0	37000	410
190.0	78000	410
500.0	180000	360
900.0	230000	310
1400.0	410000	290

The costs in Table 21 are ex-factory costs for freezer and refrigeration equipment only.

Irregular and intermittent operation can also influence the cost of freezing. The more hours a freezer is operated and the more often it is operated at fully capacity, the lower will be the cost per kilogram of fish frozen. Freezers used during short seasonal fisheries for instance will have high freezing costs per kilogram of fish frozen since all the fixed costs must be absorbed by a relatively small quantity of fish.

Freezing costs must also take into account factors other than direct money values. Product freezer losses can be significant, especially if the product is highly priced. Losses can occur due to evaporation, mechanical damage which results in some of the product being rejected, and also mechanical damage which merely reduces the price obtained for the fish.

Other quality losses must also be taken into account.. if the freezing method is unsuitable or insufficient so that there are obvious quality defects. Drip loss, and loss in appearance or texture will lower the sale price and this may be attributed to freezing process.

Table 22 Cost of vertical plate freezers

Number of stations	Nominal capacity (kg/h)	Cost (US $)	Cost rating (US $/(kg/h))
12	135	20000	148
20	225	27000	120

Table 23 Cost of horizontal plate freezer

Number of stations	Plate area (m 2)	Nominal capacity (kg/h)	Cost (US $)	Cost rating (US $/(kg/h))
7	8.9	180	25000	139
10	12.8	260	28300	109
12	20.8	425	35400	83
15	26.1	534	39800	75

Table 24 Cost of horizontal plate freezers installed with refrigeration plant

Number of stations	Nominal capacity (kg/h)	Cost (US $)	Cost rating (US $/(kg/h))
7	180	47800	266
9	232	55600	240
11	386	80900	210
15	534	93600	175

The cost in Table 24 are those of the freezer and refrigeration plant. The cost includes transport to a UK site and the cost of installation but does not include preparation of the site, supply of services such as electricity and water, and the erection of buildings. Comparing the costs in Table 23 with those in Table 24 shows that the cost of the freezer is more than doubled if the costs of the refrigeration plant and erection are included.

10.2 Costing freezing plant and process

Costing means a thorough investigation of all costs likely to be involved in the freezing process. This may be done to investigate the viability of a project at the design stage or to assist in budgeting and pricing of a product.

Many freezer operators may already have well established costing and budgeting systems and it is beyond the scope of this document to introduce or suggest systems that may be appropriate. However, guidance can be given on the particular considerations that have to be given to a freezing plant when a costing is made.

Costs are generally divided into three areas:

- First costs
- Annual fixed charges
- Operating costs

The above costs areas can be further broken down into individual costs. The following list gives some guidance but individual circumstances may add to or subtract from it:

First costs

- Buildings
- Land
- Service charges for electricity, water, roads
- Freezer plant
- Delivery charges
- Installation charges
- Design and consultation charges
- Refrigerant and oil charges

Annual fixed costs

- Depreciation
- Interest
- Insurance
- Taxes
- Capital maintenance

Operating costs

- Electricity - refrigeration plant, building, handling
- Fuel - heating, electrical generator
- Water - condensers, washing, glazing, general refrigerant
- Oil
- Labour - freezer operation, handling, supervision, office
- Plant hire costs
- Social dues

Costs should generally be calculated as the cost per unit weight (kilogram or metric ton) of product frozen. This gives the real cost of the process and also takes into account the plant utilisation factor which is extremely important.

Inquiries have shown that there are great differences between processors in the proportions of the total cost accounted for by each area of costing. Obvious differences such as the number of hours per year the freezer plant is operated can greatly change the cost pattern. The method of allocating capital costs to the freezing process can also vary widely especially when the building is used for other processes. One method used is to divide the cost on the basis of floor space occupied by the various processes but other methods may also be justified. One UK processor divides the freezing costs in the proportions stated below:

Preparation labour costs	48%
Packaging	10%
Freezing	10%
Overheads	32%

Another source quotes that about half the cost of air blast and plate freezing systems are accounted for by labour charges.

A worked example of the method of costing is given below for an air blast freezer freezing 1000 kg/h. The prices are 1993 prices but the installation is fictitious and is only used to demonstrate the method of calculation.

First Cost

	US $
Building and services	100000
Land	15000
Freezer plant	315000
	430000

Annual fixed charges

	US $
Depreciation (10%)	43000
Interest (10%)	43000
Insurance and taxes (4%)	17000
Capital maintenance (4%)	17000
	120000

Operating costs

Power 60 kW for 2 000 h = 120 000 kWh	
add 15 % for auxiliaries - 13 8 000 kWh	
138 000 kWh at US $ 0. 1/kW	13800
Water	2000
Labour 3 men for 2 000 h - 6 000 h	
6 000 h at US $ 8/h	48000
Office work accountable to freezing	
Supplies refrigerant, oil, packaging	10000
Office supplies	5000

Summary of annual operating costs

Power	13800
Water	2000
Labour	58000
Supplies	5000
	78800

Total annual charges

Fixed	120000
Operating	78800
Total charges	**198800**

Fish frozen

1000 kg/h for 2000 h = 2000000 kg

Cost of freezing

198000 ÷ 2 000000 = US $ 0.099/kg

If the freezer was fully utilised for 3 000 h/year, the cost of freezing would be reduced to US $ 0.079/kg.

10.3 Cold store costs

Cold store costs may be integrated with freezer costs if freezing and cold storage facilities are provided at the same time and used only by the owners. Cold stores operating as public stores and providing low temperature storage facilities for customers will have to be costed to determine the charge to be made and the profitability of the store.

It is particularly difficult to give the reader some guidance on the likely cost of a cold store since, unlike freezers, refrigeration costs are relatively small. The main costs are in the construction of the building, preparation of the site and provision of services. These costs will depend to a great extent on the location of the site. The reader may appreciate however some costs to indicate the likely sum involved in the construction of a cold store, and the figures given below in Table 25 are UK prices for 1993. The prices are for cold stores, operating at -30C, constructed from prefabricated panels and the prices include building, land, engine room equipment, electrical installation and other services.

Table 25 Cold Store Costs

Size of store (m^3)	Cost (US $/$m^3$)
500	315
1000	294
10000	260
40000	208

10.4 Costing of cold storage

The method of costing cold stores will be similar to that used for freezers and the check list presented earlier in this chapter can be used as a guide.

An analysis of cold storage costs in the UK has shown wide variations in the distribution of costs depending on the function and method of operation. Whether the cold store is public or private, general purpose or special, used for distribution or for long term storage and land costs all influence the cost distribution and account for the ranges shown within the brackets.

<u>Survey of cold store costs</u>

<u>Administration</u>

Clerical
Order processing
Invoicing
Stock control 15 % (13 to 42)
Selling
Management
Postage
Telephone

<u>Handling</u>

Labour and equipment
Pallets 25 % (23 to 32)
Trucks

<u>Storage</u>

Site
Buildings 60% (53 to 62)
Refrigeration

(Maintenance, depreciation, taxes, water, electricity, refrigerant, etc.).

The preceding survey showed that utilisation was an important factor, and utilisation should be calculated on a volume basis in metric tons per cubic metre. This figure indicates not only the quantity in store but also relates to the bulk density and the space it occupies. The survey also showed that increased mechanisation did not. necessarily reduce the handling costs. About 50 percent of the handling cost was accounted for by equipment and, with public cold stores in particular, the cost of pallet losses can be high. This fact should not however detract from the importance of handling goods in and out of the store quickly and efficiently. Loss in product quality due to poor handling methods is also an important consideration.

Operating costs for a 10 000 m^3 cold store can be twice as much per cubic metre of storage space as those for a 100 000 m^3 store. The size of a cold store is therefore a very important factor in costing.

Private cold stores are also likely to have a lower level of occupancy than public cold stores since seasonal stock variations for different commodities are more likely to balance each other in a public cold store.

The following calculation is typical of the kind that would be made by a cold store operator who is hiring out low temperature storage space for already frozen produce. The calculation does not take into account transport costs outside the store since this is assumed to be the responsibility of the owner of the frozen goods.

Again it must be said that the prices and rates used as accurate as they can be made for this type of operation and are applicable to UK practice in 1993. However, operators should substitute their own figures when making a similar calculation.

First Cost

	US $
Buildings, land, refrigeration equipment and services	294000
Additional handling equipment	52000
	346 000

Annual fixed costs

Depreciation (10%)	34600
Interest (10%)	34600
Insurance and taxes (4%)	13800
Capital maintenance (4%)	1380
	91600

Operating costs

Power 35kW for 4380 h = 153300 kWh 153300 kWh at US $ 0.01	15330
Water	2000
Labour 2 men at US $ 320/week	33280
1 man at US $ 400/week	20800
supplies oil, refrigerant, office supplies	4000

Summary of annual operating costs

Power	15330
Water	2000
Labour	54080
Supplies	4000
	75410

Total annual charges

	US $
Fixed	91600
Operating	75410
Total charges	**167010**

Return on investment required = 20%

Annual profit required = 346 000 x 20 100 = 69200

Cold store capacity: 500 t

Estimated utilisation: 60%

Utilisation - 500 x 0.6 x 365 - 109 500 t days

Charge for storage = (167 010 + 69 200) ÷ 109 500 = 2.16 US $/t/day

A similar calculation can be made for calculating the cost of hiring space within the store rather than on the basis of cost per unit weight of stored produce as shown above.

11.0 SPECIAL OPERATION CONSIDERATIONS

This document is not a full manual of the operation of cold stores, some information on factors of special interest and importance are given below.

11.1 Care and Cleanliness

Close attention to care and cleanliness will minimise loss of quality, and the risk of introducing food poisoning micro-organisms.

Good handling practice should begin on board fishing vessels and be carried through to consumption. The fish should be stowed as soon as possible after catching, but always in a clean condition. Guts, trash fish, etc., should be kept separate and not allowed to contaminate fish for storage or processing. Offal and refuse should be kept away from processed fish and there should be an adequate system of disposal. All plant and equipment, fish rooms, containers, tables, etc., should be designed for case of cleaning, and they should preferably be made of non-corroding, washable material, especially where in contact with fish. They should be kept clean by frequent washing. Care must be taken in the choice of cleaning and sterilising materials and methods.

Personnel should be trained to understand the causes of food poisoning and to practise high standards of hygiene. Coughing, sneezing, spitting, smoking and some minor injuries are potentially dangerous. Proper toilet and washing facilities are essential. Suitable clothing must be worn and kept clean. Personnel should be medically free from diseases.

All facilities and operations should be checked regularly with regard to care and cleanliness. The importance of high hygienic standards at the cold store cannot be overemphasised. In order to assure that storage facilities are continuously maintained in a manner which satisfy both company and regulatory agency standards and regulations, a store quality assistance audit should be scheduled on a regular basis and followed point by point. One example of such a quality assurance audit is given in Appendix 3. Obviously such a programme must take local requirements into consideration.

11.2 Personnel Working in Cold Stores

Working in a cold store means exposure to extreme cold and demands high physical and mental standards. Heat losses from the body must be minimised by proper clothing. In addition, working in a low temperature environment creates special effect on the human body, which must be counteracted by a special working routine and provisions for personal welfare. As for anybody else working in the food industry, the employees must undergo regular checks and maintain the necessary level of personal hygiene required for this industry.

Among the initial effects of exposure to low temperatures are numbness in the fingers and toes and reduction in dexterity. Muscular activity and increased metabolism would help to maintain the body temperature around 37°C. On average, the heat dissipated by a man in W/min varies according to the physical activity e.g. at rest 1.5, light work 2.5-3, moderate work 4.5-5 and hard work 8. Shivering is the principal mechanism of the body to momentarily increase its metabolism, but a shivering worker becomes ineffective, when the heat losses are greater than the heat generation, the body temperature will continue to fall and thus causes unsatisfactory physical response. It is usually considered that the metabolism will decrease by 12 percent for every 1°C decrease of the body temperature. The lungs begin to freeze at about -53°C. The human body will lose liquid through cold when exposed to low temperature. However, working in a low temperature environment is not hazardous to health, provided the worker is physically fit, i.e., submits himself to the necessary medical examination before employment and uses all the precautionary measures provided by the cold store properly.

11.2.1 Protective clothing

The term clo was introduced in order to define the insulating quality of clothing assembly. By definition, one clo will provide thermal comfort to a man sitting in an ambient of 21 °C, 50 percent relative humidity and 0.1 m/s air velocity. A long suit corresponds roughly to one clo, a linen suit to 0.8 clo, and a woollen suit under which is a waistcoat, shirt and underclothes to 1.3-1.5. One clo is equal to 0.18 °C m2 h/kcal. In polar climates 3 clos generally are considered suitable for moderate activity in a -20C ambient with a low wind velocity. However, this relates to selected individuals and for similar conditions in a cold store a value of 4 clos may be considered necessary. The importance of correct clothing is shown in Table 25, which shows the relation between ambient activity and heat production.

Table 26 Metabolic rates for various activities

Activity	**Total heat production in watts**
Sleeping	80.5
Sitting	117.2
Typing	161.2
Walking slowly	263.7
Shovelling sand	536.2

Physical activity therefore has a significant bearing on the type of clothing worn. Clothing with a value of 4 clos will effectively protect a man at rest in an ambient of 0C or carrying out moderate work in an ambient of -30°C. Thermal protection of only 2 clos would be necessary for heavy work in an ambient of -40°C. If dressed in too heavily insulated clothing staff could be susceptible to a heat shock when doing heavy work in a cold environment.

The insulating value of the air layer surrounding the subject varies with the air velocity. The face is particularly sensitive to very cold air circulating at high velocity. Special clothing is always designed to be windproof.

The protective clothing for personnel working in cold stores should be properly tailored to the body and dimensioned to the work. The latter aspect is very difficult to achieve, as the intensity of work varies. The needs and preferences of individuals also vary. While ensuring good thermal protection, clothing should not be too thick, too stiff or too heavy. Clothing should not be too tight in order not to hinder internal air circulation or restrict blood circulation. Best results are obtained if the clothing assembly is constructed according to the so-called several-layer-principle, e.g., in three layers:

1. The inner layer next to the skin should regulate the micro climate around the body. With a thermal vest, appropriate regulation is automatically affected by the movements of the body. The vest produces a thermal insulating stratum of still air next to the skin. If the work is not too heavy, the body will require increased insulation at a minimum of ventilation and the reverse takes place when the body is subjected to heavy work. The greater the body motion the greater the ventilation should be. The vest also allows for evaporation of perspiration, which is essential, as the perspiration sooner or later will cool off the body, if allowed to be absorbed in the clothing.
2. The middle layer should be insulated as well as permeable to water vapour produced by perspiration. Sweaters, pullovers, etc., are conventional garments. Warmer items can be made from synthetic materials, e.g., non-woollen, polyester or nylon fur padding.
3. The outer layer should generally be wind and watertight, but should also be as permeable as possible to water vapour to avoid excessive perspiration. It should allow ventilation at certain areas. Clothing should be adjustable at the wrist and the neck.

The helmet should be lined. It should protect the neck, ears and forehead. Shoes and boots should be lined and fitted with non-skid soles. Gloves are not produced in any standard form and should be chosen to suit the actual work. They should be properly lined and not too tight. Overtight gloves can cause frost-bite. For psychological reasons the personnel should be allowed some degree of freedom in selecting their clothing.

11.2.2 Working in cold rooms

Cold rooms should provide as good a working environment as possible. Analysis of environmental stresses show that draughts have a great influence on comfort and must therefore be avoided. Lighting should be adequate to facilitate handling operations. Psychologically, a well lit room appears less cold than a dark room. Staff should be provided with heated rooms, where they can rest and dry their clothes if necessary. Resting periods require time and cost money hence they should be properly planned and supervised. A well spent rest, even if relatively short, restores the physical as well as the mental capacity of the worker and contributes greatly to improved physical performance. A normal work period in cold rooms is 50 min followed by a rest period of 10 min.

A warm rest room is essential. It should be strategically located to enable easy access during rest periods and at the same time provide proper supervision. There should be a free issue of hot beverage, coffee, tea, chocolate and also of cold non-alcoholic drinks. Smoking should be prohibited. Furniture should be comfortable, robust and easy to clean. Floor and walls should also be easy to clean. The room should be maintained at a temperature between 20C-27C and be well ventilated.

It is essential that people are instructed in the proper use of the heated rest room and in the maintenance and use of their protective clothing.

11.3 Safety

Safety is a very broad subject and it is impossible to cover all the hazards that different situations create. Large variations safety regulations are found from country to country and only general safety risks of are dealt with here.

11.3.1 Fire

Special attention must be paid to local fire regulations and the cold store should be planned to avoid obvious fire risks, e.g., air trunking, piping, fire walls, etc. With regard to fire-fighting equipment, it is advisable that full consultation be made with the local fire-fighting authorities who, in most cases welcome any approach. The fire brigade should also be invited to the cold store in order to familiarise themselves with layouts and equipment available. It is also recommended that training involving the local fire brigade, as well as the employees at the cold store, be carried out at regular intervals. For cold stores located remotely from local fire brigades, it is essential that an in-store fire brigade is organised and trained. In the training, it should be remembered that it is the action taken during the very first minutes which determines the size of a fire.

With regard to equipment, fire extinguishers are obviously essential, but care must be taken in choosing the right type. Various extinguishing agents are used and some can be dangerous both for humans and for equipment and property, if not properly used. This goes especially for fire-fighting in cold rooms, engine rooms and electrical installations. It is obvious that danger exists in the combination of water and electrical installations. Carbon dioxide, also poses danger as it displaces oxygen for breathing. This is especially important in small-size rooms. Normally the local fire-fighting authorities can give recommendations on equipment to be used and how the equipment should be marked for various purposes.

It is not advisable to position extinguishers in the cold rooms, because of low pressure in the equipment at the low temperature of the room. They should be placed outside and at strategic points like the loading ramp, entry point to roof cavities, and outside, as well as inside the engine rooms. All the extinguishers should be regularly maintained, preferably by the manufacturer or by other authorised personnel.

Breathing apparatus must be within easy reach and is normally placed close to the engine room entrance. There should be at least one set of pressurised air breathing apparatus at both the normal entrance and at the escape entrance to the engine room. It should be observed that no reliance can be made on the simple filter type gas mask in heavy concentrations of smoke, ammonia or other refrigerant, but this type can be useful in lower concentrations. It is of obvious importance that a sufficient number of the employees are trained in the correct use of breathing apparatus.

Space around the outside of the buildings is important in order to give the fire brigade quick access to any point, and provision of water hydrants are necessary, particularly if the buildings are placed at some distance from public roads. It is important to check that the couplings at the fire-points fit the fire brigade hoses and that the water pressure is adequate.

Welding operations have a high fire potential risk and therefore very strict precautions must be taken. The welder, who may not be a member of the employees of the cold store, should always be accompanied by a member of the staff. It is also advisable that the local fire brigade is informed when major work is to be carried out and in some countries welding is not allowed without a representative of the local fire brigade being present. It is important that there are always two men at the working place equipped with fire extinguishers. If working close to timber, insulation or other combustible material, the area of work should be covered, e.g., by asbestos blankets.

Where electric welding sets are used care must be taken to ensure proper earthing, but not to the structure of the building since this can lead to arcing and the initiation of a fire at a point far away from the actual welding operation.

11.3.2 Emergency escape

Adequate escape from cold stores is very important due to the low temperatures. Emergency doors should always be installed to give at least two alternative escape routes from any point in the cold room. Maximum distance to a door from any point is often set to 40 m. This is equally important for engine rooms. Gangways with dead ends should be avoided, as well as blocking of gangways with products. The emergency exits should preferably lead to the outside of the building where easy escape from the area is allowed. Escape onto roofs of a joining building should be avoided if possible.

Emergency exits present a security risk and therefore outside handles should be eliminated and the door secured on the inside. The latter must, however, be done with a simple, easy to remove device which must be regularly checked and maintained in order to avoid icing up.

11.3.3 Emergency lighting

Lighting must be provided at all times in low-temperature rooms. The minimum requirement is one lamp at each doorway, gangway and section.

11.3.4 Alarms

An acoustic alarm system must be provided for anyone who is accidentally locked up in a low-temperature room or for an injured person who cannot open the doors. The switches for the alarm should preferably be placed by every door and not more than 0.5 m from the floor. Other places for alarms are gangways around evaporators, roofs, engine room, etc. The sounder should be positioned where there is always someone in attendance, e.g., the loading bank or in the reception office.

Fire alarm systems are normally placed outside the cold rooms (to allow anyone to escape before raising the alarm). The alarm should sound both inside and outside the storage chambers. Automatic systems and smoke detectors are normally not a good alternative inside the low temperature rooms due to frosting up and reacting on to warm, moist air, etc.

11.3.5 Refrigeration plants

All personnel responsible for or working with refrigeration plants must have a clear understanding of:

- the effects of the refrigerant on people,
- the function of the refrigerant plant, and
- the properties of the refrigerant in the plant.

The engine room should be equipped with a plate outside the room giving information of the supplier of the refrigeration plant, type of refrigerant and amount of refrigerant used in the system. In the engine room there must be a highly visible flow diagram of the refrigeration plant. There must be fire extinguishers and at least one respirator or breathing set, placed in a separate box outside the engine room. The mask should be complete with a suitable filter and there must be separate filters available together with two sets of protective gloves or rubber or similar suitable material. There must be a water tap and adjacent hose available which makes it possible to spray water at all points of the engine room. One of the most important safety equipments is a first-aid kit complete with eye-washing facilities.

11.3.6 Smoking regulations

Most food legislation prohibits smoking on and in premises used for food production, processing and handling. Therefore all personnel must be informed, when employed, about those regulations. Clear signs or markings should show where smoking is not allowed - any area where food is stored, processed, packed or handled. Special smoking zones should be located at convenient places and equipped appropriately with ashtrays and fire extinguishers. As a general rule smoking should be discouraged.

11.3.7 Safety instructions

Safety instructions must be issued to all employees and cover emergencies such as fire, refrigerant leaks, escape doors, assembling points, etc. The instructions should be written in simple language and kept brief and to the point. An example of a safety instruction is given in Appendix 4.

11.4 Security

The objective of the security at a cold store is to, as far as possible, eliminate theft, sabotage, etc. A cold store is a most attractive place for thieves, as well as terrorists. The following are general guidelines for preventive security.

The gatehouse is best located at the end of the access road, where incoming vehicles and goods can be directed to respective areas of the store. The gatehouse is a check-point for vehicles and employees. Ample space must be available for these purposes, e.g. a small lay-by for vehicles during checking and a waiting room for employees and visitors. For security reasons it is recommended that private cars be parked outside the store perimeter. A rail-siding, when this is of interest or necessary, must be long enough to suit a reasonable number of wagons. A combined rail and road traffic system at the same loading ramp or dock is not recommended.

Fencing and gates are important to prevent theft at a warehouse. Where it is not practical to put a lock or a guard at a gate, the manager should have a clear view of the traffic in and out of the site. The fence should be high enough so that it cannot be climbed easily and there should be a reasonable distance between the sides of the building and the fence.

Persons coming and going regularly within the site should have an identification badge that can be clearly seen, preferably with a photograph which is changed periodically.

Vehicles should also be identified with an appropriate sticker or temporary pass issued at the gate.

In small facilities supervisors should be asked to question people who are not readily identifiable. Parking lots should preferably be outside the fence, or if this is impractical the lot should be well away from the store.

Access in and out of the store itself should be limited, and the entries not in use should be locked. Modern inventory control methods emphasise the importance of one or two checkpoints for shipping and receiving, rather than a multitude of doors; the material handling disadvantages being more than offset by the product control advantages.

If parking is permitted within the premises a clear view of employees on their way to the parking lot is a must. Lights in the parking lots and other areas will pay off in theft prevention. The store itself should be well lit for safety and security. Employees should be trained to ask questions of people who they do not recognise as employees or authorised visitors.

Drivers of vehicles and their helpers have a great opportunity for theft. Unfortunately, experience has shown that outside drivers are a possible problem and should be treated as such. This problem has to be dealt with defensively by employing policies and procedures which prevent drivers or their helpers from loitering around the dock when not working. A good way to overcome this problem is to provide a waiting room for rest, food and relaxation. The vehicles should be checked on the way in, as well as out, (either on a continuous basis or by spot checks) and their authority to pick up a load should be verified. When practical, conduct random unloading and recounting. Such a procedure has a considerable psychological effect.

A large proportion of industrial crime is committed by employees and therefore a major part of the security efforts must be concentrated internally. Besides ordinary theft of products, special attention should be given to so-called "white collar" pilferage, such as paying a supplier twice, keeping the second cheque for personnel, and abuse or manipulation of time-cards.

Security starts at the top and it is important that the chief executive of the cold store complex is firmly against illegal or improper conduct. It is important that he takes immediate and correct action when something is wrong.

11.5 Instruments

The chamber temperatures are measured either by recorders which are placed outside the chamber or centrally covering more than one chamber, or by indicating instruments which are placed inside the chamber or centrally.

In order to obtain meaningful readings thermometers (probes) should riot be placed close to the door and it is recommended that the probe is buffered in order to avoid large fluctuations in the readings and the recordings. These fluctuations in air temperature, caused by door openings, etc., have normally no bearing on the product temperature. The buffering of the sensing probes is easily done by, e.g., placing the probe in a cylinder filled with a glycol solution with a lower freezing point than the actual room temperature.

The instrument used for checking product temperature should be a robust instrument as it is often handled in a rough manner. There are a large number of instruments to choose from, mainly battery powered. For measuring product temperatures liquid and glass thermometers are prohibited. Mercury thermometers may only be used for calibration of the instruments in daily use.

This thermometer should be a standard instrument with a certificated accuracy and the calibration should preferably be carried out at the actual operation temperatures.

11.6 Energy Management and Conservation

In view of the increasing demand for energy and the escalating costs of energy from all sources, energy management and energy conservation are becoming increasingly important in all industries and obviously also in the food systems.

Even if a number of investigations have shown that freezing and frozen storage, as well as chilled storage, are less energy demanding than some other preservation methods used for foods, good energy management and energy conservation are important factors in the operation of cold stores.

Energy consumption obviously has to be regarded already at the planning and design stages of a cold store. Large savings can be made by careful selection and assembly of components. Choosing efficient evaporator fans with the correct mass air flow and air throw for the store dimensions and optimising the insulation thickness taking relevant location conditions into account can show considerable savings.

Heat pumps can be used to utilise condenser heat for heating purposes, e.g., hot water for cleaning or heating. All buildings should be of a light colour. The loading dock should preferably be enclosed. This is just to mention a few measures to be taken. Today, most of the relevant actions are taken in the cold store design as long as experienced consultants are used.

The measures to be taken from an operational point of view range from proper control of lighting and air conditioning, to the proper running and maintenance of the engine room.

However the storage temperature should be kept lower than -18°C and preferably -24°C to -30°C, especially for fish products. Even if the energy bill could be reduced by increased storage temperature, this saving is minimal compared to the total saving possible by an adequate energy management.

12.0 PLANNING A COLD STORE

The correct planning of a cold store requires a feasibility study, which investigates market, distribution, technical and administrative solutions and routines and possible sites, assessing their suitability for the project in mind from a technical, as well as financial, point of view.

Each location of a cold store has a logical catchment area, where it is economic to operate with regard to transport of the products to be stored. Normally the main part of the business is done within this area.

Proper analysis of the existing and possible future market is an essential first step in the establishment of a cold store as this is a link in the preservation, processing and distribution of the fish landed. The store must therefore provide the service of freezing and frozen storage at the right time, place and price. The success of the operation is entirely dependant on the marketing strategies of the industry. There are other factors influencing the location from a construction and operating point of view. Examples are nature of ground, subsoil, topography of sites, availability of water, electrical services, labour and regulation to surrounding community, other industries, etc.

It is also important to provide space for movement and parking of vehicles and to allow for extensions. A cold store is not only a cold box, but needs handling areas, parking lots, plant rooms, roads, railway connections and different types of service buildings as discussed previously in this document.

The investigations mentioned must be carried out extremely thoroughly, since any one of them could greatly affect the cost of the project and eventually its entire feasibility. Very often it is necessary to compromise, when selecting the site, as the investigations will show one site being more acceptable from an operational point of view, whereas another is cheaper to develop from a construction point of view. It is advisable to utilise experts in some of the studies, especially those concerning market and technical solutions and for large-scale installations, which often have to be integrated in a nation-wide network, it is recommended that experienced experts carry through the study. Some factors influencing the design of the cold store are given in Appendix 5.

13.0 FREEZING AT SEA

13.1 Why Freeze at Sea?

The length of time a fishing boat can remain at sea depends on the time the fish can be kept so that they are still edible on reaching the consumer. Storage in ice or by other means which keep the fish chilled is adequate for periods not much in excess of two weeks.

Fish such as haddock and cod caught in the North Atlantic fisheries can be stored for up to 15 days in ice and then rapidly become inedible. It has been found that fish caught in tropical waters can remain edible for even longer periods when stored at chill temperatures. This may not be a general rule and the limitation of chilled storage must be established by local experience.

In practice, the time restriction for storage in ice often means that fishing vessels must return to their home port with the fish room partly empty. There is therefore a need for some means of preservation that will extend the storage life without substantially altering the nature of the raw material. Quick freezing and cold storage is an excellent way of doing this.

When newly caught, fish are frozen quickly and stored at a low temperature on board, so there is no limit imposed on the length of voyage due to spoilage of the catch. Fishing vessels can remain at the fishing grounds until the hold is full. This increases the proportion of time spent at the fishing ground and improves the economics of fishing. It also allows the fish to be distributed to a wider market even without the existence of an elaborate "cold chain ". Fish which have been frozen at sea are of very good quality when landed; therefore, more time is available for the fish to be distributed over a wider area and still be in good condition.

Freezing at sea has therefore an important role in world fisheries. A look at a map will show that large areas of ocean are far distant from any centres of population or even land, and many potential fisheries are therefore unexploitable without a method of preserving the fish for long sea voyages. Only quick freezing and low temperature storage has so far satisfied this need and, as traditional near water fisheries become overfished or are unable to satisfy the growing demands of an ever increasing population, freezing at sea will become more and more necessary.

13.2 Type of Freezer Vessel

Fish frozen at sea may be frozen whole, immediately after catching and when thawed on shore, can then be used in much the same way as fish traditionally preserved in ice. Alternatively, the fishing vessel can operate as a fish processing factory and the fish may then be filleted, packaged and frozen, and the waste products converted to fish meal and oil.

Freezing of the whole fish has the following advantage over processing before freezing. The number of crew required is not much greater that for a fishing vessel of comparable size preserves its catch in ice. Processing equipment and factory deck space, are a good deal less. The whole fish, when thawed after landing, are available for any form of traditional processing. The problems associated with freezing newly caught fish are less with whole fish than fillets. For the above reasons, it may therefore be advisable as a first step for a developing country to freeze whole fish and progress to a factory-freezer operation as the situation demands.

13.3 How Good. Are Sea-Frozen Fish?

Sea-frozen fish, properly handled between landing on deck and loading into the freezer, when thawed are almost undistinguishable, from fresh fish kept in ice for a few days.

The loss in quality as a result of freezing, cold storage and thawing is small when these treatments are properly applied. Thus, when very fresh fish are frozen at sea, the final product can be equal to the best on the market.

13.4 Freezers for Use at Sea

A number of conventional freezer units may be used at sea with little modification but may have to conform with national regulations and insurance requirements for fishing vessels. Many countries, for instance, do not allow the use of ammonia as refrigerant because of its toxicity and because there is a potential explosion hazard. The design and operation of the freezers and the refrigeration system must take into account the movement of the vessel, vibration, sea-water corrosion and the extra rough usage likely under the arduous conditions experienced at sea. Another factor that may influence the choice of type of freezer is the type and variety of fish species to be frozen. The freezer should be able to cope with the variation in fish sizes in fisheries where many different species are caught.

The VPF was specially designed for freezing whole fish at sea. In most applications, a 100mm spacing between plates was found to be adequate. This spacing allowed a very high percentage of the catch to be quick-frozen and reduced to the cold storage temperature of -30°C in the recommended time of 4h. Oversized fish were normally frozen in a separate air blast freezer room.

The UK design considerations which led to 100mm spacing being used, were based on the freezing of gutted fish with heads on. Other countries' requirements may be for ungutted fish to be frozen or for fish to have the heads removed as well as guts before freezing. These considerations will have to be taken into account as well as the size, shape and variety of species to be frozen before a decision is made on the preferred plate spacing.

Another factor to be taken into account with any type of freezer is the overall size and weight of the frozen product. If the product has to be lifted and stacked in the fishing vessel cold store, care should be taken that the block weight is well within the physical capabilities of the crew. It has been possible to operate in the UK with 45 to 50 kg blocks measuring approximately 1060 x 520mm.

Many other types of freezer are also suitable for freezing fish at sea, and HPF, brine freezers and a variety of air blast freezers have been used. Most of these freezers have been described in Chapter 4 but for use at sea they have to satisfy some special requirements.

The following design and operational requirements for freezers to be used at sea will give the reader guidance on whether a freezer is suitable for this application.

1. The freezer should be easily loaded and unloaded.
2. Freezers with trolleys should have special arrangements to make them safe during rough weather.
3. The freezer should be able to retain the product during the loading and unloading procedures; serious damage or injury can result from a dislodged frozen block or tray of fish.
4. The freezer should be able to operate with part loads which may result from variations in the catching rate.
5. The refrigeration system should not give rise to uneven freezing due to displacement of the refrigerant with the movement of the vessel.
6. The freezer should be robust.
7. The material used in the construction of the freezer should be resistant to seawater corrosion.
8. The freezer should be constructed so that it can be cleaned by hosing with seawater.

The above list is not exhaustive but it is sufficient to indicate that many types of freezer would, in fact be unsuitable for use on a fishing vessel.

Space on a fishing vessel is limited especially the height available between decks. Freezer designs and layout should therefore be made to suit this space restriction. The quicker the freeze, the smaller is the size of a freezer for a given capacity. Freezers for use at sea should therefore be designed for short freezing times, taking into account both the refrigerant operating conditions and the product shape and size. Large fish like tuna are frozen individually. Brine immersion freezers have been used but there has been a recent trend toward air blast freezers for this purpose. Shell-on shrimp and other shellfish are also frozen individually, but apart from these few exceptions, freezers for IQF products are unlikely to be required on a fishing vessel.

Extra care has to be taken with the refrigeration equipment. Pipework should be secure and routed so that it is unlikely to be damaged. The use of secondary refrigerants for many shipboard systems has resulted in a system that can be maintained in a relatively leakfree condition. When a secondary refrigerant is used, the primary refrigerant is confined to the condensing unit and heat exchanger. Since secondary refrigerants are liquids at atmospheric pressure which only operate at pumping requirement pressures, there will be a greatly reduced incidence of refrigerant leaks. Calcium chloride brine is by far the most popular in use today. However there is controversy at the present concerning the corrosion inhibiter required for multi metal units. The existing chemical is alleged to be harmful to health and although there are alternatives proposed, the problem has, as yet, to be resolved. The major requirement for both the freezer and the refrigeration system on a fishing vessel is <u>reliability.</u>

13.5 Handling Fish Before Freezing

The layout of a stern trawler illustrates a good arrangement for handling fish before freezing. The fish are pulled up the stern ramp, poured from the net through hatches to the factory deck below and then moved forward as they go through the various stages of processing. Not all vessels can use this preferred arrangement and it would be impossible to cover all the potential layouts for the wide variety of vessels now used for freezing at sea.

The pre-freezing procedures described below are typical of a freezer trawler fishing in the North Atlantic. They may, however, have a more general application, and only minor modifications may be necessary to accommodate other vessels and their particular requirements. Fish must not be left lying on the upper deck exposed to direct sunlight but stored on a sheltered working deck immediately below. The fish should be kept as cool as possible immediately after catching and throughout the time they are awaiting freezing. Some means of cooling, such as a of seawater spray or chilled sea water (CSW) tanks, is therefore recommended when the fish are subject to any delay before gutting. Cooling of the fish not only helps to retard spoilage but also stops the blood from clotting too quickly. In tropical conditions, it will be necessary to provide a means of chilling the water used for this purpose.

Gutting of fish should commence as soon as possible after being caught not only to ensure the continuity of supply to the freezers, but also to reduce the rate of spoilage. The removal of the gut releases blood from the fish and must be followed by immediate washing in chilled water. Blood which is not released soon enough, clots within the tissues resulting in a permanent pink or red discoloration of the flesh which detracts from the appearance of the fillet. The liver must also be removed as it contains a fat which is highly perishable and could become rancid even at low temperatures. A time of 15 to 30 min in cold water is usually required for bleeding to be complete. However, in practice it is often difficult to ensure that all fish are given time to bleed properly. One solution is to make washing a two stage process. The gutted fish are first put into an open tank where they can bleed while they are kept cool by chilled water sprays, and then they are conveyed to an automatic fish washer where they are given a final rinse before freezing. The need for delay for proper bleeding of the fish before freezing must seem an added encumbrance. However, where it is desirable to gut before freezing, time must be allowed for the blood to be released from the fish to ensure they have good appearance. If appearance is not important in the final product, this delay for bleeding may not be necessary. Traditionally, some fish may only be marketable ungutted and in this case a special effort should be made to handle the fish quickly. They should be kept chilled and rough handling should be avoided.

Fish are usually sorted before freezing so that each block or package contains only one species. With some species, further subdivision into size grades may also be necessary. This extra handling for sorting and grading is viable when a premium is paid for graded fish. Some sorting is required before processing to reject unwanted and undersize fish and any trash material. Whether it is feasible at this time to sort the fish to be frozen into species and size grades will depend on individual requirements.

Heading of the fish may be desirable in some cases. Headed fish make a more compact block and heading allows larger fish to be frozen in some freezers. Removing the heads also means that the freezers can be used more efficiently and the proportion edible fish stored is also increased. One disadvantage of heading is that a small but not insignificant amount of edible fish is removed with the head. The cut surfaces may also become discoloured in time and trimming may be necessary.

Small pelagic fish such as herring are traditionally landed in the whole ungutted state and should also be kept cool since spoilage rate will be higher than for larger fish that have been gutted. Freezing if required should be done as soon as possible.

Another major problem, which usually only applies when fish are frozen at sea, is due to the effects of rigor mortis. Very often fish are bent prior to rigor. This should be avoided as far as possible since the flesh of the fish on the outside curve will be put under a strain and, when rigor sets in, the extra forces involved will pull the fish apart. This results in gaping of the fillets. The fillet in the inside of the curve, on the other hand, will shrink and contract so that two different looking fillets will be obtained form the same fish. One will be elongated with much gaping and the other will be short and compact. Freezing will of course maintain the fish in this bent condition, and will no doubt be blamed for the phenomenon. If bent fish in rigor are straightened before freezing, gaping of the short compact fillet will result. The onset of rigor mortis is quicker at higher temperatures and may occur only 10 to 20 min after death at temperatures near 30C. It is therefore essential that the fish be chilled quickly if problems due to rigor mortis are to be avoided during freezing.

If the fish are to be filleted at sea and frozen as fillets, it is even more important that chilled conditions exist along the entire production line. When a fish goes into rigor, there is a gradual increase in the tension of the muscle fibres and, as long as the muscle remains attached to the skeleton of the fish, shrinkage is restricted. However, once a fillet is cut from the fish, this restraint is removed and, if the onset of rigor mortis is not complete, the fillet will shrink. This contraction gives the fillet a corrugated appearance and a distorted shape. Temperature has an important bearing on this process, the higher the temperature, the faster the shrinkage and hence, the greater the effect in a given time. Fillets that are allowed to shrink at a high temperature before freezing can lose greater quantities of drip on thawing. In addition, excessive flexing or contact with water can increase the amount of shrinkage of a pre-rigor cut fillet.

A fillet taken from a fish before rigor has set in will, after freezing and thawing, have a dull appearance. This absence of gloss is probably due to the cut ends of muscle cells projecting upward. The fillet has a velvety feel and will not, for instance, produce an attractive smoked product. There is no known solution to this problem so far, apart from delaying filleting until after the onset of rigor mortis.

Before freezing, the fish may be stored in bins of an equivalent volume and adjacent to the freezers. This ensures that only the correct quantity of fish is available to fill the freezers and none are left on conveyors. The working space adjacent to the freezers should be kept cool to ensure that the fish do not warm up at this stage and the bins should be emptied in strict rotation so that no fish lie longer than necessary. Final sorting can be made at the freezer and a facility e provided for the storage or return of rejects.

Any chilling of the fish prior to freezing will not be an extra refrigeration requirement since any heat removed before entering the freezer means a reduction in the subsequent refrigeration loading. Chilling will be a low cost process with considerable benefits in improved fish quality.

13.6 Handling Frozen Fish

Fish should be transferred to the cold store immediately they are removed from the freezer. Even large blocks of fish warm up rapidly at ambient temperatures particularly in tropical climates. Heat added to the fish at this stage means that it has to be removed in the cold store and this will mean some loss in quality and an additional cold store load. Mechanical aids, such as chutes or conveyors, should be used since the less handling the frozen fish receives, the less chance there will be of the fish being damaged. Damaged blocks require more storage space and extra handling in the cold store. Damaged fish should be kept separate in the store since they may require special discharge arrangements.

Unfrozen or partially frozen fish should never be placed in the cold store as it is not designed for freezing. Partially frozen fish are also more easily damaged during handling. When fish are graded before freezing, the blocks or packages should be clearly labelled and, if possible, the different grades kept separate within the cold store. Labels placed on the surface of frozen fish and brushed over with clean water will adhere to the surface and this method of marking can be used if the fish are unwrapped. If wrappers are used for the fish, they should be suitable for marking so that the fish can be identified and handled more quickly at the time of discharge or later.

13.7 Cold Stores on Freezer Vessels

The cold store on a fishing vessel should operate at the temperature and on the same principles as recommended for shore based cold stores. Even if the storage time on the vessel is to be relatively short, it must be remembered that poor practice at any stage of handling and processing will have a cumulative effect which may become obvious by the time the fish reaches the consumer.

Loading and unloading of a fishing vessel's cold store is usually done through hatches at roof level. This is a good arrangement since there will be little exchange of air between the store and outside when the hatches are open. One distinct disadvantage of this hold arrangement is that even small refrigerant leaks can result in an accumulation of refrigerant in the cold store and, although the refrigerant may not be toxic, the resulting low oxygen level may be dangerous. Shipboard cold stores must therefore have an effective alarm system and the crew disciplined to use it and obey all other safety rules and regulations.

Frozen fish in the cold store of a fishing vessel may have to be stacked with a retaining system to prevent movement of the product. A structure similar to that used to form partitions and shelves in the fish room of a wet fish trawler has been used for this purpose. The following figures should only be used as a rough guide since the finer details of store construction and layout, the shape and size of the frozen product and the method of packing can mean considerable differences in storage densities for apparently similar installations.

Table 27 Stowage rates for frozen fish in the cold store of freezer vessels

	(m^3/t)
Large blocks of cod (including allowance for support structure)	2.0
Large blocks of cod (open stowage with no support structure	1.4 to 1.7
large blocks of fillets (including allowance for support structure)	1.2 to 1.5
Frozen cod stowed as single fish	2.2 to 2.6

Insulation of a cold store on board a fishing vessel creates some special problems. The cold store insulation is usually attached directly to the ship's side; therefore, the rib structure of the vessel will penetrate into the insulation for some distance. Although the thickness of the insulation need not be increased to more than would be necessary for corresponding store on shore, the design should ensure that there is an effective thickness of insulation at all points in the store (Figure 44). Any internal structure within the cold store space should be attached to the main framework of the vessel with an effective heat barrier. Metal or any other material with a high thermal conductivity should not be used for this purpose.

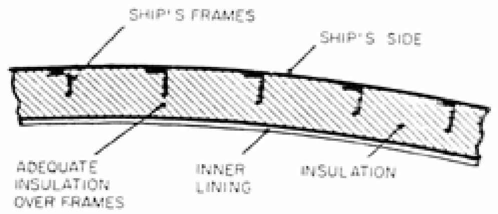

Figure 44 Insulation of a fishing vessel cold store

Foamed-in-place polyurethane insulation and polyurethane slabs have been used for the insulation of shipboard cold stores. The application of this type of insulation is difficult and requires skilled operators and special equipment. Loose fill insulation may however be used in combination with others for instance for packing awkwardly-shaped areas where cutting of slabs would be difficult. Another desirable property of an insulation for a steel fishing vessel is that it should be reasonably heat-resistant to enable welding or other heat treatment to made to the outer hull. Unfortunately, none of the insulations that are likely to be used can completely satisfy all the requirements but some are significantly better than others. Insulation choice and method of application can only be made after consulting the relevant codes of practice or legislation for shipboard insulation for the country in which the vessel is registered or insured.

Increased insulation thickness can be costly on a fishing vessel since only a few centimetres increase in thickness can mean a significant reduction in the storage space. A store holding about 100t of fish, for instance, would be reduced to about 95t if the insulation thickness is increased by only 5cm.

The choice of cooling systems available for the cold stores of fishing vessels is much the same as that for other stores. Pipe grids and forced circulation coolers have both been used successfully. When large blocks of fish are stored, the system selected should not be vulnerable to damage due to block handling or movement. Grids on the sides of the vessel require to be protected since a 45kg block of fish can damage pipework particularly since metal is a good deal more brittle at cold store temperature. Plain pipe grids on the roof only have been used but, in order to get the required heat transfer surface, finned grids are usually required and care must be taken to ensure that the frost on the pipes does not bridge the air space between the fins. If plain pipe grids are used, it will normally be necessary to continue the grids to at least halfway down the sides of the hold.

Attempts have been made to avoid using wall grids by having two or more rows of plain pipe grids on the roof. In terms of cold store quality, this is an inferior arrangement and also makes defrosting more difficult than when a single row only is used. Cooling grids together with any protective lining take up a good deal of space in a store but some of the space would normally be kept free as clearance around the produce.

As in some modern stores on shore, unit coolers may be used and they can be located outside the main storage area, for easier defrosting, and the cold air circulated uniformly within the room.

13.8 Unloading Freezer Vessels

Handling frozen fish is obviously different from handling iced fish and cannot be unloaded in the same manner. Any unloading system should handle the fish quickly between the vessel's cold store and the cold store on shore. Delays at this stage, particularly in warm climates, can result in partial thawing of the fish with a resultant loss in product quality.

There should be no delays on the quayside and any grading of the frozen fish according to species or size should be left until the produce is in the cold store or a least under cover. Ideally, cold stores should be adjacent to the landing place and fish can then be moved quickly, preferably by conveyor, into cold storage. Alternatively, if the store is reasonably near to the quay, unrefrigerated vehicles may be used for transporting the fish provided there are no delays. Vehicles however, should be of the enclosed type and they should be loaded under a canopy so that fish are not exposed to direct sunlight. Large capacity vehicles should not be used since extended loading times will result in a good deal of heat being added to the fish. Even when smaller vehicles are used, if delays are unavoidable the vehicle should be despatched to the coldstore with a partial load rather than wait to be fully loaded. In some countries, labour may be relatively cheap and mechanical handling may be considered an expensive luxury. In these cases, it may therefore be more economic and quicker to manhandle the fish. The rate of unloading of frozen fish from a vessel will depend on the size of blocks or packages or the containers used for loose fish. It will also depend on the facilities provided on the vessel, such as number and size of hatches and also the degree of accessibility and hence the number of men that can be employed at one time. With a mechanical unloading system and a skilled crew, unloading rates of 1 to 1.5 t/man hour can be achieved. Mobile cranes and ship's derricks have also been used to unload frozen fish into enclosed containers in the hold which are then transferred to the quayside. This operation should ensure that there is no delay on the quayside in order to transfer and sort fish. Storing the fish in containers in the ship's hold has been suggested but unless the vessel is specially designed for this purpose, up to 30 per cent of the available storage space could be lost due to the presence of the pallets and the need for squaring off the hold. This would mean that a fishhold capable of storing 600t of unpalleted frozen fish in open storage would only be able to hold 400t if the fish were graded and stored in containers. Only if a freezer vessel reached the proportions of a cargo ship would palletization be achieved without a significant loss since a vessel of that size would have parallel sides for a good length of the hold. The stowage rates given in Table 26 give some guidance for calculating the likely hold capacity.

14.0 TRANSPORTING OF FROZEN FISH

Frozen fish delivered to a destination where they are to be sold immediately are likely to be consumed within a few hours and no harm is done if they are partially thawed on arrival at their destination. The frozen fish may in fact be carried in uninsulated containers depending on how long the journey takes. Enclosed vehicles, however, should be used or at least a cover provided to protect the fish from direct sunlight. An insulated vehicle will be required for long journeys depending on the initial temperature of the fish, whether the vehicle is fully or partly loaded, the size of the load, the insulation quality and thickness, the degree of air ingress and the local climatic conditions. A local trial will ascertain the maximum range attainable.

Frozen fish that are to be transferred to other cold stores must be transported in an insulated vehicle preferably with some form of refrigeration equipment to maintain the air space at a temperature of approximately -20C. The following lists refrigeration methods that may be used:

1. Mechanical refrigeration using either wall coolers or forced convection coolers blowing air throughout the storage space. In some cases, a jacketed system for distributing the air is employed. This is the most common system.
2. Rechargeable eutectic plates.
3. Solid or liquid carbon dioxide or liquid nitrogen can be used with a total loss system.

The cost of a vehicle complete with a mechanical refrigeration system suitable for maintaining a temperature of -20C would be approximately US $110,000. This vehicle would be suitable for transporting 15t of frozen produce. The price is the 1993 figure for delivery to a UK port.

Prior to loading, the vehicle or container should be precooled and the loading should proceed quickly. Palletized loading and the formation of a scaled connection between the vehicle and cold store are both helpful in keeping the temperature rise at this stage to a minimum. The size of a package affects the speed at which it warms; the smaller the pack the greater is its surface area in relation to its volume and the quicker it warms. Fig 45 shows laboratory measurements made on a single consumer pack and on a carton of the same packs. Packaging the product in a master carton will clearly reduce the temperature rise during handling outside a refrigerated space.

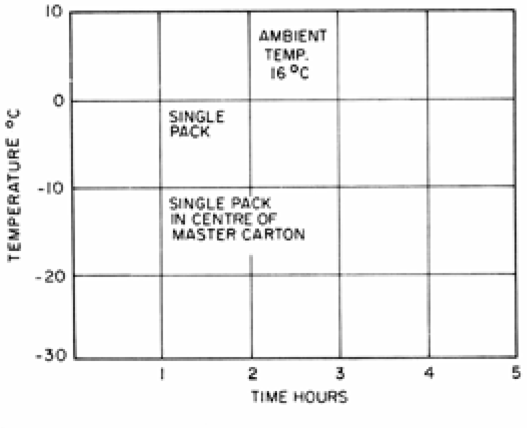

Figure 45 Comparison between the rates at which fish in single packs and cartons warm up

Fish at the edges and corners of the load will warm more quickly than those at the centre of the load during unrefrigerated transport, and the extent of this temperature difference is not often appreciated by the operator. Fig 46 shows the result of temperature measurements made across the middle of a load in an uninsulated container. The temperature rise was almost entirely in the outer 300mm layer of the load which in this case was packed firmly against the container wall without an airspace. It must be remembered that the outer 300mm layer represents a considerable part of the total load. For example, in a container measuring 5 x 2 x 2m almost 60 percent of the load would be located within 300mm of the wall.

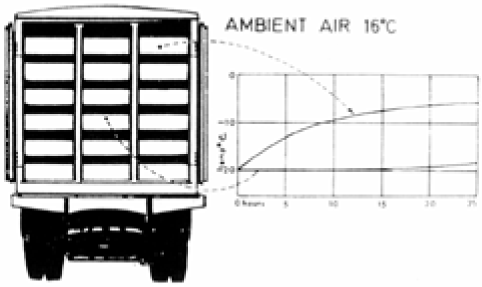

Figure 46 **The effect of position in the load on the temperature of frozen produce in an unrefrigerated and uninsulated vehicle**

The above temperature measurements were made during the transport of frozen fish in a temperate climate where the ambient temperature was about 16C. The results clearly show the effects of bulk, size and position in a load on the rate of warming when no refrigeration is used. The differences will be even greater in warmer climates.

15.0 REFRIGERATION PLANT REQUIREMENTS

Most of the mechanical refrigeration plant used for freezing and cold storage of fish is of the vapour compression type basically consisting of compressor, condenser, expansion valve and evaporator (cooler). In simple terms, a refrigeration system takes in heat at a low temperature and rejects it at a higher temperature. The following is a brief description of the major components. Reference should be made to the appropriate text books for a more detailed description.

15.1 Compressors

The selection of a compressor to suit a particular installation is better left to a qualified person. Detailed information on compressor design cannot be given in a document such as this. As a general rule, small freezer and cold store installations should not share the same refrigeration machinery. Load fluctuations brought about by the freezer being loaded and unloaded, could result in temperature fluctuations within the cold store. In addition, when only the cold store only is in operation, a refrigeration compressor of large capacity will be used for what is a relatively small refrigeration load. Apart from being uneconomic, this will result in problems with capacity control. On the other hand large installations usually have multiple compressor systems and are maintained and controlled by competent engineers.

15.2 Condensers

Table 28 gives some indication of the water requirement for various types of condenser.

Table 28 Condenser water requirement (t/h)

Type of condenser	100 kg/h freezer	1000 m^3 cold store
Shell and tube (water rejected)	5 to 7	10 to 14
Shell and tube with water recooling	0.03 to 0.06	0. 06 to 0. 12
Evaporative	0.03 to 0.06	0.06 to 0. 12

Selection of a condenser must take into consideration many factors relating both to the system used and to the climatic conditions. Selection must again be left to a qualified person who is aware of all the relevant information about the project.

15.3 General Notes on Refrigeration Plant

Duplication of cold store plant

The value of frozen product in a cold store can be high and precautions must be taken to ensure that the contents are not damaged in the event of a major breakdown of the plant. Cooling by multiple units, each with a separate condensing unit, is one way of ensuring that sufficient refrigeration effect is available to maintain the store at the operating temperature or slightly higher should a unit break down. Another method is to cross-connect the cold store and freezer refrigeration pipework. This allows the freezer refrigeration machinery to be used to cool the store in an emergency. With normal operation, the two would be isolated and only a competent person would be allowed to make the cross-connection.

Centralised plant

Centralised machinery enables one operator to take care of all the refrigeration equipment. Care should be taken in arranging plant layout such that the refrigeration lines to and from the cooler are not too long, as this can give rise to a number of difficulties. Plant operation and economics are considerations that also have to be taken into account.

Standardisation of plant

Standardisation of equipment is another good policy to follow especially in remote areas. Parts can be interchangeable and stocks of spares will be kept low. If possible, the same refrigerant should be selected for each installation and similar machinery made by one manufacturer should be specified. The size of individual units should also be standardised

whenever possible even if it means that some adjustment has to be made in their capacity to suit each requirement.

Simplicity and reliability

Small plants seldom justify a full time engineer in attendance; therefore, simplicity and reliability should be major considerations when selecting the equipment particularly in a developing country. The plant and all auxiliaries should also be well tried and tested. Although these requirements apply particularly when plant is unattended, conditions in most developing countries are such that they should be applied there as a general rule. Whatever incentive there may be to purchase plant that is new and offers potential economic or other benefits, the purchaser should place a good deal of importance on reliability.

15.4 Power Requirements

The power required for the operation of a refrigerated warehouse is high-voltage main electricity. A transformer unit must supply low-voltage mains in the establishment via a general switchboard. The regulations in force in most countries imply that refrigerated premises act as good conductors due to moisture condensation risks and consequently impose a certain number of precautions. Those precautions include earthing of motors and all equipment through a special circuit connected to an earth-point that is independent of the high voltage earthing connector. Equipment should be waterproof with water-sealed cables, including those of lighting circuits. The supply for mobile equipment should be low voltage. The mains circuit within the store must include a conductor to earth the frames of fans, coolers, small machine tools and other equipment. An outdoor main contactor to switch off the entire installation except the engine room extractor fans should be provided for emergency purposes. With the increasing use of electrical trucks, provision for battery charging is required. Further plug-in facilities for refrigerated vehicles may be necessary. All work concerning the power supply must be carried out by specialists.

It is obviously difficult to quote general figures for either freezing or cold storage requirements, especially when both the installed power and the peak power requirement figures are needed to plan for the connection of a suitable electrical supply. The examples that follow are therefore hypothetical and merely illustrate the calculations that may be made at the planning stage before details of the actual equipment to be used is known.

Freezer power requirements

The requirements in Table 29 are based on a heat extraction figure of 110 kcal/kg of fish frozen which includes the heat to be extracted in reducing the fish from +5°C to -30°C, fan power, insulation heat leaks, heat from trays, trolleys and so on.

Table 29 Compressor power (kW) requirements to freeze 100 kg/h

Condensing temperature	**Evaporating temperature**		
(°C)	**- 35°C**	**- 40°C**	**- 45°C**
20	6	7	9
30	7	8	10
40	8	9	10

Additional power requirements that may be added are:

Condenser water pump and fan	0.5 kW
Electrical defrost (2 x 8 kW in sequence)	8 kW
Door heaters etc.	0.5 kW

The total power to be installed for an air blast freezer operating at 30°C Condensing temperature, -40°C evaporating temperature and capable of freezing 100 kg/h of fish from +5°C to -30°C will therefore be 17 kW. An electrical defrost is not activated while the compressor is running or the cooler fan in operation; therefore, the maximum power requirement will not exceed 12 kW.

Cold store power requirements

A cold store of 1000m^3 capacity keeping frozen fish at -30°C, maximum ambient temperature of 35°C, would require a refrigeration capacity of 30,000 kcal/h. If the operating conditions are 30°C condensing temperature and -35°C evaporating temperature, the compressor power requirement will be 20 kW. Additional power requirements may be:

Condenser pump and fan	0.6 kW
Door and underfloor heating	0.5 kW
Mechanical handling equipment	1.5 kW
The total power required would therefore be	22.6 kW

The above examples for freezer and cold store power requirements illustrate the type of calculations that have to be made to determine the power supply required for a project. Other factors and the application of safety margins may, however, increase these calculated values and expert advice should be taken on this aspect of planning.

16.0 REFRIGERATION PLANT OPERATORS

Two people are important for operating a freezing plant and cold store; the engineer in charge of the refrigeration plant and equipment and the store operations manager or store keeper. Whatever the size, type or function of the plant a capable person should be employed to operate, maintain and repair all the equipment. The qualifications and ability of the operator required will depend on whether help is available locally to deal with major problems in the plant. Where skilled help is available locally or where the plant is small, a qualified refrigeration specialist is probably not required and recruits for this position need only be skilled or semi-skilled engineers who have experience in other industries. The engineer, however, has to be self-reliant, adaptable and able to make do with whatever facilities and materials are readily available to keep the plant operating. An ex-marine engineer for example, would be ideal particularly if he has had experience with steampowered plant. Only a minimum amount of training would be necessary to enable such a person to appreciate the particular problems that are applicable to refrigeration plant and he should also appreciate the reasons for good freezing and cold storage practice.

Even in industrial countries specialist training in refrigeration engineering is not widely available and it would be unreasonable to expect most developing countries to provide an organisation of their own for this purpose. However, qualified professional engineers have a broad-based training and where it is justified, attendance at a short course which deals with refrigeration and food technology may be all that is required. Fortunately, in most developing countries with a hot climate, there already exists a pool of technicians and plant operators who have gained refrigeration experience with ice-making and air conditioning plant. Recruitment from this source would mean that only the minimum amount of training would be necessary to enable them to operate new plant.

The recruitment of a qualified store operations manager should not be difficult. This person should be able to keep records of the movements of goods in and out of the store, be responsible for stowage of the goods and be able to keep simple accounts and deal with dispatch and invoice notes. An efficient store manager could considerably reduce the handling costs and improve the utilisation of the plant and storage space. The person selected for this post should therefore have good organisational ability and have experience in a similar post, but not necessarily connected with the refrigeration industry. Additional training for this person, should give him an appreciation of the perishable nature of the goods he is handling and a knowledge of appropriate cold store practices for maintaining the quality of frozen fish products.

17.0 TEMPERATURE MEASUREMENT OF FISH

Temperature measurement is important at all stages of fish handling and processing to ensure that the fish and their environment are at a suitable temperature for maintaining the good quality of the fish. The temperature of the fish is important during the period before freezing since both the eating quality and appearance of the final product depend on the rate of spoilage at this time. Even small differences in the temperature of the fish can result in discernible differences in quality. Checks should therefore be made on the effectiveness of any chilling method used during the prefreezing period by periodically measuring the temperature of selected fish.

Freezing times must be known in order to design freezing plant correctly. Periodic checks on the freezer performance are also useful so that any faults that develop can be quickly corrected. Even after freezing, cheeks are frequently made on the temperature of the frozen product during handling, transportation and cold storage as a means of quality control. All these temperature-measuring requirements need special instruments and special techniques in order to give meaningful results and what follows gives some guidance on the correct methods of temperature measurement to suit each requirement.

17.1 Temperature Measurement of Wet Fish

In any batch of fish, it is important to know the temperature of the warmest fish. Depending on whether the fish are, at the time of measurement, being cooled or warming up, the warmest fish may be at the centre or on the outside of the batch or container. Even when the location of the warmest fish is known, it is advisable to take a number of random temperature measurements. Fish temperatures should therefore be taken at the outside, the top, the bottom and any other position that may be thought to be significant.

A convenient instrument for measuring the temperature of wet fish is a probe thermometer which has been specially developed for this purpose. The instrument must be robust and have a rapid response so that readings may be taken quickly. The temperature sensitive element in the probe should be small so that the temperature at the point of the probe-only is indicated. The probe should then be inserted in the fish to the point to be measured with sufficient length of the probe in the fish to keep errors due to conduction of heat along the probe to a minimum. It has been found in practice that an instrument used to measure the temperature of wet fish should have an accuracy of within 0.5 Celsius degree.

17.2 Temperature Measurement of Fish During Freezing

Since fish is frozen from the outside inwards, it is impossible to judge by the outward appearance or the feel of the fish whether the whole of it is frozen. The surface of the fish, which is close to the freezing medium such as the cold air in a blast freezer or the cold metal of a plate freezer, will very quickly be reduced to a temperature near to that of the freezer. The temperature inside the fish will, however, change more slowly.

The most suitable instrument for measuring freezing times is one which uses a thermocouple wire. The thickness of the thermocouple wire can be chosen to suit the product being frozen, and since it is comparatively cheap and expendable, the wire can be cut off after freezing leaving a short length in the fish which must be recovered when the fish is thawed.

Since the freezing time of a product is the time taken for the warmest point of the fish to reach a desired temperature, it is essential that temperature measurements be taken at the points which are likely to freeze last. In the example shown in Figure 47, the apparent freezing time to -20°C an vary from less than 1 to 21/2 h depending on where in the fish the temperature is measured. The shape of a good temperature time curve is characterised by a plateau at a steady temperature somewhere between 0°C and -3°C followed by a steep plunge to near the temperature of the freezer.

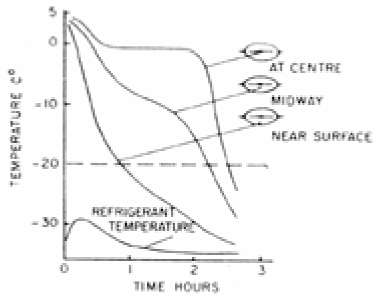

Figure 47 Position of a thermometer in fish during freezing

The centre of the fish or package is not necessarily the last part to freeze; this will happen only when freezing is carried out equally from all sides. The thermocouple should therefore be inserted in the fish so that the temperature- sensitive point is likely to be in the part that will freeze last. It is also important that as great a length of wire as possible is in the same layer of fish and hence at the same or nearly the same temperature. This has a twofold purpose: it ensures that there is no error due to conduction of heat along the wire and also that, if the wire is pulled slightly out of position during the loading operation, the temperature-sensitive junction of the thermocouple will remain in a part of the fish that freezes last. Small items such as shrimps are too small to ensure that a sufficient length of the thermocouple is in the fish. In this case a number of shrimp should be threaded on to the thermocouple behind the temperature- sensitive junction which is then located at the centre of the last shrimp.

Thermocouples should be placed in fish which are likely to have the most significant freezing times. Choice of positions in an air blast freezer, for example, would include fish nearest to and furthest from the incoming cold air, fish close to the tunnel walls, at the top and bottom of the load and at any other point where there is a likelihood of fish freezing faster or slower than the average. Once the performance of a freezer with a particular product has been established, subsequent periodic checks need not be so comprehensive.

In the absence of any temperature measuring instruments, some indication can be obtained by examination of the product. The surface of the fish being frozen remains comparatively soft and can be penetrated with a sharp probe down to a temperature of about 4°C. if this penetration can be made, the product is far from being frozen. At the completion of freezing, further examination can be made by breaking open a selected sample of fillet. If the fillet is frozen hard all the way through then the freezing time may have been sufficiently long. If, however, the centre remains soft, a longer period is required in the freezer.

17.3 Temperature Measurement of Frozen Fish

It is sometimes necessary to check the temperature of frozen fish during handling, transport or cold storage and because of the hardness of the product. A spear-type thermometer cannot be inserted in a fish that has a surface temperature lower than -4°C unless it has been specifically designed to be driven into the flesh. This type of spear is often much thicker and robust and may not react quickly enough. If thermocouples have already been used to check the freezing rate of the fish, the ends of the wires remaining in the frozen product can be reconnected to a suitable instrument to measure temperatures at any time during the storage or transport. The fish or packages containing thermocouples should be located at points in the store or vehicle where temperatures are most critical or where they are representative of the bulk of the product. Where there is no thermocouple frozen into the product, it will be necessary to drill a hole so that a thermometer may be inserted but this method is only accurate if the correct procedure is carried out. Errors as great as 20°C are possible when an unsuitable thermometer and an incorrect technique are used (Figure 48). A probe thermometer similar to that described for wet fish temperature measurement should be used and the following measurement procedure should be adopted. Before removing the fish from the cold store drill a neat hole in the fish just large enough to take the thermometer probe, some time before the measurement is required. The hole should preferable be at least 10cm deep to avoid errors due to conduction of heat. This depth of penetration will obviously not be possible with all frozen products. Insert the probe and read the temperature continuously until the lowest reading is reached and the temperature starts to rise again. The lowest temperature observed should then be within 0.5°C of the true temperature. Errors using this technique are mainly due to the fish warming up. The operation should therefore be quick and should not take more than 2 or 3 min. The drilling of the hole has no measurable effect on the temperature of the fish since the heat introduced is quickly dissipated. In the case of fish fillets or small packs which are too thin to drill to a suitable depth the probe can be placed between two fillets or packs. The fillets or packs are then held tightly together, until the lowest temperature is reached.

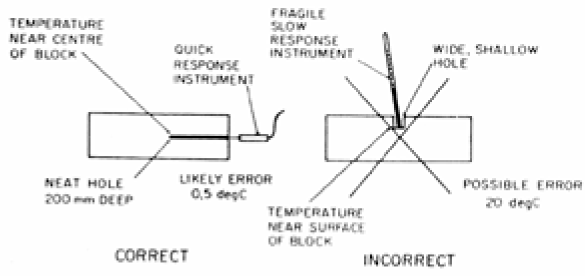

Figure 48 Temperature measurement of frozen fish

For routine temperature checks of packaged fish, measurement with a spear sensing unit can be accurate to ±1°C but this method is particularly susceptible to error in the hands of an inexperienced operator.

17.4 Summary of Rules for Measuring Fish Temperatures

1. Always measure the most significant temperature, identify and check those fish that are slowest to cool, quickest to warm or are at a high temperature.
2. The temperature probe should penetrate the fish as deep as possible to avoid errors due to conduction of heat.
3. Measure the temperatures quickly with little or no handling of the fish.
4. Use an instrument that responds quickly to temperature changes and that reads to within a 0.5 Celsius degree of the true temperature.
5. Use an instrument with a small temperature- sensitive element.
6. Periodically check and recalibrate instruments.

18.0 CFC's

18.1 History

In the early days of vapour compression refrigeration, many different working fluids were used. More recently, ammonia (R717) and halocarbons (R12, R22 and R502) have mainly been used.

Ammonia is generally used in larger plants and the halocarbons are used for smaller installations. The halocarbons are, in many respects, ideal refrigerants. Recently serious drawbacks were discovered. Some of halocarbons, known as CFC's and HCFC's, were causing breakdowns in the ozone layer round the Earth which protects the lower atmosphere from excess UV radiation. In addition the chemicals were suspected of causing global warming.

18.2 Phase-Out

Because of the drawbacks it has been agreed internationally to phase out the production and use of CFC's by 1995 and HCFC's by 2020. The 1987 international agreement is known as the Montreal Protocol. In addition, the EC has introduced stricter timetables for phasing-out the refrigerants.

18.3 Alternatives

The most likely strategy to meet the phase-out is an increased use of ammonia, coupled with the introduction of newer halocarbon refrigerants, HFC's, either separately or in

18.4 Advice

Because of the uncertainties about the halocarbons, it is advisable to use ammonia for all plants of 7kW or greater. Although the CFC's are still available (l994) and the HCFC's are due to be available until early next century, it is now important to ensure that any refrigerant chosen will be available during the life of the plant. Both ammonia and the alternative refrigerants require skilled personnel to service them, so training is always necessary.

18.5 The future

If anything, the phase-out timetable is likely to be shortened. During the period of phase-out it is likely that the practical problems of using the newer refrigerants will be resolved. It is also possible however that some of the non-halocarbon fluids previously used will come back into use. It is therefore important to seek advice on the choice of refrigerant from a reputable refrigeration engineer.

19.0 SOME RELATED FACTS AND FIGURES

The following summary of facts and figures related to fish freezing is only presented as a guide. There will be differences between species, due to the effects of seasonal changes and due to processing methods. Even if the information were available, inexhaustible lists would have to be prepared to cover all eventualities. This obviously is not practical in a document such as this and when accurate information is required it should be obtained from the literature recommended in Selected Reading, (Appendix 1) or, in the case of freezing times, pilot scale laboratory tests

Freezing temperature of fish	about -1°C
	55% frozen at -2.2°C
	70% frozen at -5.0°C

Table 30 Heat to be removed when freezing white fish (kcal/kg)

Initial temperature	**Final temperature**	
(°C)	-30°C	-18°C
40	107.7	100.9
30	98.8	92.0
20	90.1	8.3
15	85.7	78.9
10	81.3	74.5
5	76.9	70.1

Specific heat and heat content of a fish (See Table 31 and Figure 49)

Table 31 The enthalpy and specific heat

Temperature (°C)	Enthalpy datum -40 °C (kcal/kg)	Specific heat (kcal/kg °C)
-40	0.00	0.44
-36	1.77	0.45
-32	3.60	0.47
-28	5.55	0.51
-24	7.67	0.55
-20	10.03	0.62
-16	12.69	0.72
-14	14.18	0.78
-12	15.84	0.87
-10	17.73	1.01
-8	19.99	1.27
-6	23.01	1.85
-4	28.05	3.61
-3	32.70	6.34
-2	42.16	15.68
-1	71.16	24.54
0	77.16	0.99
2	78.90	0.87
4	80.65	0.87
6	82.39	0.87
8	84.14	0.87
10	85.89	0.88
12	87.64	0.88
14	80.39	0.88
16	91.94	0.88
20	94.65	0.88
24	98.17	0.88
28	101.69	0.88
32	105.21	0.88
36	108.73	0.88
40	112.25	0.88

Note: Enthalpy is the heat content of the fish measured above an arbitrary datum of -40°C. The change in enthalpy between 10°C and -30°C will therefore indicate the amount of heat that has to be removed when freezing fish.

Specific heat is a measure of the heat that has to be added or subtracted to change the temperature of the fish by 1°C. Specific heat of the fish is a combination of sensible heat and latent heat at temperatures below 0°C.

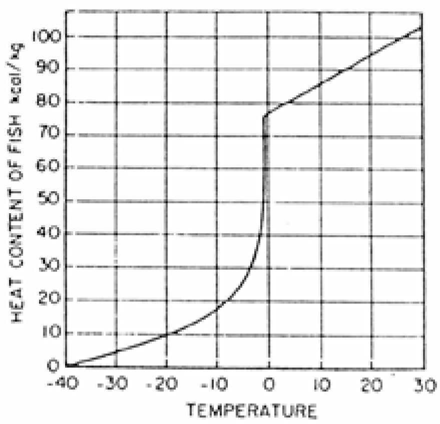

Figure 49 Heat content of lean fish based on a datum of -40°C

Thermal conductivity of fish (kcal m/h m^2 °C)

Unfrozen white fish at 0°C0.37 to 0.5
Frozen white fish at -1°C1.12 to 1.49
Frozen white fish at -30°C1.61

Density of white fish muscle (kg/m^3)

at 0°C1 054 at -20°C 966

Specific heat of white fish (kcal/kg deg C)

Unfrozen 0.9
Frozen 0.4

Stowage rates for frozen fish

	(m^3/ t)
Whole round fish 25 to 30 cm in length frozen in blocks	1.2
Whole round fish 30 to 100 cm in length frozen in blocks	1.02 to 1.12
Frozen whole fish 30 to 100 cm in length stored as single fish	2.08 to 2.5
Frozen whole fish 30 to 100 cm in length frozen in blocks with allowance for pallets, passageways etc.	2.0
Fillets.frozen in large blocks with allowance for pallets, passageways etc.	1.25 to 1.56
Frozen fillets in consumer packs in master carton with allowance for pallets passageways etc.	2.5

Yields from cod

Component	Ungutted weight (%)	Gutted weight (%)
Head	21	25
Guts	7 (5-8)	
Liver	5 (2-7)	
Roe	4 (1-7)	
Backbone	14	1
Fins and belly flaps	10	12
Skin	3	4
Fillets, skinned	36	43
Total	100	100

20.0 CONVERSION FACTORS

Metric and British Units
Metric, British and SI Units

Metric and British Units

	To obtain	from	multiply by the following
3.281	metres	Feet	0.3048
10.76	square metres	square feet	0.0929
35.32	cubic metres	cubic feet	0.0283
0.22	litres	UK gallons	4.546
0.264	litres	US gallons	3.785
2.205	kilogrammes	pounds	0.454
1.016	metric ton	ton	0.984
0.00142	kilogrammes per square metre	pounds per square inch	703
3.97	kilocalories	British thermal units	0.252
1.341	kiloWatts	horsepower	0.746
0.00156	kilocalories per hour	horsepower	642
0.001163	kilocalories per hour	kiloWatts	860
0.0003307	kilocalories per hour	tons of refrigeration (U. S.)	3.024
Multiply by the above	to convert	to	

Metric, British and SI Units

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

Mass

1 metric ton = 1 tonne = 0.984 tons (UK)

Pressure

1kg/m^2 = 1 kgf/m^2 1 Kp/m^2 = 9.807 Pascal (Pa) = 9.807 Newton/m^2 (N/m^2)

Energy

1 cal	= 4.187 Joules (J)
1kWh	= 3.6 Megajoules (MJ)
1 Btu	= 1.055 kilojoules (kJ)

Power

1 hp (U.K. or U. S.)	= 0.746 kW	= 0.746 Joules/second (J/s)
1 hp (metric)	= 0.736 kW	= 0.736 J/s
1 Watt (W)	= 1 J/s	

Heat flow rate

1 kcal/h	= 1. 163 J/s	= 1. 163 W
1 Btu/h	= 0.293 J/s	= 0.293 W

The units of measurement used throughout the text are the conventional metric units supplemented on a few occasions by the British units. However, for the convenience of the readers who are familiar with the new International System of Units, their conversion factors into the conventional units, and *vice versa,* are given below for all the units that are not identical in the systems and that have been used in the text.

1. SELECTED CONVENTIONAL UNITS

Length

1 metre (m) = 3.28 ft; 1 foot (ft) = 0.305 m

Area

1 square metre (m^2) = 10.76 ft^2; 1 square foot (ft^2) = 0.093 m^2

Volume

1 cubic metre (m^3)=35.314 ft3; 1 cubic foot (ft^3) = 0.028 m^3

Weight

1 kilogramme (kg) 2.205 lb; 1 pound (lb) = 0.454 kg

1 tonne (t) = 1000 kg = 2205 1b = 0.984 UK ton = 1.102 short ton

Density

1 kilogramme per cubic metre (kg/m^3) = 0.0624 1b/ft^3

1 pound per cubic foot (1b/ft^3) = 16.03 kg/m^3

Velocity

1 metre/second (m/s) = 196.8 ft/min;

1 foot/minute (ft/min) = 0.00508 m/s

Energy (work, heat)

1 kilocalorie (kcal) = 3.968 Btu = 0.001163 kWh

1 British thermal unit = 0.252 kcal = 0.000289 kWh

Power (heat flow rate)

1 horsepower (hp) = 0.7457 kW

1 kilocalorie per hour (kcal/h) = 3.968 Btu/h = 1. 163 W

1 British thermal unit per hour (btu/h) =0.252 kcal/h = 0.2931 W

1 ton of refrigeration = 3024 kcal/h = 288000 Btu/24h

Specific heat capacity, mass basis

1 kilocalorie per kilogramme, degree Celsius (kcal/kg° C) = 1 Btu/ lb°F = 4.187 kJ/g °C

1 British thermal unit per pound, degree Fahrenheit)Btu/lb°F 1 kcal/kg°C = 4.187 kJ/g°C

Heat transfer coefficient:

1 kilocalorie per square metre, hour, degree Celsius (kcal/m^2h°C) = 0.205 Btu/ft^2h°F = 1.163 W/m^2°C

1 British thermal unit per square foot, hour, degree Fahrenheit

(Btu/ft2)h °F = 4.882 kcal/m^2h°C = 5.678 W/m^2°C

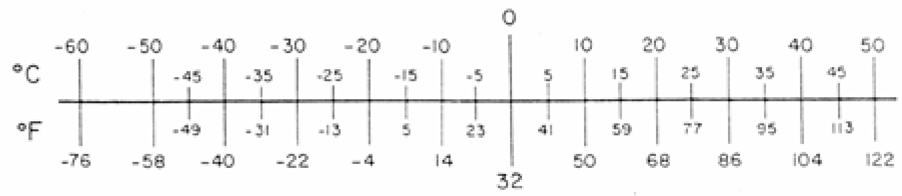

Figure 50 Temperature

2. SELECTED INTERNATIONAL SYSTEM UNITS

Energy (work, heat)	1 kilowatt hour (kWh) = 860 kcal = 3412 Btu
Power (heat flow rate)	1 kilowatt (kW) = 1.34 hp
	1 watt (W) = 0.860 kcal/h = 3.412 Btu/h
Specific heat capacity, mass basis	
	1 joule per gramme degree Celsius (Jg/°C) =
	0.239 kcal/kg°C = 0.239 Btu/Ib°F
Heat transfer coefficient	
	1 watt per square metre degree Celsius (W/m^2°C) =
	0.860 kcal/m^2h°C = 0.176 Btu/ft^2h°F

APPENDIX 1

SELECTED READING

The following list contains literature without indicating priority which can be utilised for further studies of the topics discussed in this technical paper.

Aitken,A *et al.* (eds) 1982	Fish Handling and Processing. Second Edition, Edinburgh, Her Majesty's Stationery Office, £10.
FAO,1975	Ice in Fisheries. FAO Fish Rep. (59) Rev. 1 (issued also in French and Spanish), 57p.
FAO/WHO	Food Standards Programme, Codex Alimentarius Commission, Recommended international code of practice for fresh fish. Rome, FAO, (CAC/RCP 9-1976) : (issued also French and Spanish)
FAO/WHO, 1980	Recommended International Codes of Practice for Frozen Fish. Rome, FAO, (CAC/RCP 16-1978) : (issued also in French and Spanish)
International Association of Refrigerated Warehouses	Energy Conservation Manual. Washington DC, International Association of Refrigerated Warehouses
International Association of Refrigerated Warehouses	Operation Manual. Washington DC, International Association of Refrigerated Warehouses
International Institute of Refrigeration	Recommendations for the Processing and Handling of Frozen Foods. Recommendations pour la Préparation et la Distribution des Aliments Congelés. Paris, International Institute of Refrigeration, 3rd ed.
International Institute of Refrigeration	Guide to Refrigerated Storage. Guide de l'Entreposage Frigorifique .Paris, International Institute of Refrigeration.
International Institute of Refrigeration, 1979	Recommendations for Chilled Storage of Perishable Produce. Conditions Recommandées pour la Conservation des Produits Périssables à l'État Réfrigéré. Paris, International Institute of Refrigeration
Jenkins, CH 1968	Modern Warehouse Management. New York, McGraw-Hill Book Company
Myers, M 1981	Planning and Engineering Data. 2. Fresh Fish Handling. FAO Fish. Circ., (735), 64p.

APPENDIX 2

SPECIFICATION FOR SENSORY EVALUATION OF RAW COD

by Torry Research Station, Aberdeen, UK (Now Food Science Laboratory, Torry)

General appearance (5 marks)	**Score marks**
Eyes perfectly fresh, convex black pupil, translucent cornea; bright red gills, no bacterial slime, outer slime water white or transparent; bright opalescent sheen, no bleaching	5
Eyes slightly sunken, grey pupil, slight opalescence of cornea; some discolouration of gills and some mucus; outer slime opaque and somewhat milky; loss of bright opalescence and some bleaching	3
Eyes sunken; milky white pupil, opaque cornea; thick knotted outer slime with slime bacterial discolouration	2
Eyes completely sunken pupil; shrunken head covered with thick yellow bacterial slime; gills showing bleaching or dark brown discolouration and covered with thick bacterial mucus; outer slime thick yellow-brown; bloom completely gone; marked bleaching and shrinkage	0
Flesh Including Belly Flaps (5 Marks)	
Bluish translucent flesh, no reddening along the backbone and no discolouration of the belly flaps; kidney bright red	5
Waxy appearance, no reddening along backbone, loss in original brilliance of kidney blood, some discolouration of belly flaps	3
Some opacity, some reddening along backbone, brownish kidney blood and some discolouration of the flaps	2
Opaque flesh, marked red or brown discolouration along the backbone, very brown to earthy brown kidney blood, and marked discolouration of the flaps	0
Odours (10 marks)	
Fresh seaweedy	10
Loss of fresh seaweediness, shellfish	9
No odours, neutral	8
Slight musty, mousy, garlic-peppery, milky or caprylic and like	7
Bready, malty, beery, yeasty	6
Lactic acid, sour milk, or oily	5
Some lower fatty acid odours (for example acetic or butyric acids), grassy, 'old boots', slightly sweet, fruity or chloroform-like	4
Stale cabbage water, turnipy, 'sour sink', wet matches, phosphene-like	3
Ammoniacal (trimethylamine and other lower amines) with strong ;byre-like' (o-toluidine)	2
Hydrogen sulphide and other sulphide odours, strong ammoniacal	1
Indole, ammonia, faecal, nauseating, putrid	0
Texture (5 marks)	
Firm, elastic to the finger touch	5
Softening of the flesh, some grittiness	3
Softer flesh, definite grittiness and scales easily rubbed off the skin	2
Very soft and flabby, retains the finger indentations, grittiness quite marked and flesh easily torn from the 1 backbone	1

APPENDIX 3

WAREHOUSE QUALITY ASSURANCE AUDIT - SANITATION AND HOUSEKEEPING

1. Outside grounds

1. Are there any rodent harbourage such as tall weeds and grass, junk piles, rubbish, etc?
2. Is waste disposal adequate to minimise attraction of insects, rodents and birds?
3. Are there excessive trash and scrap accumulations?
4. Is there any evidence of rodent activity?
5. Is the dock area properly maintained?
6. Is there any evidence of birds nesting around dock areas?
7. Is outside drainage satisfactory?
8. Are there any other conditions which may contribute to contamination of product being loaded or unloaded?

2. Storage areas

1. Is product stored away from walls to permit inspection and pest control?
2. Are floors and walls cleanable and in good repair?
3. Is product properly stored on pallets and off the floor?
4. Is lighting adequate to permit clean-tip and inspection?
5. Is there any evidence of spilled merchandise?
6. Are floors and floor wall junctions clean?
7. Is there any evidence of contamination of stored goods by insect, rodents, dripping water etc?
8. Is there any evidence of insects, rodents or other vermin?
9. Are chemicals or other non-food items stored separately to prevent contamination of food?
10. Is there any evidence of mould or objectionable odours in the storage areas?
11. Is rubbish disposal adequate?
12. Are floors cleaned as pallets are removed?
13. Are lights in exposed food storage areas protected with safety shields?

3. Wash-room and locker facilities

1. Are wash-rooms and locker-rooms properly cleaned?
2. Are wash-room facilities in good repair?
3. Are hot water, soap and clean towels available?
4. Are 'have you washed your hands ... ?' signs posted?
5. Are wash-rooms provided with self-closing doors which do not open directly into food storage rooms?
6. Is there any evidence of insect or rodent activity?

4. Lunch-room

1. Is the lunch-room properly cleaned?
2. Is the lunch-room segregated from food storage areas?
3. Are there adequate rubbish bins available?
4. Is there any evidence of insect or rodent activity?

5. Office areas

1. Are office areas properly cleaned and maintained?
2. Is there any evidence of insect or rodent activity?

6. Employee practices

1. Is there any evidence of smoking or tobacco-chewing in warehouse areas?
2. Is there any evidence of careless employee practices which could contribute to product damage or spoilage?
3. Do employees eat and drink only in designated areas?
4. Do employees dispose of trash properly?
5. Are employees properly attired when handling exposed food products?
6. Is there any other evidence of potential contamination of food by employees?

7. Shipping

1. Are railway trucks and transport vehicles inspected, cleaned and repaired or rejected if necessary prior to loading?
2. Are trucks and vehicles carefully loaded and unloaded to prevent damage to product?
3. Are loading areas properly protected to prevent contamination prior to unloading?
4. Are incoming shipments of product inspected for contamination prior to unloading?
5. Are contaminated shipments properly handled or rejected?
6. Is there any evidence of contamination of product or potential avenues of contamination in loading or unloading operations?
7. Are frozen and refrigerated products handled so as to prevent thawing or warming up?

8. Storage

1. Are the storage temperatures satisfactory?
2. Are recording thermometers used to record storage temperatures? Are they checked for accuracy?
3. Is a system for proper stock rotation in effect?
4. Are food products properly protected during defrosting of cold stores?

9. Handling of damaged goods

1. Are damaged goods properly handled to prevent spoilage?
2. Is there a special area maintained for reworking damaged merchandise?
3. Is this area properly maintained to prevent contamination by insects or rodents?

10. Cleaning operations

1. Is a cleaning programme and schedule available?
2. Are cleaning operations carried out so as to prevent product contamination with dust, dirt, chemicals etc?
3. Is equipment for cleaning adequate?
4. Are proper cleaning materials used?
5. Are pallets inspected for cleanliness to prevent contamination of product?
6. Is cleaning of materials handling equipment a part of daily servicing procedure?

11. <u>Pest control</u>

1. Is the store serviced by a pest exterminator? Who?
2. How frequently is the store serviced?
3. Is a list of pest control chemicals used available and on file at the plant?
4. Are proper chemicals used? What materials are used?
5. Does the exterminator prepare a report form after each visit?
6. Are the store and the exterior areas adequately covered with traps and bait boxes for proper control of rodents?
7. Is any pest control work done by the store personnel?
8. Is rodent proofing adequate?
9. Is pest control adequate?
10. Are pest control chemicals properly stored?
11. Is a map of rodent bait stations available?

APPENDIX 4

SAFETY INSTRUCTIONS FOR COLD STORES

New employees should read these instructions carefully. They have been prepared for your safety and to ensure that you remain able to support yourself and your family.

Experienced employees, should read these instructions fully as a reminder and advise your newer colleagues on how to best obey them. By drawing their attention to the dangers involved, you are playing an important part in the fight against industrial accidents and newcomer's lack of knowledge of the risks involved in the daily work

1. Fire protection

There is fire-fighting equipment placed at various locations in all departments. It is the departmental manager's responsibility to see that it is correctly placed, of the correct type and in perfect order. It is the responsibility of every employee to know where it is and how and when to use it.

Fire-fighting equipment must not be used for any other purpose and, if used, the responsible manager must be informed.

2. Fire prevention

Welding and gas cutting in any place other than a permanently allocated area may only be carried out after permission has been given by the manager or foreman responsible for the safety of the area in question.

All welders are obliged to follow the standing instructions regarding fire prevention and welding permission may only be given be persons with the appropriate authority.

Welding in a cold room, chill room or on ammonia pipes must only be carried out when a recognised member of the fire fighting team is present with the appropriate equipment.

3. Fire alarms

In the case of a fire, sound the alarm by using the local equipment, call the fire brigade and use the local fire appliances until the arrival of the fire brigade.

4. Reports of accidents, in-juries and damage

All accidents, whether they involve permanent injury or not, personal injuries and damage to equipment, must be reported at once to the foreman responsible for the area in question.

The foreman is then required to inform the supervisor, who will make an investigation and report to the plant manager.

5. Reports of 'near misses'

When (a 'near miss') an accident is narrowly avoided or a dangerous situation occurs, give others the benefit of your experience by reporting the situation in the same way as an accident. Tell the foreman in charge should report such incidents to the operation supervisor. In this way everyone can help to make the plant a safer place to work.

6. First aid equipment

The supervisor is responsible for making sure that the appropriate first aid materials are available at each working area, securely housed, clearly marked and permanently placed.

7. General safety requirements

Smoking is strictly forbidden, where signs are placed to that effect.

Intoxication at work is forbidden. Consumption of any alcoholic beverage is forbidden. Consumption of drugs is forbidden.

Suitable footwear is essential.

8. Good order and tidiness

Good order and tidiness are an essential part of accident prevention. Every employee should keep his place of work, changing room, wash-room, shower, toilet, etc. tidy.

Make yourself acquainted with your surroundings and the equipment you use. Note the locations of fire fighting equipment and the first aid box and find out which of your colleagues has first aid or fire fighting knowledge.

Follow the advice of your foreman carefully, his knowledge and experience can be of considerable advantage to you.

Anyone who works, no matter how frequently, in cold rooms should be acquainted with the safety precautions to prevent personnel being locked in. It is essential to know how cold store doors are opened manually from the inside and to be able to do this in darkness. The location of the 'shut-in' alarm should also be memorised.

Gangways and areas around doors must be kept clear at all times and trucks, pallets, boxes etc should be left in their proper place.

Pick up and replace any article that has been dropped and pay particular attention to spilled oil and other liquids. Some of the most serious industrial accidents are caused by simple faults.

Pay particular attention to inflammable materials.

Faults in machines, trucks, tools and leaks in pipes or ducts which cannot be rectified at once by the observer should be reported immediately to the foreman concerned.

9. Hygiene

Keep your workplace, wash-room, shower and toilet clean and use the facilities available. Cleanliness promotes health and comfort. Play your own part in maintaining healthy conditions and do all you can to encourage others to do the same.

10. Protective devices and guards

Fixed guards on machines and tools must not be removed except for repairs and maintenance by authorised personnel, when they must be replaced before restarting the machine.

Protective goggles, gloves and other clothing are available for hazardous jobs such as grinding, welding, etc and should be used at all times.

11. Machines

As a general rule, only those workers who are trained to use a particular truck or machine as part of their duties are allowed to operate them. The person using a truck or machine is responsible for ensuring that the appropriate safety regulations are followed.

Except for a person being lifted on a properly constructed safety platform to perform a duty, no one is to travel as a passenger on a forklift truck.

Batteries being charged give off an explosive and inflammable gas. Smoking or naked flames are forbidden adjacent to battery charging points.

12. Repairs, cleaning and greasing

Only properly authorised personnel may repair and maintain machinery and trucks. Faults in machines and trucks must be rectified immediately.

Forklift trucks must always be operated a safe speed and a constant watch must be kept in the direction of travel. The forks should always be kept lowered when driving an unloaded truck. Whenever a load is lifted, be especially careful about others who may pass under the load.

13. Safety instructions for ammonia

All personnel who work with ammonia must be instructed in the proper handling of containers and equipment and given instructions in the use of breathing apparatus, gas masks, protective clothing and goggles.

The nearest showers, drinking fountains and water taps should be known by all who may be exposed to an ammonia leak, as a quick and thorough rinsing is the first requirement if ammonia comes in touch of any part of the body.

14. Welding and soldering

When welding or soldering ammonia pipes and vessels, every precaution must be taken as certain mixtures of ammonia gas and air could ignite. It is therefore important to flush out pipes and vessels by blowing them through with air or inert gas.

Pipes and vessels which have contained refrigerant may be expected to have residual oil in them after purging of refrigerant. It is important also to remove oil before welding as this too can cause fire and explosions.

15. Refrigeration plant

Charging with refrigerant and start-up of a plant must not take place until all safety valves, blow-off pipes, bursting disks, high pressure cut outs and pressure gauges are connected and brought into service.

If it is necessary to warm refrigerant cylinders to increase the rate of charging, hot water should be used, never an open flame.

The marking and coding of refrigerant cylinders should also be checked and double-checked before adding or extracting refrigerant. Different types 'of refrigerant and other industrial gases must never be mixed or their cylinders contaminated. Operators must never leave open oil drain valves unattended. He must also dispose of drain oil.

16. Special standing instructions

It is the specific responsibility of the plant manager to ensure that the operations and work carried out under his authority conform to the various statutory requirements of any factory's act, local utility board's regulations, the company's own instructions and the requirements of the local chief fire officer.

The plant manger should cheek the fire fighting equipment under his control at least once a month and satisfy himself that sufficient personnel have the necessary knowledge of fire fighting and alarm procedures.

An exercise in fire drill with all personnel should be conducted at least once a year and a yearly discussion and contact with the local fire office should be made as a matter of routine.

APPENDIX 5

BASIC CHECK LIST FOR PLANNING REFRIGERATED WAREHOUSE

Type of operation

Type of merchandise
Type of packaging
Capacities
Turnover, number of items and turnover for each of them
Maximum intake and despatch
Bulk storage
Break-up

Handling equipment

Pallet sizes and weights
Type of forklift trucks and pedestrian trucks
External transport, railroad, containers, etc.

Temperatures and climatic conditions

Ambient climatic conditions
Temperature of arriving products
Storage temperatures
Special requirements

Services

Packing rooms
Inspection rooms
Offices, locker-rooms, canteen
Parking areas Changing stations, workshop, pallet store
Site information
Site plan
Levels
Ground conditions
Access roads
Rail siding
Water supply
Electricity supply
Fuel supply
Effluent drainage

Planning restrictions

Height
Distance from boundaries
Architectural features
Traffic

Law requirements

Sanitary requirements
Fire precautions
Labour facilities

Existing facilities

Expansions planned

Storage
Services

Timing

When shall store be in operation?
When will decision be taken about engineering and execution?

Special demands

Local taxes and tax exemptions
Insurance requirements
Design and engineering requirements
Installation requirements
Commissioning Training requirements
Initial operation
Direct labour requirements
Indirect labour requirements
Management and administration requirements