COLD CHAIN IN SEAFOOD INDUSTRY

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Abstract: When seafood is freshly caught eating quality is high, but over time quality will deteriorate and eventually will become unsuitable for consumption. Maintenance of the cold chain and careful handling are a fundamental part in minimizing seafood spoilage. The cold chain in seafood industry is a temperature chain and begins once the seafood is caught. From the quality and regulatory perspective fresh seafood means that has been stored at 0°C and for frozen seafood it means –18°C or colder (from the sea to the consumer). The cold chain is broken every time the temperature of the seafood rises above 1°C. Fluctuations in the cold chain increases quality loss, these losses cannot be reversed by any means after the event. There are many avoidable and unavoidable occurrences that cause fluctuation in the cold chain. Good chilling and/or freezing practices on board harvest vessels are a condition *sine qua non* for maximizing the best possible quality of all seafoods. Best practices on seafood handling and the minimization of temperature fluctuations are paramount for seafood distributed under refrigeration (i.e., chilled and/or frozen) to maintain its quality and maximize its shelf–life. The present chapter addresses some of the developments in seafood cold chain under four mainly headings: i) cold chain in seafood industry; ii) selected aspects of refrigeration (chilling and freezing) process (including equipment and storage conditions); iii) safety and shelf–life issues in seafood cold chain; iv) regulation and legislation.

1. COLD CHAIN IN SEAFOOD INDUSTRY

1.1. Introduction

Fish is an exceptionally important constituent of the human diet and an global industry exists to provide a huge variety of consumer products in which fish is the only nd/or major component. These offerings range from whole fish, large and small, to pieces of fish such as cuts and fillets, to canned fish in a multitude of forms, to dried and cured products, to fish oils and extracts, to frozen portions and complete meals through to reformed and gelled products. The variety even within one product type is extensive and the range of species used as food runs well into the thousands. Each of these variations and combinations presents a huge matrix of possibilities, opportunities and problems.

Fish technologists and scientists have been endeavoring to draw some general rules from observation and experimentation on fish and fish products to control and predict their properties under a vast variety of circumstances. The two main driving themes for these efforts have been in safety and quality – expressed mostly in terms of measurable properties.

Seafood quality, including safety, is a major concern facing the seafood industry today and also, is one of the most abused words in food science and especially fisheries and aquaculture research. A number of surveys have shown that consumer awareness about quality of their food is increasing. Fish and fishery products are in the forefront of food safety and quality improvement because they are among the most internationally traded food commodities. It has been used to describe a wide range of characteristics of the fish, from the flesh and skin, to how well it can be processed to the impact of the fish on the environment.

Quality deterioration of seafoods may originate from poor slaughter process, handling of raw materials during processing and post–harvest periods. Freshness makes a major contribution to the quality of seafoods and the contribution of cold chain during the seafood chain is crucial to guarantee its freshness and overall quality.

1.2. The seafood supply chain

Firstly, in any product supply chain there are points at which potential improvements may be made. However, to obtain real benefits, the supply chain must be viewed in its entirety. Thus, there may be little to be gained by controlling the quality attributes of raw materials if inappropriate freezing and storage conditions are employed during processing and distribution.

Generally, better raw materials tend to continue better during freezing and frozen storage. The processes occurring during the freezing and frozen storage of fish products are complex. A number of measurement techniques may be employed in order to monitor these changes. However, the significance of the measured changes must always be related to observable sensory changes and ultimately to consumer response.

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The seafood supply chain differs in relation to the species and product type. The wild caught fresh seafood products (seafood in ice at about 0°C) and frozen seafood products have a different supply chain structure.[2] The current chain structure dealing with fresh and frozen fish can be described in general with the following steps in Figure 1 and also are listed in Table 1.

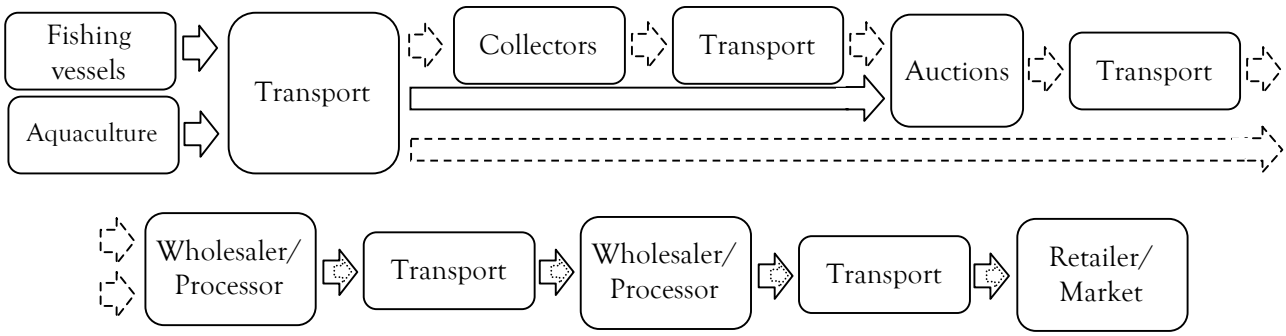


Figure 1. Types of fresh and frozen seafood chain in the fish industry.
Arrows show the product flow (dashed arrow: frozen seafood chain)[2]

Traditionally, every single step competes with other steps in the chain in order to survive. For that reason every step in the chain after the vessel step considers it must have its own buffer store to ensure it is possible to provide product for its customers. In this sense, it is evident that the cold chain at each step should be a priority in order to ensure the quality of the fish. [2]

Table 1. Processes in fresh and frozen seafood chains

Step	Processes in the chain
Fishing vessels for fresh fish	Catch, gut, bleed, wash, sort in species, size grade, weigh, icepack, store and unload
Fishing vessels for frozen fish	Catch, gut, bleed, wash, sort in species, size grade, weigh, freeze, store and unload
Collectors	Size grade, weigh, icepack, store and bring to auction
Auctions	Store and auction (sell)
Wholesalers/processors	Size grade, process, weigh, icepack, store and sell. There can be one or several steps of wholesalers/processors in a fish supply chain.
Transport companies	Load, store and unload
Retailers/markets	Process, weigh, icepack, store and sell

Adapted from Frederiksen[2]

Refrigeration processes are therefore of capital importance in the food chain, especially in the case of fresh aquatic food products. Indeed, more than 50% of foodstuffs in developed countries (with 1.2 billion inhabitants) are commercialized under refrigeration conditions. These figures offer an idea about the economic importance of the international trade of aquatic food products, and the marketing opportunities that may emerge if it becomes possible to improve the quality, shelf life and added value of such fresh products. [1 2 3]

As fish has a very short shelf–life compared with other products there are very high requirements placed on the chain for it to be effective. In general the high–value fresh fish market demands fresh fish at a maximum of 8–9 days from catch and the demand on performance of the logistics system is very dependent on the distance between the harbor for unloading the fish and the retailer/end user in the chain. The transport system for fresh fish has become more and more effective. Transport is by refrigerated trucks so the fish products are in good condition when they arrive. [2]

The first part of the supply chain for fish fillet products involves catching the fish, removing their heads and guts, skinning and filleting followed by freezing. These stages are referred to as the primary process, whereby a frozen raw material is produced. This frozen raw material may either be sold to consumers 'as is', for example as bags of IQF fillets, or converted by secondary processing into, for example, coated fish products such as fish fingers and coated fish steaks. The types of supply chain for frozen fish may be distinguished from each other by where the latter stages of the primary processing operation take place, in particular where the filleting, skinning and final freezing are carried out. Thus, there are either land–based or sea–based operations. [5]

A *sea–based operation* requires a factory ship that has the capability to catch, process and freeze the fish. All of the primary processing for 'frozen at sea' fish may be carried out only a short time after catching. This eliminates the requirement for storage of the catch in boxes containing ice. For *land–based processing* other factors become more significant. In a typical land–based process the fish are caught and the guts and sometimes the heads are removed. The fish are then stored on ice until the vessels return to shore. The time that fish are stored on ice, therefore, is dependent upon the time that the vessels are at sea. A trawler may be at sea for several days before sufficient fish are caught. Therefore, it is possible that fish may have been stored for several days on ice prior to being landed. In addition, fish caught early on in the catching cycle will be stored for longer on ice than those caught towards the end of the time at sea. Clearly fish which have experienced different lengths of time in ice storage may ultimately be processed together. This may have implications for the consistency of the raw material. [5]

A third, hybrid, supply chain also exists. In this supply chain only part of the primary processing is carried out at sea. The fish have the guts and in some cases the heads removed. The headed and gutted fish are then frozen, often with a water glaze, and typically in a vertical plate freezer. In this way many fish can be frozen together, surrounded by ice. The fish 'block' can then be easily wrapped in plastic and packed into cardboard cartons. The frozen fish are then transported to land where they are thawed, filleted, skinned and re–frozen. Because two freezing stages are involved in this supply chain the resulting raw material is often referred to as double or twice frozen. This supply chain is most commonly used for Alaska pollack.[5]

Within each of the supply chains described there are stages that are critical to the final quality of the product. Then there are a necessity to improve the supply chain management (SCM) i.e., the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole.

1.2.1. Catching and onboard storage

Accordingly to their habitat fish are divided two broad groups, demersal (live at or around the bottom) and pelagic (living at different depths on the water column). In general terms, fish morphology is adapted to strive differently accordingly to their habitat. The shape of the fish is obviously important when it comes to the design of processing equipment, and how is handled and stored on board.

However, equally important are the biological variables affecting it prior harvest condition (such as gonad stadia, stress, seasonal diet, fat content, etc) as they affect the economic value and eating quality of the species concerned.

On the other hand, the farming of fish in salt, brackish or fresh water is a growth industry in many parts of the world and the safety and quality procedures are the same of the traditional catching.

Fish, crustaceans and mollusks deteriorate rapidly after death due to the effects of a variety of biochemical and microbial degradation mechanisms. Once fish has been caught, on-board storage conditions exert a strong effect on the quality of manufactured fish products and hence on their commercial value. Accordingly, optimal combinations of both hygienic handling practices and refrigeration are key parameters to be considered with a view to guaranteeing seafood safety and wholesomeness. In this sense, in order to preserve the greatest proportion of a fish catch in an acceptable manner several on-board handling systems, such as storage in conventional ice, flake-ice, slurry ice, "slush" ice, chilled sea water (CSW), refrigerated seawater (RSW), in combination with the addition of chemicals, have been proposed. Such chilling methods have traditionally made it possible to slow down both microbial degradation mechanisms and the autolytic breakdown pathways in aquatic food products. [114,123]

Their application is normally based on the most cost effective for particular types of vessel, types of target species, facilities in the landing sites and available technologies.

1.2.2. Processing (chilled or frozen)

The main factors that determine frozen fish quality can be grouped into three main areas: pre-freezing, the freezing process and frozen storage/product distribution. These main areas will be general to the processing of any fish. It should also be borne in mind that one of the least well-defined areas in any supply chain is the consumer handling stage, and it is during this phase that potentially severe thermal abuse may occur. Indeed, thermal abuse may not be confined to the frozen state but may extend to poor cooking as wel. [100]

Chilled temperatures much below 0°C are to be avoided because of the detrimental effect of slow freezing on the texture of the flesh. The most satisfactory storage temperature is –2°C which results in an extension of the shelf life of white fish by several days (citation?). The success of this process, known as super-chilling, requires accurate temperature control. Apart from the technical problems of maintaining this temperature exactly, a major disadvantage is that the material does become partially frozen and requires thawing out before processing can start. However, to avoid excessive wastage of ice, a temperature above the freezing point of water, but below 5°C, is probably best to aim for. It is important to stress that for efficient cooling the ice should surround the fish and not be used just as a cover. [114]

1.3. Principles of refrigeration

The basic principles of vapor compression refrigeration were established in the 19th century, and this form of refrigeration is almost universally adopted nowadays. At its simplest, such a mechanical refrigeration system has four interlinked components: an evaporator, a compressor, a condenser and an expansion valve (Figure 2). Components of refrigerators are frequently constructed from copper as the low thermal conductivity allows high rates of heat transfer and high thermal efficiencies. A refrigerant (Table XX) circulates between the four elements of the refrigerator, changing state from liquid to gas, and back to liquid as follows: *i*) In the evaporator the liquid refrigerant evaporates under reduced pressure, and in doing so absorbs latent heat of vaporization and cools the freezing medium. This is the most important part of the refrigerator; the remaining equipment is used to recycle the refrigerant; *ii*) Refrigerant vapor passes from the evaporator to the compressor where the pressure is increased; *iii*) The vapor then passes to the condenser where the high pressure is maintained and the vapor is condensed; *iv*) The liquid passes through the expansion valve where the pressure is reduced to restart the refrigeration cycle. The cold vapor is then fed back to the compressor to complete the cycle. [74,78,109,114]

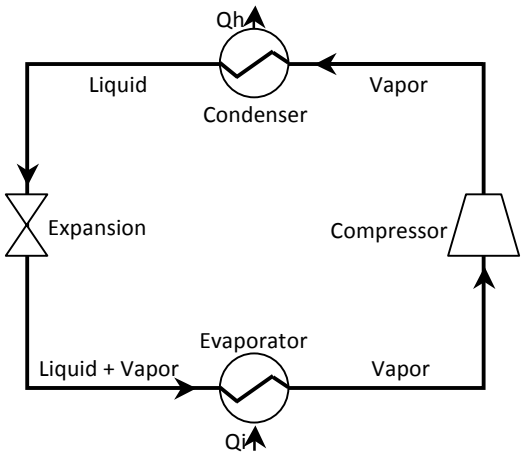


Figure 2. The basic vapor compression refrigeration circuit
(Qi, heat absorbed from product; Qh, heat rejected to environment).[74,109,114]

Whilst heat is extracted from a process at the evaporator, the extracted heat plus the heat equivalent of the compression energy must be rejected at the condenser. This means that any refrigeration device must reject a quantity of heat, which is greater than the heat energy removed from the product or space being cooled. The energy used by a vapor compression refrigeration machine depends on its design, but generally the larger the temperature difference between evaporator and condenser, the greater the energy used in the compressor for a given amount of cooling duty. Also, the greater this temperature difference is, the smaller will be the refrigerating capacity of the system. [74,109,114]

1.3.1. Chilling and freezing

One of the main preoccupations of the food industry is to improve the conservation technologies of perishable foods to reach a final product with optimal quality. Among various methods currently used, the most important are those based on the action of low temperatures which preserves taste and nutritional value. [57,68,69,70,71]

Chilling, freezing and cold storage is an efficient method of seafood preservation but it must be emphasized that it does not improve product quality. The final quality depends on the quality of the seafood at

the time of freezing as well as other factors during freezing, cold storage and distribution. Freezing and frozen storage can give a shelf life of more than one year if properly carried out. [57,63,72]

1.4. Refrigerant fluids and environment

Until the early 1990s, the choice of refrigerant fluids for use within the closed vapor compression refrigeration cycle was a matter of little concern to equipment users. Unfortunately, it is now realized that those fluids developed over the years for efficiency and for safety have unexpected environmental side effects when they are released into the atmosphere. Ozone depletion and global warming are two quite separate environmental problems. The ozone layer, which protects the surface of the earth from excessive ultraviolet radiation, is damaged by the emission of stable chemicals containing chlorine or bromine. [74,109]

The important properties of refrigerants (Table 2) are as follows: *i*) a low boiling point and high latent heat of vaporization; *ii*) a dense vapor to reduce the size of the compressor; *iii*) low toxicity and non-flammable; *iv*) low miscibility with oil in the compressor; *v*) low cost. [74,78,114] An ideal vapor-compression refrigerant has a vapor pressure slightly above atmospheric at the temperature of the evaporator, so that air cannot enter the system in the event of a leak. At the same time the curve of vapor pressure against temperature should be shallow; the steeper the curve, the higher the pressure in the condenser and the more expensive the equipment needed to contain the refrigerant safely. A good refrigerant has a low specific volume (m^3 kg^{-1}) in the vapor phase and a high enthalpy of vaporization (kJ kg^{-1}).

Table 2. Properties of refrigerants. [78,109]

Refrigerant		Boiling point (°C) at 100 kPa	Latent heat (kJ kg^{-1})	Toxicity	Flammability	Vapor density (kg m^{-3})	Oil solubility
Number	Formula						
11	CCl_3F	23.8	194.20	Low	Low	1.31	Complete
12	CCl_2F_2	−29.8	163.54	Low	Low	10.97	Complete
21	$CHCl_2F$	−44.5	254.20	Low	Low	1.76	Complete
22	$CHClF_2$	−40.8	220.94	Low	Low	12.81	Partial
717	NH_3	−33.3	1,328.48	High	High	1.97	<1%
744	CO_2	−78.5	352.00	Low	Low	60.23	<1%

The refrigerant should be chemically and thermally stable, and must not attack any of the materials used in the system, including seals and compressor lubricants. It should ideally also be environmentally benign, non-flammable and non-toxic. In practice, the choice of vapor-compression refrigerant is almost entirely confined to ammonia or one of a number of halogenated organic compounds (CFCs, HCFCs and HFCs) (see Table 3).[109]

Ammonia is cheap and has a good thermodynamic property, and also, an excellent heat transfer properties and is not miscible with oil, but it is toxic and flammable, and causes corrosion of copper pipes. Carbon dioxide is nonflammable and non-toxic, making it safer for use for example on refrigerated ships, but it requires considerably higher operating pressures compared to ammonia. Halogen refrigerants (chlorofluorocarbons or CFCs) are all non-toxic and non-flammable and have good heat transfer properties and lower costs than other refrigerants. Partially halogenated CFCs (or HCFCs) are less environmentally harmful and existing HCFCs are being temporarily substituted for CFCs, but these too are to be phased out before the first decades of the new century.

Newer, ozone-friendly HCFCs are being developed and are likely to become important refrigerants: *i*) CFCs, fully halogenated chlorofluorocarbons, use of which is being phased out as rapidly as possible; *ii*) HFCs, hydrofluorocarbons, which contain no chlorine and as a result have no damaging effect on the ozone layer. Unfortunately there do not appear to be sufficient of these compounds with the appropriate properties to replace all of the CFCs in current use. The HFCs, for example HFC-134a, are all new products; *iii*) Fluorocarbons. These contain only carbon and fluorine; a few of these compounds are available and have no effect on the ozone layer, for example FC-14; *iv*) HCFCs, hydrochlorofluorocarbons, which do contain chlorine but are not fully halogenated. HCFCs do have an adverse effect on the ozone layer, but this is very much less than that of the CFCs. Certain HCFCs, notably HCFC-22, were already known and widely used before the ozone depletion theory was first proposed; others, e.g. HCFC-123, are new. HCFCs and HFCs are sometimes collectively referred to as HFAs, hydrofluoro-alkanes.[114]

The developed world ceased the production of ozone-depleting CFCs during the 1990s. This was made possible by the substitution of less environmentally harmful HCFCs. The HCFCs themselves are expected to be phased out by 2010–20, if not earlier, and in some applications there are no known effective substitutes at present available. [74,109] Main refrigerants that are now used are Freon-22 and ammonia, with the possibility of future use of propane. However, the latter two in particular are more expensive and could cause localized hazards, thus requiring additional safety precautions and training for equipment users. [74,78,109]

Table 3. Refrigerants.[109]

Refrigerant	R number	Class	Formula	Temperature range, °C	Applications
Ammonia	R 717	Ammonia	NH_3	−60 to +10	Medium-size and large refrigeration systems; all compressor types
Trichlorofluoromethane	R 11	CFC	$CFCl_3$	−10 to +20	Chilled water; turbine compressors
Dichlorofluoromethane	R 12	CFC	CF_2Cl_2	−40 to +20	Refrigeration and heat pumps; all compressor types
Azeotrope R 12/R 152a	R 500	CFC	–	−40 to +20	Refrigeration and heat pumps; reciprocating and screw compressors
Azeotrope R 22/R 115	R 502	CFC	–	−60 to 0	Refrigeration; reciprocating compressors
Chlorodifluoromethane	R 22	HCFC	CHF_2Cl	−70 to +20	Widely used for refrigeration; all compressor types
Tetrafluoroethane	R 134a	HFC	$C_2H_2F_4$	–	More environment-friendly replacement for R 22
Ethane	R 170	HC	C_2H_6	−110 to −70	Low-temperature cascade refrigeration, usually with turbine compressors
Ethene (ethylene)	R 1150	HC	C_2H_4	−110 to −80	As for ethene
Propane	R 290	HC	C_3H_8	−60 to −20	Large refrigeration systems, usually with turbine compressors
Propene (propylene)	R 1270	HC	C_3H_6	−60 to −20	As for propene

Notes:
R numbers: a compound with the formula $C_aH_bCl_c F_d$ is numbered R [a−1][b+1][d]
Unsaturated compounds take a leading '1'; 'a', 'b' etc. denote isomers; 'B' = brominated; 'C' = cyclic

2. CHILLING

Chilling is the most important control measure for fresh fish quality, and this includes food safety. Reducing the temperature to 0°C rapidly, after catching, and then maintaining the cold chain, effectively controls enzyme, bacterial and rigor spoilage for up to 12–14 days. At the same time, growth of any pathogenic organisms that are present is also minimized. [56,114]

The post-catch and post-mortem handling of fish is different to that of meat, even though they are both usually chilled. Fish temperature reduction to about 0°C is by far the most important factor for the quality of fish. This should be achieved as rapidly as possible. Rapid chilling will slow down the rates of enzymatic- (and microbial-) induced changes occurring post-mortem.[100,114]

There are two quite distinct applications of refrigeration to chilled foods. These are the chilling operation itself, in which the foodstuff is cooled from either an ambient temperature of maybe 30°C or a cooking temperature of over 70°C, and the chilled storage, at a closely controlled temperature of between −1.5°C and +15.0°C depending on the foodstuff. Chilling equipment and chilled storage equipment are quite different in their requirements and their design, and although some chilling equipment may be used for chilled storage, storage equipment is not designed to cool products, only to maintain temperature. Transport refrigeration for chilled food distribution is a special case of storage, and transport equipment should not be expected to provide rapid cooling.[56,100,114]

2.1.1. Chilling procedures

The key to seafood preservation is therefore immediate chilling at harvest to a temperature slightly above the freezing point and maintenance of this temperature until further processing. This also applies to seafood to be frozen, because the freezing process takes time to accomplish and only slows down or stabilizes the spoilage.

Traditional fish chilling and preservation methods include ice; ice–water mixtures; refrigerated seawater (RSW); RSW usually provides a temporary means of refrigeration, particularly if discoloration and texture chages are of concern. [120]

Ice has been used to control seafood spoilage for more than a century. The latent heat of fusion of ice (335 kJ kg^{-1}) provides high cooling capacity. Ice keeps seafood not only cold but also moist and glossy. It also prevents dehydration. Block or crushed block ice, tube ice, flake ice, and shell or plate ice are ice types that have been used for decades. One common and key problem using traditional ice is the low chilling speed, no matter whether ice is directly applied to fish or mixed with water, then applied to fish. In addition, traditional ice particles have irregular shapes with sharp edges that may bruise the fish skin. The super cooled flake ice may partially freeze seafood, reducing the market value of the fresh product. Large energy consumption and space requirement of the ice equipment are also concerns associated with the traditional technology. [120]

Traditionally ice is used in the pre-chilling of fish and is the best method of chilling fish. This has several advantages. The first one is that the ice and fish are in good contact, allowing good heat transfer from the fish to the ice. The second is that melting of the surrounding ice requires a large amount of heat energy to be removed from the fish. The disadvantage with icing is that it can be labor intensive, and for fish in boxes, the contact between the fish and ice may not be optimal.[100,101]

Various types of ice may be used, crushed, block, flake, or tube. The refrigeration effect of each type is more or less the same except when the ice is very slushy, when the effect is less. Flake ice, which is 'dry', light, has tiny pockets of air between the flakes and does not coagulate into lumps, is probably the best to use with fish, whether on board the catching vessel, in a processor's premises, or in retail or catering establishment. Melting solid ice, in good contact with the surface of the fish because of the presence of liquid water, effects the cooling. In practice, cooling by ice is more effective the higher the temperature of the surroundings, because more melting takes place.[100,114]

Flake-ice is a preservation method extensively used to remove heat rapidly from aquatic food products and to extend their shelf life. Flake-ice has and continues to be a tool widely used to decrease the temperature of fresh aquatic food products down to final levels slightly above 0°C. It should be stressed that aquatic food products are poikilothermic organisms with both a high water and non-protein-nitrogen (NPN) content, a soft muscular and skin structure, and a low collagen content. Such features mean that these products are considered to be among the most perishable foods, this demanding a rapid step after harvesting in order to preserve their quality. Thus, spoilage begins as soon as the fish is harvested. The spoilage of fresh fish is a rather complex process and is caused by microorganisms and a number of physico-chemical mechanisms, some of which are inter-related and may affect one another. Among the most important degradation mechanisms, microbial spoilage and the biochemical degradation of NPN compounds and proteins, with the subsequent formation of a variety of products such as hypoxanthine (Hx), trimethylamine (TMA), among others, should be highlighted. [123]

Rapid chilling is possible with ice and ice keeps the appearance of fish glossy and attractive. Ice prevents the drying out and partial freezing of fish that can occur with mechanical refrigeration. Ice holds fish at a temperature slightly above the freezing point of fish. For sea fish this is around –1°C because the ice/fish mixture usually contains some salt and blood which reduces its freezing point to slightly below that of pure water. In order to be effective as a chilling method, ice must be able to melt. It is while melting that the ice actually performs its job of chilling the fish. In practice the usual fish to ice ratio is approximately 2:1, i.e., 10 kg of fish will be stored in 5 kg of ice. This amount of ice will be enough to both chill the fish and then maintain the chilled conditions for a reasonable period of time.[56]

Ice slurry is a mixture of flake or crushed ice and seawater i.e., consists of an ice-water suspension chilled at a subzero temperature. Due to the presence of the salt, the temperature of slurry will be around –1.5°C; although adding more salt can reduce this further. (Note: a slurry of freshwater and ice should be exactly 0°C). Ice slurries are used on catching vessels for the rapid chilling of high value fish; also in processing premises for chilling product as required at any step in the process, eg. prior to packing for chilled distribution. It is an excellent method to achieve rapid chilling of fish as the cold liquid is in contact with the entire surface of the fish. Experimental work has shown that even large fish take only four hours to chill to 0°C in slurry. To be effective, slurry must be an even mixture of ice and water throughout. As a general guide, this requires approximately 1 kg of ice to 1 kg of seawater. In practice this means two buckets of ice to one of water and continual stirring of the tank. [56,120,123]

Many experiments and applications reveal that ice slurry has the following beneficial features over conventional chilling: *i*) best chilling of fish while avoiding freezing; *ii*) effective control of fish temperature at

the most desirable and constant level; *iii*) preventing fish from skin bruising and body damage; *iv*) improved productivity as a result of easy handling and transportation of pumpable ice slurry; *v*) possibility of brine drainage to provide almost salt-free ice for extended fish storage; *vi*) elimination of ice contamination because ice is produced, stored, and distributed in a sealed environment; and *vii*) operation savings in energy, labor, and maintenance. [120]

Two main features of slurry ice are (i) its faster chilling rate, deriving from its higher heat-exchange capacity, as compared with flake-ice and RSW and (ii) the reduced physical damage caused to aquatic food products by the spherical microscopic particles characteristic of slurry ice, as compared with flake-ice, this advantage being especially relevant in the case of soft tissues, a characteristic of a wide variety of aquatic food products. The overall covering of the fish surface by the slurry ice mixture protects the fish from the action of oxygen, helping to prevent oxidation and dehydration events. [123]

Another manner to maintaining chilled fish is Cold Air Chillers. **Forced air chiller**: In most premises chilled fish is stored within chillers which have refrigerated air blown around them with fans. They operate at temperatures from –1°C to +3°C. In fact these "chillers" are not very effective at taking heat out of fish. Air is a very poor conductor and with fish stacked in bins, it is very difficult for the cold air to reach all surfaces. Chillers are designed to maintain the chilled state of fish as it arrives at the premises, or, where fish is not fully chilled, should be combined with ice to ensure effective chilling. In this situation, the temperature of the chiller should be above 0°C so that the ice can melt. **Cold rooms**: In some premises, fishing vessels, retail outlets and transport vehicles a cold environment is created through the use of refrigerated coils. As for forced air chillers, the actual chilling ability of such facilities is very limited and they should only be used to maintain chilled conditions or in conjunction with melting ice.[56]

Fish may be cooled in refrigerated sea water (RSW). This allows faster heat removal from the fish and makes the chilling processes faster. Also, the temperature of the fish can be reduced to –1°C to –2°C, and this may offer advantages in reducing rates of spoilage. An extension to super-chilling is to allow the fish to freeze partially. By reducing the temperature of the fish to –2°C to –4°C fish can be partially frozen.[100,103]

RSW is generally only used on board catching vessels. It is seawater cooled to below 0°C by mechanical refrigeration. Brine of about the same salt content of seawater (3.3%) is sometimes used. RSW has the advantages of rapid cooling and reduced storage pressure on soft fish such as tuna, and the ease of handling of large quantities of fish such as are handled by purse seiners. A disadvantage of RSW is that it can cause excessive salt and water uptake by the fish, leading to a loss of protein and accelerated rancidity.[56,100,103]

CSW as a cooling medium is becoming much more common in small fishing vessels. Overall temperature control in the CSW tanks is achieved by the addition of ice to lower seawater temperature and that of the catch as it is added during the trip. To prevent temperature stratification in CSW tanks, two basic systems are used, one is compressed air, also known as the "champagne" system, and the other is CSW recirculation by pump.

Stowage in chilled sea water offers the following advantages over stowage in ice; the catch is cooled more rapidly, less effort is required to stow and unload it, and there is less likelihood offish being crushed or losing weight. In addition sea water can be safely lowered in temperature to about -1°C without freezing the fish contained in it. Other advantages are effective washing and bleeding, and a tendency to firm the flesh of the fish, which can aid further processing.

Disadvantages of the method which preclude its general adoption are as follows; some species, herring for example, keep as well or a little better than in ice for 3-4 days, but thereafter spoil more quickly, and some species take up unacceptable amounts of water and salt when kept in sea water. *The use of ice on small fishing vessels FAO FISHERIES TECHNICAL PAPER 436 Michael Shawyer and*

Avilio F. Medina Pizzali

For these reasons the method is usually confined to short term storage of particular species that are caught in large quantities within a short time (J. H. KELMAN - Stowage of Fish in Chilled Sea Water. TORRY ADVISORY NOTE No. 73

Francisco, do you have some information about chilled sea water (CSW)??

2.1.2. Chilled storage

The benefit of chilled storage is the extension of life of the foodstuff in good condition, by slowing down the rate of deterioration. Chilling, it must be emphasized, cannot improve the quality of a poor product; neither can it stop the processes of spoilage. Chilled storage equipment may be seen around the world in a wide range of sizes, each suited to the particular operation for which it is designed. At its smallest, it may be an absorption cycle refrigerator in a truck or boat. There are larger domestic and commercial refrigerated storage cabinets, then small walk-in stores, and finally stores large enough to be served by forklift trucks handling pallets or bins, some of which can accommodate thousands of tonnes of produce. [74]

For most chilled food preparation and short-term storage areas, walk-in stores are appropriate. These can be constructed and designed as part of a total building, but more often are likely to be modular units sited within the overall structure. If pre-cooked chilled foods are to be stored, they should not be mixed with any other products requiring chilled storage. [114]

2.1.3. Refrigerated transport

Refrigerated transport of chilled foods must be seen as a total operation involving the movement of chilled goods from one fixed storage area to another. The operation involves a 'chain' of events, of which the actual movement of goods in a road vehicle, intermodal freight container, rail wagon, ship or aircraft is only a part. Temperature maintenance throughout the chain is essential for success, and the finest transport equipment cannot compensate for poor handling at loading, wrong packaging and stowage, or inadequate product cooling. The term 'refrigerated transport' may itself be misleading, in that frequently it should be 'temperature-controlled transport'. [74]

The distinction between 'refrigeration' and 'temperature control' is important for equipment users, who may not appreciate that a wrong temperature-setting on transport equipment may lead to foodstuffs being heated, whereas in many static stores it would only lead to lack of refrigeration. In general, transport equipment is designed to maintain temperature, and not to provide cooling. Whilst foodstuffs can be cooled to some extent during transport, this is a slow and non-uniform method of attempting to cool, and it should not be depended upon. Pre-cooled foodstuffs should be loaded under temperature-controlled conditions wherever possible. In some cases, packaging designed for horizontal airflow coolers may not allow further cooling in transport, where vertical airflow is usual. [74]

The range of transport refrigeration equipment is wide, as are the needs for transport. At its simplest, it could be an insulated box containing water ice. At its most complexes, it might be an intermodal freight container with integral refrigeration machinery. This equipment is capable of maintaining either frozen or chilled goods at any selected temperature between –25°C and +30°C in ambient temperatures from –20°C to +50°C. Most frequently it will be a road vehicle designed either for local deliveries or for long distance or bulk distribution. Intermodal freight containers ('ISO' containers) with integral refrigeration machinery are widely used for the long-distance transport of fresh and chilled seafood. [74]

The temperature control requirements for chilled foods are more difficult to achieve than those for frozen foods. Typically, it may be necessary to maintain cook-chill products between 0°C and 5°C, and for many products closer tolerances are required, whereas with frozen foods there will be an upper limit temperature, perhaps –18°C, but no lower limit. To ensure temperature uniformity in a load of chilled foodstuffs, relatively high rates of continuous air circulation and high levels of temperature control are necessary, and careful stowage within the vehicle may be needed to achieve this. [74]

2.1.4. Refrigerated display cabinets (supermarket)

The refrigerated display cabinets used in retail premises fall into two distinct groups. Most are vertical multi-deck cabinets for the display and self-service retailing of packaged chilled seafood. There are also the delicatessens or 'serve over' cabinets for foods which are normally not packaged but cut and served. Multi-deck cabinets have a refrigeration evaporator in the base, and this may be supplied either from a self-contained condensing unit or, in larger installations, be piped to a central store cabinet refrigeration system. The evaporator coil is mounted in the lower part of the cabinet behind or under the display area, and fans blow cooled air both from behind the shelves in a forward direction and also downwards in an air 'curtain' from the top front of the cabinet. Warmed air is returned through a grille at the base of the cabinet. [74]

Modern multi-deck cabinets may be designed to maintain food temperatures at 5°C or below, but some older cabinets will frequently have difficulty achieving temperatures below 10°C. Food temperatures are

not just a function of cabinet design: they also depend on method of use. Very tight or untidy cabinet loading can prevent proper air circulation, as can indiscriminate placing of large price or advertising tickets. High store temperatures or excessive radiant heating from lights can lead to warm foodstuffs. Good housekeeping allied to the use of some type of night covers when the store is closed will give the best results. [74]

Cabinets are designed to maintain temperatures, and should not be loaded with foodstuffs which are warm. In some countries, cabinets with doors have largely superseded the use of open-fronted multi-deck cabinets, to provide more positive refrigeration at all times. Such cabinets have severe disadvantages to the retailer, both in loading time and in customer resistance. Some open-fronted cabinets also incorporate shelves for display of non-chilled goods related to the chilled products on display. [74]

Serve-over display cabinets have food displayed on a base over which cold air flows, and normally have a glass front from behind which the food is served. Air from a rear evaporator may be gravity-fed or fan-assisted, but, as much of the food in these cabinets is not wrapped, excessive air speeds must be avoided to prevent dehydration and weight loss. For the same reason, these cabinets are usually used for display only whilst sales are in progress, and other storage cabinets are used to store food overnight. [74]

3. FREEZING

Fish is largely water, normally 60–80 (up to 90!) 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 3. 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. [63,85,100,114,115,124]

The process of freezing as a method of preserving fish quality has been long established. It was back in the early 20th century that Clarence Birdseye discovered that seafood and meats frozen in the bitter arctic winter tasted better than those frozen in the milder spring and autumn. It was from this observation that he developed, and refined what was described as 'the quick freeze machine'. [5,115]

The process of quick–freezing is still a good, and arguably the best, way of preserving fish in a natural and safe manner for periods of many months or even years, but there is no widely accepted definition of quick freezing. Since the temperature just below 0°C is the critical zone for spoilage by protein denaturation, an early 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, 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 stricter than is necessary to ensure a good quality product. [63,85,100,117,124]

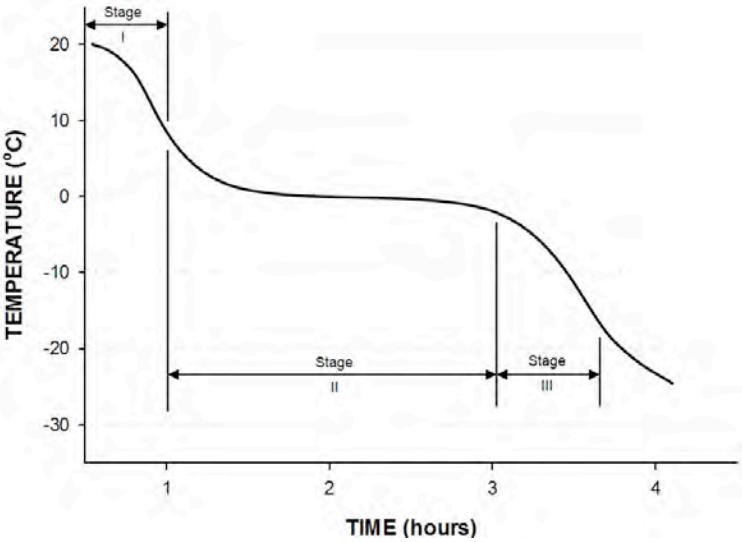


Figure 3. Temperature-time graph for fish during freezing. [63]

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. 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. [63,85,100,114]

Freezing and freezing methods have a major effect on water relations in fish and the consensus is that fast freezing (1°C/min) produces the best quality in that it induces small ice crystals, evenly distributed in the muscle. Slow freezing (5°C/h) produces large, damaging ice crystals. [115,116] 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 4. [63,85]

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 "Sashimi" 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 (to avoid enzymatic activity causing off rancidity flavours). 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. [63]

Table 4. Freezing rates[63,85]

Freezing rates*	Freezing characteristic
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	Ultra rapid freezing in liquefied gases such as nitrogen and carbon dioxide

*thickness frozen in unit time

The challenge for producers of frozen fish and frozen fish products is to optimize the natural preserving ability of the freezing process to provide products of consistently high quality from raw materials that are mostly from a wild origin. In addition, with the increasing pressure on the stocks of traditionally processed fish, another key challenge is to make better use of fish that are currently under–utilized for human consumption and that are also from sustainable sources.[5,117]

In simple terms the freezing process is a conversion of the water content of the fish to ice. Fish are made up of 60–80% water depending on the species or fat content (high fat fish such as eel and salmon have lower water content). As the temperature decreases below –1.5°C, water in the flesh begins to freeze, and when -5°C is reached, ¾ (75%) of the water has been frozen. As the temperature decreases further more and more of the water is frozen but at normal storage temperatures of –25°C, there is still a small amount of the water which remains unfrozen within the cells of the fish. The phase from –1.5 to –5°C is known as the critical zone because this is where most of the freezing is done and also where most of the damage from the freezing process can occurs. Processors must aim to get through the critical zone as quickly as possible to minimize the damage due to freezing, i.e. within 2–4 hours. [56,63]

Fish are currently either frozen into regular blocks or individually as fillets or portions. For frozen blocks the fillets are placed into cardboard liners within rectangular stainless steel moulds. The liners are sealed around the fish and lids placed on the moulds. The sealed moulds are slotted into plate–freezers, whereby the moulds are clamped between two extremely cold plates (between –30°C and –40°C).

Ice is less dense than water and on freezing expansion will occur. However, because the moulds are sealed the expansion of the frozen fish fillets is restricted. This causes any trapped air to be expelled and gives a regular shaped block. Regularity of shape and elimination of voids is an important part of block manufacture. This is because blocks need to be subsequently cut into portions of consistent shape, and irregularities in the block will lead to excessive losses during this process. An alternative to block manufacture is to freeze the fillets either whole or as portions cut from the fillets prior to freezing. [5,63]

These types of product are referred to as individually quick–frozen (IQF) fillets or portions. IQF products are frozen as single units which need not be thawed for sub-division or perhaps even for cooking purposes (ex.: single fillets and shrimp). 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. [63] One of the issues with processing IQF fish portions is in controlling the weight of the final product(s) in the product box or bag. The following sections will describe the types of supply chain that produce the frozen fish. [5]

3.1.1. Pre–freezing treatments

Freezing and cold storage is an efficient method of fish preservation but it must be emphasized 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 handling, pre-chilling, 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. 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. In some countries chemicals are currently used to treat fresh fish in order to assist with such things as color 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. [57,58,59,60,63,100]

3.1.1.1. Phosphates

Aware of the loss of water during the capture and processing, the commercial practices have been involving the control, addition (hydration) and retention of the moisture of the fish during the capture, processing, distribution, storage and preparation. [58,59,73,119]

The phosphates solution are generally applied by immersion, spray, injection or tumbling into fillets prior to freezing. The main objective for this is to provide a product that has more moisture and is therefore more succulent to eat when cooked. Polyphosphates are used because they are able to bind with water and then bind onto the proteins of the fish fillet. They work best with fresh fish, when the proteins have not been broken down by enzyme spoilage. [56,58,59,73,119]

The phosphates are an indispensable additive for the maintenance of the functional properties of the seafood myofibrillary proteins which helps the preservation of the muscle integrity, inhibits the drip loss of the fresh fish, and helps to prevent the economic loss during the thawing and the cooking. The phosphates also increase the thermal stability of the proteins of the fish which is usually lower than the one of other animals. [58,59,119]

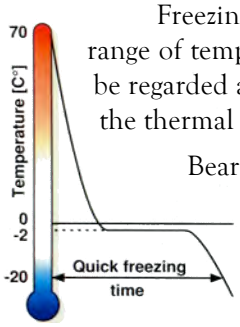
3.1.1.2. Cryoprotectants

Extension of shelf life of fish during frozen storage can be achieved by the incorporation of ingredients (e.g., cryoprotectants) that are able to prevent ice crystal growth and the migration of water molecules from the protein, thus stabilizing the protein in its native form during frozen storage. A wide variety of cryoprotective compounds are available, and these include mono- and dissaccharides, glycerol, sorbitol, some salts, ascorbic acid, citric acid, amino acids, polyols, methyl amines, carbohydrates, some proteins and inorganic salts such as potassium phosphates and ammonium sulfate, carboxymethyl cellulose, gums or their combinations, are satisfactorily used to freeze-preserve fish.[100,104,115] The selection of cryoprotectants will depend on whether the application is for a comminuted product, that is a system into which the cryoprotectants can be intimately mixed, or whole fish fillet. [100,115]

Probably the most extensive applications of cryoprotectant molecules have been in the stabilization of surimi. For example, cryoprotectants such as carbohydrates (particularly sugars) and polyphosphates (only allowed in some countries) have been used to minimize the loss of protein functionality properties caused by the freezing and frozen storage processes on surimi. A useful review of general principles of cryopreservation of food quality is given by MacDonald & Lanier[106]. For whole-fillet applications the most frequently used cryoprotectant to control the water-holding capacity is tripolyphosphate. It has been reported that polyphosphate addition will improve the texture and color of fish products also.[100,107,108]

3.1.2. Freezing process

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. 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 remain 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.[63]



Freezing process is a process that is carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C (0°F) or lowers at the thermal centre after thermal stabilization.[66]

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 favorable economic conditions (Table 5). 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 space required for a freezer obviously depends on the capacity and type of freezer. The following table gives some typical operating temperatures for various freezers.[63,85]

Table 5. Freezer operating temperature.[63,85]

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

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 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. Some variables determine the overall heat transfer coefficient and hence the freezing time, such as[63,100]:

- **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 (ex.:, 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 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.
- **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.
- **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 aluminum 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 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.

The freezing times in Table 6 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 6 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.

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

Table 6. Freezing times for fish products

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.

3.1.2.1. Cryomechanical

Cryomechanical or combined freezing consists of an association of two freezing systems: an on-line cryogenic immersion freezer (using a cryogenic fluid like liquid N_2 or CO_2) combined with a mechanical freezer (with cold air produced by conventional refrigeration equipment). The combined process uses the following sequence for most: *i*) *Cryogenic freezing*: when the foodstuff is submerged in the cryogenic liquid, a fast freezing of the outer layers occurs forming a thin crust. This freeze-crusting treatment provides higher resistance strength to the foodstuff and prevents small and/or wet products from sticking on the conveyor or between them: *ii*) *Mechanical freezing*: the freeze-crusted product completes its freezing until the centre of the foodstu reaches the required final temperature. [60,82,83]

The use of the combined freezer provokes a reduction of the freezing time and of water loss during the process. These reductions may cause an improvement in the final quality of the product. Besides, the combined system also offers a simple and economical solution to increase freezing capacity. However, its most important application is for freezing of delicate products, i.e., products not having a good mechanical resistance (shrimps) or products that otherwise change their appearance (chicken scallops). Another important use is for food pieces that tend to stick or clump (diced potatoes). In these cases, the higher cost caused by liquid nitrogen (LN) consumption, is compensated by the attainment of a product with a lower weight loss and a higher final quality or an overall better appearance. [82,83]

3.1.3. Freezing equipment

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. [63]

3.1.3.1. Air blast freezers

Air blast freezing is carried out in insulated rooms using high speed cold air circulating around the product (Figure 4), which is generally packed into cartons and stacked on trolleys. The cold air is at around −35°C to −40 °C and well designed blast freezers can easily achieve the fast freezing required to minimize any damage while reducing the final internal temperature of the product to −25°C within 12–16 hours. In addition to good design best efficiency is obtained by ensuring that cartons are not too thick, are well spaced to allow air flow, and that the product temperature at the start of freezing is as low as possible. [56,85,114]

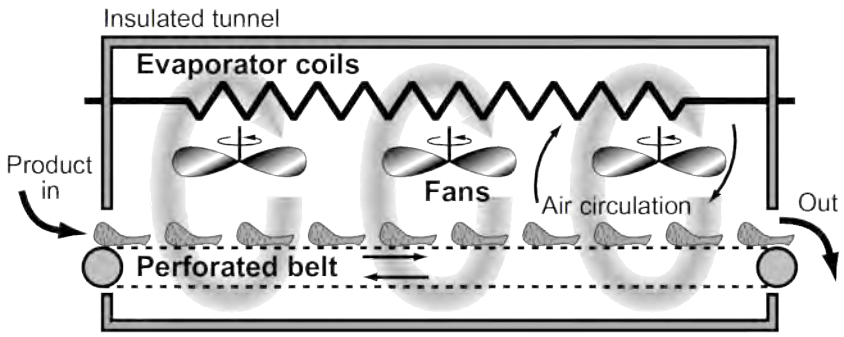


Figure 4. The blast freezer has a horizontal belt to carry the food. Above the belt are fans to mix the cold air and improve heat transfer[109]

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. [63]

3.1.3.2. Cryogenic tunnel freezers

The cryogenic version of the mechanical refrigeration blast freezer is known as a tunnel freezer. The general design is like that of the blast freezer, but instead of a bank of evaporator coils it has nozzles to spray liquid nitrogen or carbon dioxide 'snow' directly onto the food. Evaporation or sublimation of refrigerant from the surface of the product makes an important contribution to the overall heat transfer.[109,114]

Cryogenic freezing is most successful with small products which are to be IQF (Individually Quick Frozen) and which are of high value. The rapid freezing produces a superior product in terms of appearance, but the cost of these types of freezers is very high and therefore the price of the product must warrant the expense. Liquid nitrogen or carbon dioxide is used in cryogenic freezers. The temperatures are so cold that freezing occurs very rapidly. Liquid nitrogen freezers operate at between –50°C and –196°C, liquid carbon dioxide at –50° to –70°C. In this freezer, the product is brought into direct contact with the refrigerant. An advantage of cryogenic freezing is that the freezing unit itself takes up a very small amount of space, but conversely, storage of the gases can be a major problem. [56,63] 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. [63,85,109,114]

Refrigerant consumption is measured as a 'consumption ratio' equal to the weight of refrigerant used divided by the weight of product frozen. For a typical liquid nitrogen freezer the consumption ratio ranges from 0.3 for foods with a low moisture content, up to 2 for difficult foods such as seafood. High refrigerant consumption can be a significant problem with cryogenic tunnels, especially following a change in throughput or product type. The reason for this is poor control. Figure 5 shows the gas temperature profile along the length of a typical liquid nitrogen tunnel with one spray zone. The inlet temperature is fixed at around –150°C, just above the boiling point of liquid nitrogen. To avoid wasting energy, the gas exit temperature should be close to the entry temperature of the food – say –30°C for a product entering at 20°C. Liquid nitrogen injection rate and fan speed are normally controlled so as to maintain a constant temperature at a single point part-way along the tunnel (Figure 5). This is not a good control strategy, because it causes the gas exit temperature to change whenever the load on the freezer changes and this in turn either causes under-freezing or wastes refrigerant. [109]

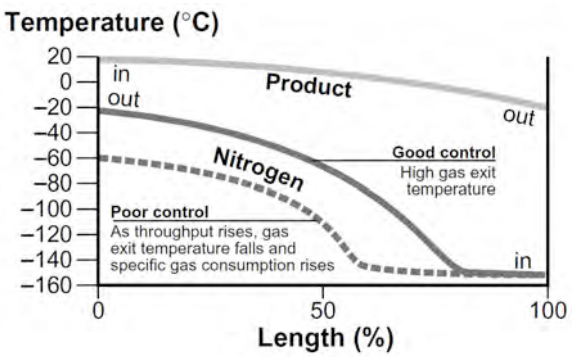


Figure 5. Understanding and controlling the temperature profile along the freezer is key to minimizing gas consumption in a cryogenic tunnel freezer. Conventional single-point control, as here, is not a good control strategy. [109]

3.1.3.3. Belt freezers (spiral freezers)

Spiral freezers are one of the commonest freezer types in the food industry. Capacities are in the range 500–10 000 kg h^{-1}, with a typical 2600 kg h^{-1} unit measuring 7.6 m long, 5.3 m wide and 4.6 m high. Applications and performance are generally as for straight blast and tunnel freezers, with overall heat transfer coefficients around 35 W m^{-2} K^{-1}. [109]

Belt freezers (spiral freezers) have a continuous flexible mesh belt which is formed into spiral tiers and carries food up through a refrigerated chamber. In some designs each tier rests on the vertical sides of the tier beneath and the belt is therefore 'self-stacking'. This eliminates the need for support rails and improves the capacity by up to 50% for a given stack height. Cold air or sprays of liquid nitrogen are directed down through the belt stack in a countercurrent flow, which reduces weight losses due to evaporation of moisture. Spiral freezers require relatively small floor-space and have high capacity (for example a 50–75 cm wide belt in a 32-tier spiral processes up to 3000 kg h^{-1}). Other advantages include automatic loading and unloading, low maintenance costs and flexibility to freeze a wide range of foods including pizzas, cakes, pies, ice cream, whole fish and chicken portions. [85,109]

3.1.3.4. Plate freezers

Used to freeze large blocks of product, plate freezers are aimed at bulk storage and distribution rather than individual product portions for retail sale. Typical applications are in freezing whole fish or fillets, including on board vessels[109,114]. Plate freezing is, as the name suggests, carried out between hollow metal plates through which liquid or gas refrigerant is circulated. Banks of these plates are arranged and connected within a cabinet. When cartons of product are placed between the plates they are compressed together so that the plates are in close contact with both upper and lower sides of the product. The close contact means that freezing can be very rapid and even faster than blast freezing. 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). 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). For efficient operation plate freezers need to have evenly sized cartons and product inside the cartons must be free from any air gaps which act as insulation. [56,63,114]

A typical horizontal plate freezer (HPF) has up to 20 plates, and the product may be manually loaded on to trays or, alternatively, automatically loaded, with unfrozen packets displacing frozen ones. Plate separations of 25-75 mm are the most usual and hydraulic actuators are used to contact the plates and products. The compression forces are about 5-30 kPa, and allowance for expansion of the product has to be made during the freezing operation. Vertical plate freezers (VPF) work on similar principles; however, the methods of handling the products are different. This type of freezer is best suited to unpackaged products such as wet fish, meat and offal. Typical freezing times for fish blocks 75 mm thick are 120 min at –34°C and 90 min at –40°C. Plate freezers require about half the time to achieve freezing compared with air blast freezing for the same thickness of product. [63,114]

3.1.3.5. Immersion freezers

Immersion freezers, in which products come into direct contact with liquid refrigerant, are important for two quite different classes of foodstuffs: prawns and other IQF products on the one hand, and bulky items such as turkeys on the other. [109] By using a liquid for the removal of heat from a product, favorable 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 form 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.

Where it is not possible or convenient to use the expanded refrigerant gas for cooling, a secondary refrigerant is employed. In most cases, a brine, either calcium chloride or sodium chloride, is used for this purpose. *Calcium chloride* is used for industrial process cooling, product freezing and storage, and applications where temperatures below –18°C are required. The lowest temperature, which is attainable without solid calcium chloride bring precipitated is –55°C with a 29.87% weight solution (eutectic temperature). *Sodium chloride* solution is used for applications not requiring such low temperatures or where the solution is used in

direct contact with packaged food, e.g. chilling and freezing of poultry and meat products. The lowest temperature (eutectic) which may be achieved is –21.2°C with a 23% weight solution. [56,109,114]

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. [63,85]

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 flavor. Ethylene glycol and propylene glycol are also used as direct contact freezants. Aqueous freezants tend to become diluted in use, and care should be taken to maintain the concentration at the required level. The concentrations of aqueous ethylene glycol solutions range from 15-50% vol., corresponding to temperatures of –5.3 to –35.8°C. For aqueous propylene glycol solutions, the concentrations range from 5-59% vol. corresponding to temperatures of –1.7°C to –49.4°C. Propylene glycol is one of the most extensively used antifreeze agents in the refrigeration industry. It is particularly stable and is non-corrosive. [56,114]

3.1.3.6. Fluidized–bed freezers

Gas or liquid flowing upwards through a layer of solid particles can cause the solid material to behave somewhat like a fluid (Figure 6). This is a fluidized bed, and freezers using this operating principle are a good way to freeze small IQF items such as shrimp.[109,114]

Fluidized-bed freezers are modified blast freezers in which air at between –25°C and –35°C is passed at a high velocity (2–6 m s^{-1}) through a 2–13 cm bed of food, contained on a perforated tray or conveyor belt. In some designs there are two stages; after initial rapid freezing in a shallow bed to produce an ice glaze on the surface of the food, freezing is completed on a second belt in beds 10–15 cm deep. [63,85] One type of air blast freezer fluidizes the product with a strong blast of air from below. 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 have been successfully frozen by this method. [63,85,114]

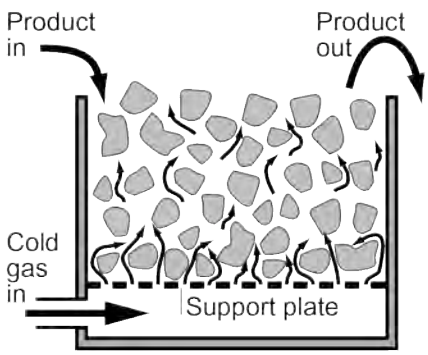


Figure 6. The principle of the fluidized bed: A uniform stream of cold air or other gas can lift a 'bed' of solid particles, causing them to behave like a fluid. Fluidized beds transfer heat well and stop frozen product from clumping.[109]

A modified fluidized freezer which may be termed a semi-fluidized freezer has also been used for fish-freezing applications. 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. [63,85]

3.1.3.7. Tumbling and rotator tunnel freezers

As an alternative to fluidized-bed freezers for IQF products, tumbling or rotary tunnel cryogenic freezers offer high product quality and high throughput for a given floor area. The product must be able to withstand the tumbling action. Typical applications are coating diced vegetables with breadcrumbs, and minced or diced meat, either cooked or raw. Product enters an insulated stainless steel tube mounted at a slight angle to the horizontal and rotated at several r.p.m. by a set of external driving wheels. Liquid nitrogen is sprayed into the same end of the tube. As the tube rotates, the product is thrown about in a mixture of liquid nitrogen and cold nitrogen gas. The inclination of the tube causes the product to move slowly towards the other end, along with the exhaust nitrogen. The tumbling motion stops the product from sticking together. [109]

3.1.3.8. Stationary tunnels and carton freezers

The stationary tunnel is one of the simplest types of mechanical-refrigeration freezer. Product is placed on trays, racks or trolleys and loaded into an insulated box equipped with refrigerated coils and air circulation fans. The freezer can operate entirely batch wise, in which case product is loaded into the freezer and left there until it freezes. In a more sophisticated variant, wheeled trolleys are moved continuously through the freezer, either by hand or automatically. Heat transfer coefficients are generally in the range 20–40 W m^{-2} K^{-1}. The stationary tunnel is a versatile freezer but it is labor-intensive and dehydration losses can be high. The racks of product must be carefully positioned to ensure a uniform airflow, with gaps that are neither too large nor too small. [109]

3.1.4. Post–freezing treatments

Deterioration of seafood begins immediately upon harvest, and continues to various degrees depending on storage conditions. The best method of preserving of seafood is freezing and storing at low temperatures. If properly frozen, seafood retains quality and flavor. A great problem encountered by producers of both fresh and frozen seafood is dehydration of product and so the product must be protected from dehydration. Two protective methods are used, usually in combination: glazing and packaging. Good packaging prevents the circulation of air over the surface of the product and protects the moisture in the surface layers of the product. [64, 119]

3.1.4.1. Glazing process

Weight loss by dehydration during freezing and storage is directly proportional to the exposed surface area and can be reduced by two methods: covering the surface with packaging material, and surrounding the product with a thin layer of ice. The use of ice-glaze for small and irregularly shaped seafood products, like prawns and shrimp (IQF), may be considered essential when stored without packaging or is packed in pillow packs. [61,62,63,64,66,118]

Glazing (or ice-glaze) means applying a coating of ice to product which has already been frozen. Generally the glaze is simply water, but ingredients can be added. A glaze provides an excellent barrier to oxidation and freezer burn during frozen storage. Added ingredients include thickeners to ensure a good coating of glaze is applied, anti-oxidants to assist in preventing fat rancidity and color loss for whole fish, or sometimes just salt to maintain flavor. [56,61,114,119]

As soon as seafood is 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 to rapidly refreeze and to preserve taste, smell and texture as well as to minimize thaw drip loss. [61,64,65,119] The glazing process is carried out by dipping or spraying the product with water (which is most common, but also salt-sugar solutions are used) to apply a thin layer of ice. The aim of this process is to reduce the impact on quality resulting from cold storage deterioration; and another argument for implementing glazing is that if the product is subject to inadequate cold storage, the glaze will evaporate instead of the tissue water itself. [61,64] Then, glazing is just a form to assure the moisture loss by sublimation during the frozen storage which becomes an important quality and economic factor in the seafood industry. [85]

The application of glaze can be difficult to control. If it is applied in an uncontrolled way the amount of glaze added will not be constant and the thickness will not be uniform. This will affect the amount of protection offered by the glaze. In order to form a complete and uniform glaze on the surface of the seafood, the glazing process requires to be closely controlled (Table 7). The amount of glaze applied depends on the

following factors[61,63,64,65]: (i) glazing time; (ii) seafood temperature; (iii) water temperature; (iv) product size; and (v) product shape.

Table 7. Practical glazing methods: Advantages & Disadvantages[85]

	Method	Advantages	Disadvantages
Dipping	Placing the frozen product in a tank of water for a period of time.	Cost-effective. Low capital costs. Relatively simple.	Inconsistent glaze coverage. Uncontrolled. Seafood can be left too long or 'soaking'. May need repeat applications.
Spraying	Typically involves purpose designed equipment to spray water over a product.	Controlled. Consistent glaze coverage.	Capital costs.
Packaging only	Involves packing the seafood in plastic packaging (e.g. film or bags) or vacuum packing.	Can be simple. Semi-controlled.	Can be difficult to exclude oxygen from non vacuum packs. May only suitable for short storage periods. Packaging costs.

In industry, glaze is typically applied from 4-10% depending on the product. In extreme cases it has been known to have up to 25% glaze for some products. Some companies prefer only to rely on packaging itself to protect product during storage. This is usually only for product that is held for short periods in frozen storage. Some problems associated with glazing are listed in Table 8. [85] According to Gonçalves & Gindri Junior[61], a reasonable range of water uptake could be between 15% and 20% to guarantee the final frozen shrimp quality. Nevertheless, abuse has been reported with coatings as thick as 25–45% (or up), but the most appropriate way to attain quality assurance must be to introduce the standard procedures for ice-glazing, and complying to a regulated glazing content are important to the producers and consumers.

Table 8. Some problems associated with glazing [85]

Problem	Cause
Glaze is brittle and easily dislodged during handling.	If the product surface temperature is at –70°C or less, the glaze is fractured and broken due to the thermal stress during formation of the ice. Product temperature is thus too low.
Glaze is soft and easily dislodged during handling.	If the product is immersed in glaze water for too long, a thick glaze is formed but the temperature difference between the fish and ice is high and only slightly below 0°C. This prevents the glaze from forming properly.
Despite being glazed, product surface dehydrates during frozen storage.	The glaze has been applied unevenly or incorrectly. Review glazing method used and improve. Consider whether glazed product requires additional protection i.e. packaging during storage. Check the temperature of the cold store to eliminate fluctuations.

3.1.5. Freezing 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. 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. [63] 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.[63]

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 "limited" processing establishments producing headed and gutted fish (H&G), or "full" processing factory 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. [63]

A number of conventional freezer units may be used at sea with little modification but may have to conform to national regulations and insurance requirements for fishing vessels. Some 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. Many other types of freezer are also suitable for freezing fish at sea, and horizontal plate freezers (HPF), brine freezers and a variety of air blast freezers have been used. Most of these freezers have been described in this chapter but for use at sea they have to satisfy some special requirements. [63]

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: Freezers with trolleys should have special arrangements to make them safe during rough weather; The freezer should be able to operate with part loads which may result from variations in the catching rate. The refrigeration system should not give rise to uneven freezing due to displacement of the refrigerant with the movement of the vessel. The material used in the construction of the freezer should be resistant to seawater corrosion. But overall its construction and operation should withstand different levels of vibration for long periods of time. [63]

The choices of what type of freezing equipment to be used on board is dependent of the type of fishery targeted. The more expensive the value per unit of capture the more specific and refined the system. For example, longliners targeting tuna for the top end sashimi market have blast freezers capable to reduce the temperature of whole fish to -60C, for less stringent requirements blast freezers aiming to -18 -25C are used. Trawlers targeting white fish for H&G and filleting pack in boxes and use plate freezers again aimed to -18-25C. Purse seiners targeting tuna for the canning industry and /or small pelagic freeze in brine in batches of many tons to -10C, as beyong that the brines becomes to dense to circulate and maintain cold.

In many contemporary trawlers, the freezing capacity conditions the volume of fish captured per tow, as there is an optimal time for processing after harvest in order to maximize the yields and edible quality, therefore if the optimal yields is obtained processing all the fish in the tow in 3 hours from the moment that the fish is landed on the deck and the vessel's freezing capacity is 3 tons/hour, the skipper will bring the tow on board, once the net sensors show that there 9 tons of fish

Francisco... you can insert more information and references into the text, ok?

3.1.6. Storing frozen seafood

Cold storage techniques can be applied at any stage of the cold chain between the production process and consumption. Consequently cold stores range between smaller 'batch' holding units at the production plant prior to transfer to large bulk stores and, nearer the retailer, smaller, geographically convenient 'order picking' stores to match consumer demand.[110]

The purpose of frozen storage of seafood is to extend its shelf life and to limit microbial and enzymatic activity which causes deterioration. [125] The normally recommended air temperature for the storage of frozen foods is –18°C to –20°C. For frozen fish and a few other sensitive foods the temperature should be much lower and –30°C is recommended. Even at this temperature fish do not keep indefinitely. Microbial action ceases below about –10°C, but chemical reactions leading to irreversible changes in odor, flavor and appearance will continue slowly. In addition, unless the fish is properly protected against dehydration, physical changes will make it not only unattractive to look at - the condition known as 'freezer burn' - but also unpleasant to eat.[114,115]

According to the Code of Practice for fish and fishery products [66] the frozen storage facility should be capable of maintaining the temperature of fish at or colder than –18°C, and with minimal temperature

fluctuations. Severe fluctuations in storage temperature (more than 3°C) have to be avoided (especially for quick-frozen coated fish products).

It can be seen from Table 9 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. [63]

Table 9. Practical storage lives of fish products[63,110]

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

PSL is a function of temperature. While stabilized temperatures of –18°C or colder are required to meet EU regulations, commercial designs generally use –25°C, thus allowing some tolerance for loading and travelling. [110] 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 chapter, especially in Legislation topic.

Attention to the store temperature monitoring and recording is necessary in relation to product identification. These aspects are explored in section 4. Above all, the contribution that a good cold store adds to the cold chain is consistency of temperature control, safe handling and a firm identification of records including an established temperature storage history.

3.1.7. Frozen seafood transport

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 un-insulated 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. [63]

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 –20°C. The following lists refrigeration methods that may be used: *i*) 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; *ii*) Rechargeable eutectic plates; *iii*) Solid or liquid carbon dioxide or liquid nitrogen can be used with a total loss system. [63]

During all transportation steps of end product, deep-frozen conditions should be maintained at –18°C (maximum fluctuation ±3°C) until final destination of product is reached. Cleanliness and suitability of the transport vehicle to carry frozen food products should be examined. Use of temperature-recording devices with the shipment is recommended. [63,66]

Vehicles should be designed and constructed: *i*) such that walls, floors and ceilings, where appropriate, are made of a suitable corrosion-resistant material with smooth, non-absorbent surfaces. Floors should be adequately drained; *ii*) where appropriate with chilling equipment to maintain chilled fish or shellfish during transportation to a temperature as close as possible to 0 °C or, for frozen fish, shellfish and their products, to maintain a temperature of –18°C or colder (except for brine frozen fish intended for canning which may be transported at –9°C or colder); *iii*) so that live fish and shellfish are transported at temperatures tolerable for the species; *iv*) to provide the fish or shellfish with protection against contamination, exposure to extreme temperatures and the drying effects of the sun or wind; *v*) to permit the free flow of chilled. [63,66]

3.1.8. Retail display equipment

The retail is an operation that stores, prepares, packages, serves or otherwise provides fish, shellfish and their products directly to the consumer for preparation by the consumer for human consumption. This may be free-standing seafood markets, seafood sections in grocery or department stores, packaged, chilled or frozen and/or full service. The frozen product should be packaged in advance and displayed chilled or frozen for direct consumer pick-up. And also, for full-service display, i.e. a display of chilled fish, shellfish and their products must to be weighed and wrapped by establishment personnel at the request of the consumer. [66,110]

Retail display is one of the 'weak' links in the frozen food cold chain, mainly due to the contrasting purposes that retail display cabinets have to serve, i.e. persuading the customer to buy the product, while at the same time preserving it adequately. For merchandising purposes, the product must be clearly visible and easy to reach in order to tempt potential customers; however, these features tend towards product temperature fluctuation (i.e. in excess of the recommended –18°C). This is known to be the primary cause of a loss of quality and safety in frozen foods. The best way to protect the product from temperature fluctuations is to keep it as far as possible from the shop environment, and from all possible heat sources (ambient air, lighting, etc.); but this means keeping it out of sight of customers. [66,110]

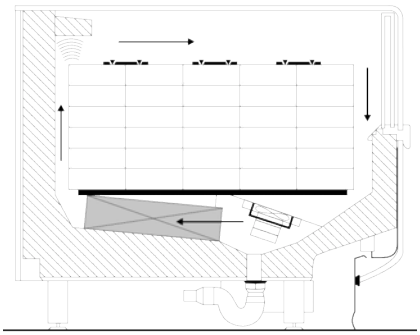
The main characteristics of a good frozen food retail display cabinet can be summarized as follows: *i*) It has to guarantee good product temperature control, whatever the external ambient conditions; complying with the standards is crucial in this matter; *ii*) It has to prove an efficient seller, so the foodstuff must be visible and easily accessible for the customer; *iii*) It has to be cost effective, not only in terms of the initial investment, but also in running costs: therefore, its energy consumption is extremely important, but so is easy access for loading, since this reduces the staff-hours required to re-stock the shelves.

While these are the main features of a good frozen food retail display cabinet, nobody – from the manufacturer to the shop managers, to their employees – must forget that it is designed neither to freeze food, nor to reduce its temperature: its purpose is simply to maintain the frozen food at the right temperature. Naturally, the environment where the cabinet is installed plays a major part in establishing how it will behave: air conditioning and exposure to warm air streams and lighting must be carefully evaluated to guarantee best use of the cabinet. [66,110]

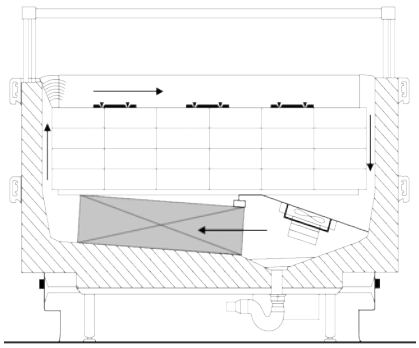
Various criteria can be adopted in the classification of display cabinets for frozen foods. The most common are cabinet geometry and product display, for example: *i*) open-top (the classical appliance for selling frozen foods), single-deck, chest units: these units are designed for self-service, and different types are available; *ii*) vertical multi-deck units, with or without glass doors. [110]

The wall-site unit (Figure 7(A)) is designed to stand against a shop wall, thus allowing shopping from one side. To improve the display function the front of the unit is often fitted with a glass panel, ensuring visibility of the stacked products via a shop window effect. The island-unit (Figure 7(B)), on the other hand, can be accessed from all sides. Here again, glass side panels may be used to enhance product visibility. Cold air distribution through the stacked products may be ensured by forced circulation (Figure 8) or, less often, by natural convection. This latter type is most frequently encountered in small, self-contained cabinets intended for smaller shops.

The characteristics of open-top cabinets make them energy efficient and effective in terms of their preserving function. They are not so good in terms of display function, however, because only the top layer of products is directly in view. In addition, the shopper also has to bend over to pick up the packages. These units also take up rather a lot of shop-floor space; by comparison, the vertical cabinets are much more effective, since they enable storage of much greater volumes of product per unit of floor space.



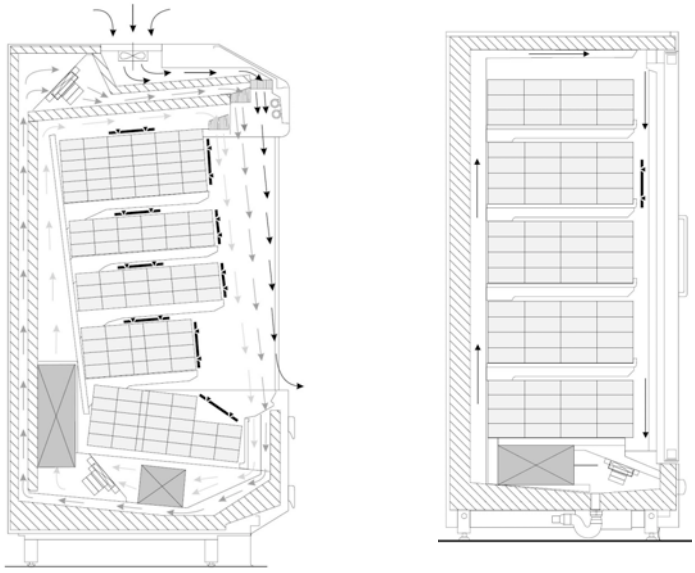
(A)



(B)

Figure X. (A) Open-top chest cabinet, wall-site unit. (B) Open-top chest cabinet, island type unit (arrows indicate air streams, while the line with triangular symbols is the 'load limit line'). [110]

Vertical cabinets are also meant for self-service operation: they are multi-decked (ranging from two to six) in order to save on space. In terms of their display function, cabinets with an open front are the most suitable (Figure 8(A)), although this open front is a source of ambient air infiltration, resulting in a high risk of temperature fluctuation and high energy consumption. Temperature fluctuations can be avoided by providing two or three parallel air curtains, as described below. This improves temperature control on the product side, but fails to reduce energy consumption. To prevent any air infiltration from the environment (and thus reduce any temperature fluctuation and improve energy efficiency), vertical cabinets are fitted with glass doors generally (Figure 8(B)). If the glazing is treated with a reflective layer, the doors prevent not only convective flows, but also the infrared radiant heat from the room.



(A) (B)

Figure 8. (A) Vertical cabinet with open front; (B) Vertical cabinet with glass door (arrows indicate air streams, while the line with triangular symbols is the 'load limit line'). [110]

Unfortunately, glass doors diminish the effectiveness of the display function, since consumers must open them to reach the product. While the doors are open, unwanted air infiltration is inevitable: incoming air humidity tends to condense on the inside of the glass door as soon as it is closed.

Larger stores are often equipped with so-called combination cabinets, comprising an open-top cabinet with an upright unit above it – typically a multi-deck cabinet with a glass door (Figure 9). This combination offers the advantage of a large capacity per unit of floor space. It is also worth mentioning the compact, open-top chest cabinets especially suitable for special offers: usually these units are self-contained, for plug-in applications, and are suitable for storing both chilled and frozen foods.

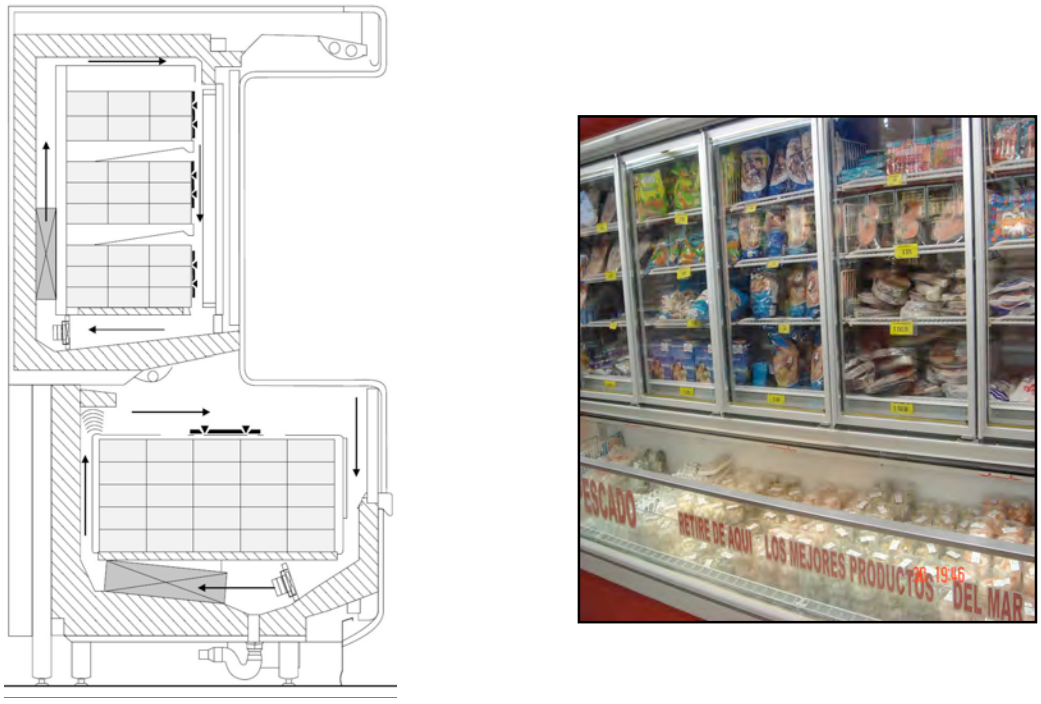


Figure 9. Combination cabinet: open-top plus multi-deck unit with glass door (arrows indicate air streams, while the line with triangular symbols is the 'load limit line'). [110]

4. MAINTAINING SAFETY IN THE COLD CHAIN

It is the aim of this chapter to describe some of the issues relating to the frozen fish supply chain, to highlight some of the key factors that need to be controlled in order to maintain quality and to describe, where possible, how this control might be exercised.

The main elements of the deep-frozen food and chilled food chains are production, storage, distribution, and sale. They are only part of a system in which a large number of steps have an influence on the final product quality. The integral processing and distribution chain may comprise the following stages: Raw material selection and collection*; Raw material storage; Product conditioning; Primary production*; Lowering of product temperature; Advanced production; Packaging; Factory storage; Transport to central storage; Central storage*; Transport to distribution storage; Distribution storage (transshipment points); Transport to retail sale*; Retail sale*; Transport to private homes*; Storage in private homes (household refrigeration)*; Preparation for consumption*; Consumption (Operations with the highest potential for quality losses are indicated by an asterisk*).[113]

To produce a product at 0–1°C and/or –20°C and transport it through the food chain to the consumer is, from a technological point of view, not at all difficult. Problems arise because of the need to use real people, machinery and buildings and to perform the operation at a reasonable price. The greatest difficulties arise at the transfer points, for example between cold stores and transport, in retail display where high visibility and easy access conflict with good temperature control, and during home transport by the consumer.

Controlling and monitoring of the cold chain is further complicated by the fact that different products will respond to changes in temperature in different ways. What is a drastic temperature abuse to one product may have no significant effect on another. Despite this difficulty there is no doubt that legislative pressure for traceability throughout the seafood industry is going to affect the logistics of frozen seafood distribution. Further economic pressures are likely to make retailers and manufacturers keen to understand the limits within which they must maintain the cold chain to protect quality and in extremis safety of frozen food products. [112]

The cold chain is a temperature chain. For fresh fish it means 0°C from the sea to the consumer. The cold chain is broken every time the temperature of the fish rises above 1°C. On each occasion that there is a break in the cold chain, there is increasing quality loss that cannot be reversed by any means. There are many opportunities for breaks to occur in the cold chain, because of the many links in the chain. [56]

There are 12 links in this example of cold chain (Live fish on deck → Iced down in the fish hold → Unloading at the wharf → Transport to the wholesaler → moved at the wholesaler → removal from cold

storage for processing → returned to cold storage or transported to retailer → moved into cold storage again → removed from cold storage for cutting → into window display → sale to consumer) and more than 20 people will handle the fish through those stages. At every stage someone must take responsibility for ensuring that the cold chain remains intact to ensure that the fish remains as close to 0°C as possible (or is maintained in the frozen state at –18°C or colder). Only at those stages in the cold chain described above which are underlined, is a temperature rise unavoidable. At every other stage a rise in temperature can be prevented, but often is not. [56]

A quality fresh fish chain delivers the right product at the right place at the right time. The physical organization and the management of the chain must support this condition, and to be competitive the number of steps in the chain from fishing vessel to end customer can be reduced to a minimum. A consequence is reduced time and costs in the chain. Ideally the only 'warehouse' in a quality fresh fish chain is onboard the vessels until they reach the quay and in the trucks on the way to the retailers. Each fish should only be physically handled in two steps of the chain after catch: 1) **Onboard the vessel**: gut, bleed, wash, sort in species, size grade, weigh, icepack, label each box with catch date; and 2) **At the retailer**: process if any, display, icepack and sell to the consumer.[2]

Size grading and weighing the catch is only possible onboard a number of big vessels today. In some countries plastic insulatedcontainers are used instead of boxes onboard vessels. Then it is very important to control the mixture of ice and water that is used to keep temperature at about 0°C in the containers. The vessels should know the amount of fish sold to the consumer each day to plan the fisheries and the length of journey and the fish should be sold before the vessel enters the harbor. [2]

Quality is considered to be the time temperature tolerance of the fish/product defined as the number of days it is kept at 0°C, after having been caught and treated gently by approved methods. If the quality of a fish is stated as the catch date in all steps, the customer has all the critical information to make a decision on what to buy. The chosen unit for quality is equivalent days in ice at 0°C (sometimes called 'ice days'). Hours at 0°C is impractical to use and the natural variation in quality attributes of raw material means that greater precision cannot be obtained. The variation in quality properties is defined as the mixture of fish with different ice days (two different or several ice days). Quality variation is minimized through avoiding mixing fish with different ice days. [2]

The most important factors deciding the properties of fish are the time temperature tolerance. In general white fish species have 'high quality' in the first 6–8 days after catch (kept at 0°C, in clean containers, caught and treated gently), but in the first 6–8 days fish properties, and hence perceived quality, changes too.[2,3]

The frozen foods market has grown throughout the twentieth century and a much wider selection of frozen foods is available. Products tend not to be just the individual components of a meal such as fish fillets or joints of meat. Now whole meals are available and the increased availability of such products is consistent with the changes in consumers' lifestyle. The trends of more people living alone and for more households with both partners working are likely to increase. Thus, the requirement for good-quality, nutritious, safe foods without compromising convenience are also likely to increase. The frozen food format is ideally suited to be able to deliver all of these consumer requirements.

As an example, let us suppose that we have a ready meal whose shelf-life when stored at –25°C is determined by the rate of lipid oxidation in the meat component. However, if it is stored at –15°C the fastest deterioration occurs due to enzyme action in the vegetable component and at –5°C shelf-life is determined by dehydration due to moisture migration from the mashed potato. In storing and transporting this hypothetical product, the manager may be asked to decide: *i*) the limits of temperature fluctuation allowed in the defrost cycle of the cold store; *ii*) the amount of time allowed in a loading day at 0°C; *iii*) when his truck breaks down for two hours, whether he or she should throw away the product, reduce its shelf-life or carry on as if nothing had happened. [112]

It has been suggested that the storage temperature on lean demersal fish should be between –24°C to –30°C. [110] For oily fish, storage temperatures of –30°C to –70°C have been recommended[17,18] in order to reduce the rate of oxidative changes. However, low–temperature storage is not currently employed as the cost to the consumer for the final product is too high.

4.1.1. Temperature monitoring

Temperature is the single most important factor affecting the rate of fish and shellfish deterioration and multiplication of micro-organisms. For species prone to scombrotoxin production, time and temperature control may be the most effective method for ensuring food safety. Therefore, it is essential that fresh fish, fillets, shellfish and their products that are to be chilled should be held at a temperature as close as possible to 0 °C. [66]

To minimize deterioration (time), it is important that: *i*) Chilling should commence as soon as possible; *ii*) Fresh fish, shellfish and other aquatic invertebrates should be kept chilled, processed and distributed with care and minimum delay. To minimize deterioration (temperature control), where temperature control is concerned: *i*) Sufficient and adequate icing, or chilled or refrigerated water systems where appropriate, should be employed to ensure that fish, shellfish and other aquatic invertebrates are kept chilled at a temperature as close as possible to 0°C; *ii*) Fish, shellfish and other aquatic invertebrates should be stored in shallow layers and surrounded by finely divided melting ice; *iii*) Live fish and shellfish are to be transported at temperatures tolerable for species; *iv*) Chilled or refrigerated water systems and/or cold storage systems should be designed and maintained to provide adequate cooling and/or freezing capacities during peak loads; *v*) Fish should not be stored in refrigerated water systems to a density that impairs its working efficiency; and *vi*) Monitoring and controlling the time and temperature and homogeneity of chilling should be performed regularly. [66]

4.1.2. Importance of temperature monitoring

Refrigeration equipment is built to function for long periods without attention; however there are many events apart from breakdown which can affect temperature control. The defrost cycles need attention to ensure they are at the correct frequency, and loading of food into refrigerated systems is often crucial to its operation and proper air flow. Air temperature monitoring can indicate whether refrigerated equipment is functioning correctly and is being operated correctly, even though it may be more difficult to extrapolate food temperatures. In some circumstances air temperature monitoring is not possible and product temperature or product simulant temperature is required. [75]

There are an enormous number of different temperature monitoring systems available commercially, from a simple thermometer to a fully computerized system linked to a local refrigeration system or even central control system. The choice of system will depend on exactly the amount of detail the operator requires and the cost at which this information is provided. If the monitoring system is to provide detailed information on the operation of a system linked with other reactive management systems, then obviously a more elaborate and complex system is required. This may include a large number of sensors to enable a very complete picture of the temperature distribution within a refrigerated system to be obtained. It may also include other information such as defrost cycles, compressor and expansion valve pressures, door openings, and energy consumption, and may be linked to an alarm system (and even telephone) stock keeping and batch codes of product. On the other hand, if monitoring is being carried out only to ensure that food is being kept within certain temperatures as a critical control point, then the amount of information which is collected may be reduced. [75]

When designing a monitoring system, there are certain considerations in the choice of temperatures to be measured in the refrigerated system. These are: *i*) The choice of whether to monitor air temperatures, product temperatures or simulated product temperatures will depend on the individual system and the way it operates; *ii*) The sensors should preferably be fixed in a position where they will not be damaged during commercial activity. If manual readings are used, these should be taken from accessible positions; *iii*) The temperatures chosen should be representative of the refrigerated system and give a picture of its functioning, and therefore be linked indirectly with the product temperature. [75]

Considering the importance of monitoring temperature in cold storage (Figure 10), a list of temperature monitoring in practice should be mentioned: *i*) chill storage (walk-in chill stores and cabinet refrigerators); *ii*) chilled transport (temperature controlled vehicles and small delivery vehicles); *iii*) display cabinets (multi-deck cabinets); *iv*) Serve-over display cabinets.

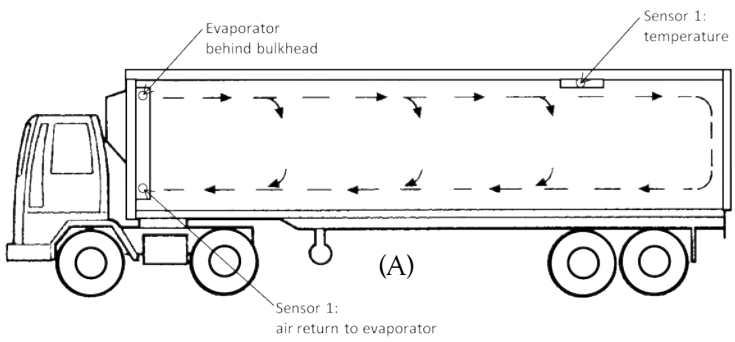


Figure 10. Air temperature monitoring: (A) Temperature controlled vehicle; (B) Serve-over cabinet; (C) Multi-deck cabinet (Adapted from Woolfe[75])

4.1.3. Temperature and time–temperature indicators (TTI)

Temperature monitoring has been discussed in terms of displaying temperature readings of the surrounding air or of the food or simulated food itself. However, it is possible to use a physico-chemical mechanism and a resulting color change to display (a) a current temperature, (b) the crossing of a threshold temperature, or (c) an integration of the temperature and the time of exposure to temperature after activation. Such devices are called temperature indicators (TIs) in the first two cases or time–temperature indicators (TTIs) in the last case. [75,76,77]

The indicators are normally integrated onto a packaging material which can be attached to the food packaging or the outside of the surrounding or bulk packaging, and can follow the food throughout the chill chain. The type of information than can be provided is one or more of the following: *i*) reject or accept on the basis of a color change; *ii*) temperature abuse above a threshold temperature; *iii*) partial time–temperature history above a threshold temperature; *iv*) full time–temperature history linked to shelf life. [75,76,77]

Over 100 patents have been filed on processes which could be used as a basis for indicators. These include changes with temperature based on melting-point temperature, enzyme reaction, polymerisation, electrochemical corrosion, and liquid crystals. The result of the change is usually a color difference, which can be represented as a static change or moving band. Available temperature and time–temperature devices have been reviewed. [75,76,77]

Lifelines have developed several indicators all of which show a full time–temperature history. The indicator part consists of polymeric compounds that change color as a result of accumulated temperature exposure. The color change is based on polymerization of acetylenic monomers which proceeds faster at higher temperatures leading to a more rapid darkening of the indicator. Developments in Lifelines technology have resulted in the manufacture of the 'Fresh-Check®' indicator, designed for consumer use. This device consists of two circles; a small inner circle which contains the polymer, and a printed dark or black outer ring. The inner ring darkens when exposed to time and temperature combinations at a rate predetermined by the durability of the food. The consumer is advised not to consume the product when the inner ring has become darker than the printed outer one (see Figure 11).

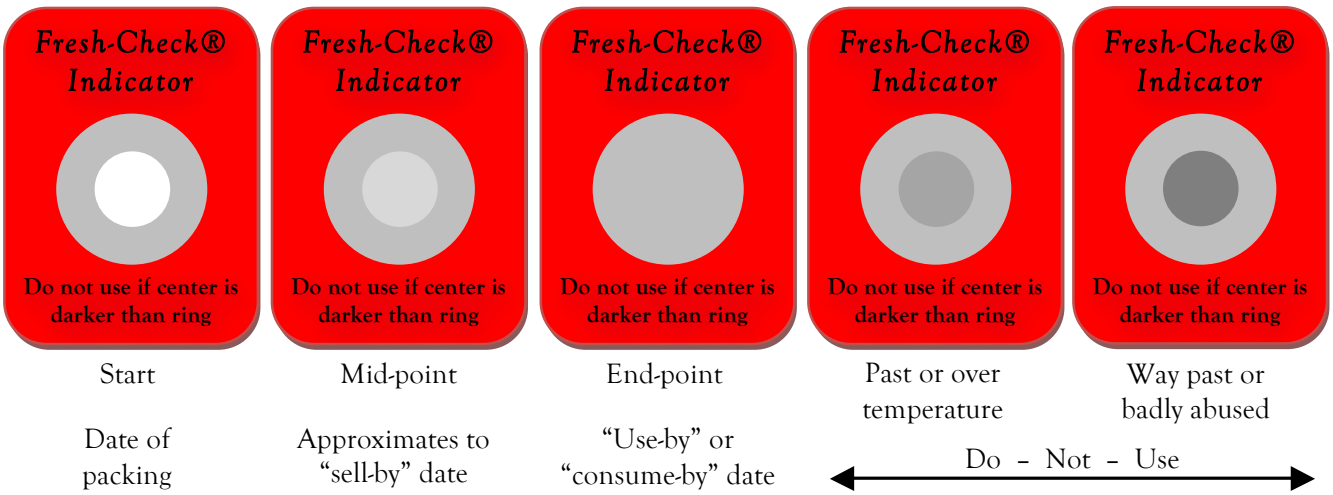


Figure 11. The Lifelines 'Fresh-Check' indicator – staged examples. [75]

In order to try to link the indicator to microbiological safety as well as quality deterioration, a new development has been the incorporation of a second polymer system in the centre ring. If the indicator stays below a pre-set maximum then the polymer will change color as above, and the change is linked to the durability. If the temperature rises above the maximum, then the second system starts to polymerize, and the centre will darken abruptly at the end of a predetermined length of time. Lifelines labels are not physically activated, and once manufactured respond to any temperatures to which they are exposed. Therefore before use, indicators must, at all times, be stored at –18°C or colder. [75]

The main causes of loss of storage life are fluctuating temperatures and the type of packaging used. Other factors, including type of raw material, pre-freezing treatments and processing conditions have a great contribution on frozen seafood quality. Temperature fluctuation has a cumulative effect on food quality and the proportion of PSL or HQL lost can be found by integrating losses over time. Time-temperature tolerance (TTT) and product-processing-packaging (PPP) concepts are used to monitor and control the effects of temperature fluctuations on frozen food quality during production, distribution and storage. [75,78,79,80,81,114]

Colored indicators are being developed to: *i*) show the temperature of food (for example, liquid crystal coatings which change color with storage temperature); *ii*) indicate temperature abuse (for example wax melts and releases a colored dye when an unacceptable increase in temperature occurs); *iii*) integrate the time–temperature combination that a food has received after packaging; and *v*) to give an indication of the remaining shelf life (Figure 12). In the last category, indicators may contain a material that polymerizes as a function of time and temperature to produce a progressive, predictable and irreversible color change. In another type, a printed label contains diacetylene in the centre of a 'bull's eye', with the outer ring printed with a stable reference color. The diacetylene gradually darkens in color due to combined time and temperature and when it matches the reference ring the product has no remaining shelf life.

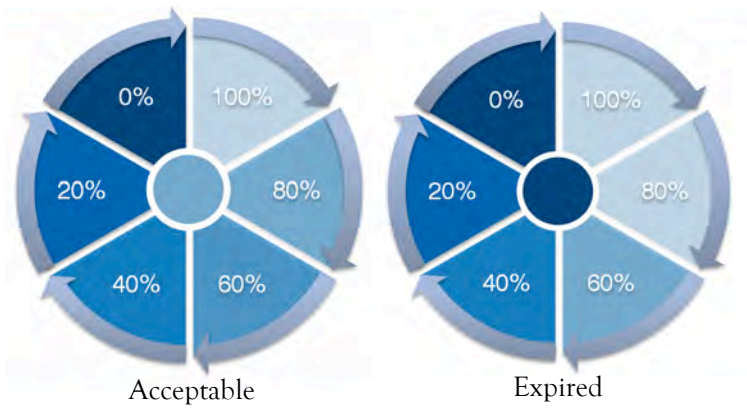


Figure 12. Time–temperature integrator (Indicator based on the color change of the inner circle: the percentages show the equivalence of color with the remaining life).[75]

More recently a bar code system has been developed that is applied to a pack as the product is dispatched. The bar code contains three sections: a code giving information on the product identity, date of manufacture, batch number, etc. to identify each container uniquely. A second code identifies the reactivity of a time–temperature indicator and the third section contains the indicator material. When the bar code is scanned by a hand-held microcomputer, a display indicates the status and quality of the product with a variety of pre-programmed messages (for example: 'Good', 'Don't use' or 'Call QC'). A number of microcomputers can be linked via modems to a central control computer, to produce a portable monitoring system that can track individual containers throughout a distribution chain.[78]

Francisco → do you have images to exemplify this cold system? (nope, sorry)

4.1.4. Chilled and frozen seafood microbiology

The effect of reducing temperature is to reduce the rate of food deterioration. This applies not only to the chemical and biochemical changes in foods but also to the activities of microorganisms. The range of temperatures over which microorganisms can grow is extremely wide. Walker & Betts[87] reported that a number of microorganisms, mainly yeasts, were able to grow below 0°C and a pink yeast isolated from oysters was reported to grow at 34°C. Therefore, chilling alone cannot be relied upon to prevent all microbial growth. The use of chill temperatures will, however, reduce the rate and extent of microbial growth.

In favorable environments growth of bacteria normally proceeds as shown in Figure 13, where the logarithm to the number of bacteria is the vertical axis and time is the horizontal axis. First there is a period of adjustment, the lag phase, where the bacteria are more or less inactive, i.e. they do not multiply. The length of the lag time depends on many factors, e.g. temperature, pH, inhibitors in the substrate (the food), etc. After the lag phase, growth begins and reaches a phase of exponential growth. In the exponential growth phase, the number of bacteria may rise very quickly, often expressed by the generation time, i.e. the time required to double the number of bacteria. The generation time varies between bacteria, and depends on several factors, in particular the temperature. The two remaining phases are of less interest.

Inactivation of micro-organisms caused by freezing and thawing may take place in three ways: *i*) When a food is cooled so that vegetative micro-organisms are kept at temperatures below their minimum for growth, some loss of viability can be expected; *ii*) Inactivation of micro-organisms takes place during the freezing process. The response of micro-organisms to freezing is mainly studied in thawed cultures; therefore, the thawing method is a very important aspect that must always be taken into consideration; and iii) Finally, inactivation of micro-organisms may take place during storage, depending on storage time and temperature.[99]

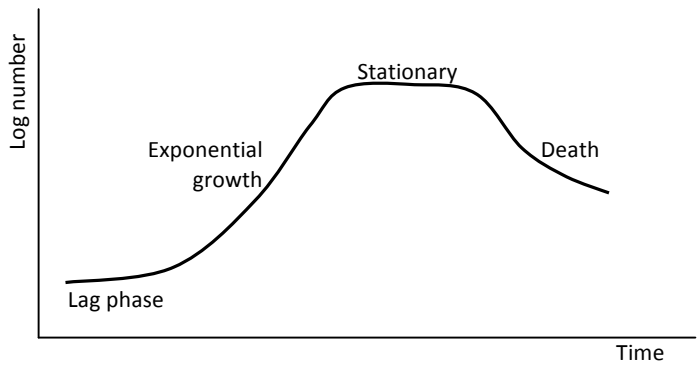


Figure 13. A typical bacterial growth curve.[78,79,85,87,88,99]

Microbiologists have attempted to characterize microorganisms based on their abilities to grow at various temperatures. Most commonly, the cardinal temperatures for growth (minimum, optimum and maximum growth temperatures) are used. With chilled foods, the factor of most concern is the minimum growth temperature (MGT), which represents the lowest temperature at which growth of a particular microorganism can occur. If the MGT of a microorganism is greater than 10°C, then this microorganism will not grow during chill storage. Based on the relative positions of the cardinal temperatures, microorganisms can be divided into four main groups, *viz*., psychrophile, psychrotroph, mesophile and thermophile (Table 10). With chilled foods,

the groups of most concern are the psychrophiles and psychrotrophs. In the past, these terms have been used synonymously, which has led to much confusion. It is now accepted that the term 'psychrophile' should only be used for microorganisms which have a low (i.e. ≤ 20°C) maximum growth temperature. True psychrophiles are rare in food microbiology and generally limited to some microorganisms from deep-sea fish. The major spoilage microorganisms of chilled foods are psychrotrophic in nature. [87,88]

Table 10. Classification of microbial growth[87,88]

Temperature (°C)	Psychrophile	Psychrotroph	Mesophile	Thermophile
Minimum	< 0–5	< 0–5	(5 to)† 10	(30 to)† 40
Optimum	12–18	20–30 (35)†	30–40	55–65
Maximum	20	35 (40–42)†	45	(70 to)† > 80

†Figures in parentheses are occasionally recorded for microorganisms assigned to a particular classification.

The composition and number of microorganisms present is affected by the indigenous microflora, microorganisms contaminating before and after processing, the growth rates and abilities of the microorganisms, the spoilage abilities of the microorganisms, the intrinsic properties of the food, the effects of processing and packaging, and the time and temperatures of storage. Consequently, the microbial safety and spoilage of chilled foods is very complex, but certain general principles may be applied: *i*) The microbiological status of all raw materials should be known and only materials of good quality used; *ii*) All stages of processing should be defined, monitored and controlled to ensure their correct operation. This is of particular significance in foods which rely on a combination of factors to ensure microbial stability; *iii*) The temperatures and times of chill storage should be controlled during all stages, from raw materials through retail sale and preferably to the home. The lower the temperature throughout the process, the slower the rate of growth; *iv*) Attention must be given to the hygiene of the entire process to ensure that microbial contamination is minimized. [87,88]

The minimum growth temperature of micro-organisms is a very important factor for chilled foods also. The organisms grow very slowly (have a long generation time) when the temperature is approaching the minimum. Chill temperature behavior is of great significance to frozen foods as microbial growth may take place before freezing, during thawing and during (chilled) storage after thawing. Table 11 indicates the minimum growth temperature of some pathogenic bacteria.

Table 11. Minimum growth temperature of some pathogenic bacteria.[87,88,99]

Microorganism	Minimum temperature, °C
Bacillus cereus	5
Campylobacter	30
Clostridium botulinum, type A	10
Clostridium botulinum, type E	3.3
E. coli O157	7
Listeria monocytogenes	0
Salmonella	5
Staphylococcus aureus	7
Vibrio parahaemolyticus	5
Yersinia enterocolitic	0

Some microorganisms may die when kept at temperatures below their minimum for growth. However, above 0°C the loss of viability is limited, even if micro-organisms are stored more than 10°C below their minimum temperature. In practice, inactivation of micro-organisms at temperatures above 0°C is negligible. The inactivation of micro-organisms may be more pronounced when bacteria in the exponential growth phase are cooled quickly. However, when bacteria experience an abrupt temperature drop, e.g. more than 12–14°C, they may respond by forming the so-called cold shock proteins. Such proteins may afterwards protect the bacteria against other stresses, e.g. heating, low pH, low water activity, etc.[99]

Frozen foods have an excellent safety record and freezing has never been reported to be the cause of food poisoning. The great advantage of freezing is that microorganisms do not grow in foods when the temperature is –10°C or colder. Foods preserved by means of other preservation methods (chilling, drying, curing, canning, etc.) have been more or less directly involved in food safety problems, because these foods are

stored at temperatures that allow microbial growth. However, it should not be overlooked that although freezing kills some micro-organisms, it does not eliminate pathogenic micro-organisms nor microbial toxins present in the food product prior to freezing. During the freezing process the product temperature is lowered and most water in the food is transformed into ice crystals. With decreasing temperature the liquid phase becomes more and more concentrated. As the volume of ice is about 10% larger than the volume of water, the internal pressure in the food may rise to 10 bar or more, especially during very rapid freezing.[99,124]

In practice, foods are frozen to be stored for a certain period, often several months. Frozen storage is always included, and it is the combined effect of the freezing (and thawing) process and frozen storage that is of interest. Warm storage, i.e. temperatures warmer than –8°C, results in much larger inactivation of micro-organisms than storage at –18°C or colder. Freezing and storage at very low temperatures, down to –150°C or even colder, seems to result in increasing survival. During frozen storage the above-mentioned mechanisms (cell dehydration, membrane damage, etc.) continue to act upon the micro-organisms, eventually leading to injury or death of a certain part of the organisms. It is also suggested that the death of micro-organisms may be caused by long-time exposure to concentrated solutions, both internal and external.[99]

The inevitable temperature fluctuations in the cold chain will cause re-crystallization of ice crystals, increasing the salt concentration and increasing the damage to micro-organisms. The increasing size of the ice crystals during storage will reduce the difference between foods frozen very rapidly and foods frozen with a normal freezing rate, and have some influence on the survival of micro-organisms.[99]

4.1.5. Non–microbiological factors affecting quality and safety

As the chilled and frozen seafood market has expanded and become more competitive, so have the demands for diversity, quality and longer shelf-life. Meeting these demands in a responsible, safe and cost-effective manner requires the application of an understanding of the factors that affect product safety and quality. Non-microbiological factors that affect quality and safety of chilled foods can be broadly divided into chemical (i.e. lipid oxidation, meat pigment discoloration), biochemical (i.e., enzymes denaturation, enzymic browning, glycolysis, proteolysis, and lipolysis) and physico-chemical factors (as a result of physical changes to the product or the chemical or biochemical reactions that follow). Each of these is dependent on properties of the food (e.g. pH, water activity) and the conditions in which the food is held (e.g. temperature, gaseous atmosphere).[89]

Non-microbiological safety issues associated with chilled foods are rarely a result of, or exacerbated by, chilled storage temperature. Some arise as a consequence of the ingredient combinations or minimal processing that subsequent chill storage enables. In most instances, judicious selection of raw materials and a carefully tailored monitoring programme, based on an assessment of the risks posed by individual ingredients and the final product, contributes to the assurance of product safety. If possible, it is always preferable for shelf-life to be limited by changes in quality rather than safety because changes in quality can usually be discerned by the smell, taste or appearance of the product, but such changes cannot be relied upon to indicate when safety limits the shelf-life.

Scombroid fish poisoning occurs throughout the world, though most incidents are recorded in the USA, Japan and the UK (???? Sure??). *Scombridae* and *Scomberesocidae* families (tuna, mackerel, saury, bonito and seerfish), but incidents have also been associated with non-scombroid fish (sardines, herring, pilchards, anchovies and marlin). Histamine has been considered to be the cause of scombrotoxic poisoning for a number of reasons. Analysis of the fish remaining 'on the plate' usually reveals it contains high levels of histamine; metabolites of histamine have been detected in the urine of victims; symptoms resemble those of known histamine responses; and administration of antihistamine drugs reduces the severity of symptoms. Histamine is a spoilage product resulting from decarboxylation of the amino acid L-histidine which is abundant in scombroid fish flesh. Formation of histamine requires the enzyme histidine decarboxylase, which is produced by the normal bacterial microflora of fish skin, gut and gills. If fish is stored above 4°C, these organisms proliferate and levels of histamine in the flesh increase. Prevention of scombroidfish poisoning would therefore appear to be highly dependent on good handling practices – rapid chilling of the catch, and adequate chilling of the fish prior to preparation for eating.[89,90,91]

5. SHELF–LIFE FOR CHILLED AND FROZEN FOODS

When fish is freshly caught eating quality is high, but over time quality will deteriorate and eventually the fish will become unsuitable for consumption. The time taken for this point of unsuitability to be reached is

known as the shelf life.[56,92] Throughout the shelf life of the fish, changes occur which result in a gradual loss of eating quality. This is also referred to as spoilage. Typically, for fresh whole fish in ice, spoilage will follow a recognized pattern:

- **Phase 1:** The fish is very fresh and has a sweet, sea weedy and delicate taste. The taste can be very slightly metallic. In many white fleshed fish the sweet taste is maximized 2-3 days after catching;
- **Phase 2:** There is a loss of the characteristic odor and taste. The flesh becomes neutral but has no off-flavors. The texture is still pleasant;
- **Phase 3:** There is sign of spoilage and a range of unpleasant odors is produced depending on the fish species. One of these is the characteristic "fishy" smell. At the beginning of the phase the off-flavor may be slightly sour, fruity and slightly bitter, especially in fatty fish. During the later stages sickly sweet, cabbage-like, ammoniacal, sulphurous and rancid smells develop. The texture becomes either soft and watery or tough and dry;
- **Phase 4:** The fish can be characterized as spoiled and putrid. For each species of fish the spoilage pattern will be slightly different.[56]

International surveys have revealed that the image of frozen fish is not very positive. Whereas European consumers emphasized the neutral and insipid taste of these products, many U.S. consumers believed that frozen fish is less nutritious and bonier than fresh, and has a tough and dry texture, bad smell and inferior taste.[19,45] However, by careful selection of raw material, processing and storage conditions, frozen fishery products of high quality can be produced.[19,46] The many reasons for quality loss of frozen food, as well as techniques to avoid or retard deterioration, have been described recently.[19,47] In the case of frozen seafood any study of quality has to take into consideration (i) the high number (several thousand worldwide) of fish species possessing different composition and biochemical properties, and (ii) the fact that most of the raw material is from wild, not from farmed, animals, in contrast to meat production.[19,48]

Deterioration of frozen fishery products depends on extrinsic and intrinsic factors. The most important extrinsic factors are the speed of freezing, storage temperature, fluctuation of temperature, penetration of oxygen into the product during storage and, not to forget, the mode of thawing or heating the product. Intrinsic factors are given by the biochemical properties of the fish or shellfish. Enzymatic equipment, type of fatty acids in the lipid fraction and presence of other metabolites, which are precursors of undesirable compounds, are responsible for main deteriorative processes.[19,48]

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

Table 12. Practical storage life for fish[63,110]

Seafood	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

Freezing of fish is accompanied by formation of ice crystals resulting in concentration of salt and organic compounds, and pH changes in the liquid phase. These processes are influenced by the freezing rate, the storage temperature [19,49] and temperature fluctuation. Muscle proteins are dehydrated and denatured, and membranes are destroyed.[19,49,50,51] The two most important pathways are lipid hydrolysis and oxidation[19,52,53] and in gadoids and a few other species, cleavage of trimethylamine oxide into formaldehyde and dimethylamine by the enzyme TMAOase.[19,54]

The spoilage pattern of seafood may be influenced by biological parameters[19,48,55]: *i*) Fish species; *ii*) Physiological condition of the fish; *iii*) Fishing ground; *iv*) Size of the fish; *v*) Sex of the fish; and *vi*) Composition of feed farmed fish. The conditions of catching and processing are of paramount importance for the deterioration of frozen fish, and the quality is affected by: *i)* Method of catching, length of trawling time; *ii*) Stunning and killing procedure; *iii*) *Rigor mortis*; *iv*) Bleeding; *v*) Single and double freezing; *vi*) glazing and

coating; *vii*) type of product (whole fish, fillet, minced fish); *viii*) Freezing and thawing conditions; and *ix*) Storage conditions.

One of the major areas to assist in shelf-life determination is predictive microbiological modelling. In particular, the development of food sector specific models will increase in the future. Models have been developed for fish products available from the Ministry of Fisheries, Technical University at Denmark (Seafood Spoilage Predictor on the internet – http://www.dfu.min.dk/micro/ssp/help/usingssp.htm). Such models will enable an evaluation to be made of the interactive effects of a mixed microbial flora typically found in these products on food spoilage. There will be an increasing use of alternative technologies to improve the quality and/or shelf-life of chilled seafood. [92]

Temperature and time of frozen storage have a large influence on shelf-life of frozen stored fish. Temperature should be as low as economically possible, but at least less as –20°C. Aweak point in the cold chain is the temperature of deep freezers in supermarkets, which often is too high and fluctuates over the day. Other conditions, like vacuum-packaging or protection from light, may have less influence on deterioration. A trial of storing catfish fillets at –20°C for 11 months did not reveal significant differences in the sensory attributes of fillets, which either had been vacuum packaged or oxygen-permeable packaged. [19,20]

5.1.1. Changes during chilling process

Seafood is highly perishable. It begins to deteriorate as soon as it dies, in water or onboard a fishing vessel. Spoilage, coupled with loss of freshness, takes place through bacterial, enzymatic, or chemical action. *Bacteria that do little harm to a healthy, live fish invade the fish body on its death and begin weakening the chemical structure. Enzymes in the living fish remain active after death and cause unwanted flavor changes during the early stages of storage. Chemical reactions between oxygen in the air and fat in the fish create additional undesirable rancid flavors. Fish spoil much faster through these reactions at higher surrounding temperatures.* For example, Atlantic cod *Gadus morhua* from the Norwegian seas kept at 0°C has a shelf life of 12–16 d, whereas the shelf life reduces to 7–9 d at 4°C, 5–6 d at 8°C, and 3–4 d at 12°C. [120,121] Similar trends are reported for crab claws, salmon, and sea bream. [120,122] The deterioration process may accelerate once fish is bruised, cut, scraped, or contaminated. [120]

5.1.2. Changes during freezing process

As freezing begins, ice crystals start to form in the spaces between the microscopic cells in the flesh. If the freezing rate is very slow, ice does not form inside the cells at all. Indeed, water in the cells is drawn out through the cell walls into the extra cellular spaces (between the cells) where ice is forming. By the time that the interior of the cells are cold enough to freeze, there may be very little water left in them anyway. Large ice crystals will form between the cells - the cells themselves are punctured and dehydrated. During rapid freezing, water does not have time to be drawn out of the cells to join with the crystals forming there - the water is frozen wherever it is found, inside or outside the cells. Also during slow freezing there can be damage caused by protein denaturation. Denaturing of proteins simply means that the proteins lose their natural structure and thus their ability to 'hold' water - they unravel. Fish which has been damaged by slow freezing tends to be soft and watery when thawed. [56,63,100]

Under most commercial freezing processes ice forms between the muscle fibers and the fibers shrink transversely as water is abstracted from them to form extra–cellular ice. Areas of ice and areas of concentrated muscle fibers may be observed. Surprisingly, even at quite low temperatures there will be a fraction of water, the non–frozen fraction, which will not be converted to ice. This fraction exits because as ice forms the solute concentration within the fibers increases, this in turn depresses the freezing point within the fiber. A point is reached whereby the freezing point of the non–frozen fraction equals the temperature at which the fish are being frozen. Once this point is reached, equilibrium is established between the ice phase and the non–frozen fraction. Table 13 shows the amount of unfrozen water in cod fillet as a function of temperature. Clearly, the amount of non–frozen fraction will vary as a function of temperature, and so will its viscosity. [5,100]

5.1.3. Changes on frozen storage

During frozen storage the quality of fish changes as spoilage continues. In fact, the degree of spoilage during frozen storage is much greater than that due to the freezing or thawing processes. But the rate of spoilage is still much slower than with chilled fish, and the factors which cause the spoilage are different. [56,100] At standard cold store temperatures of around –25°C, changes in the flavor and texture of frozen fish will be

noticed after a few months and with time, more significant changes will be noticed such as: firm elastic flesh becomes dull and spongy; translucency will be lost and the flesh will change to white, then to cream or yellow; the flesh will sag and break and lose liquid; when cooked, the fish tastes wet and sloppy – on further chewing it becomes dry, fibrous and tasteless; fats (or lipids) in the fish will change and produce bad flavors and odors; dehydration can occur leading to freezer burn (dry, white surface, texture breakdown, weight loss, increased protein and fat breakdown). [56,63,100]

Table 13. Variation of percentage of water that remains unfrozen for cod fillet

Temperature (°C)	% Unfrozen water
–1	92
–2	48
–3	33
–4	27
–5	21
–10	16
–20	11

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 favorable 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. [63]

In addition to spoilage factors which affect fresh fish, there are three further factors to consider with frozen fish: *i*) protein breakdown; *ii*) fat oxidation; *iii*) sensorial changes; and *iv*) dehydration changes. [56,63] There are a number of factors and treatments that may have a positive or a negative impact upon frozen storage stability and final quality of fish products as experienced by the consumer. These have been set out in approximately chronological order from initial catch to the freezing process. [5,63,100]

One of the problems associated with freezing and frozen storage of fish and fish–based products is that changes in the flavor and texture of the final cooked product may occur. By forming a highly concentrated phase, through freezing, potential reactants (for example, enzymes and substrates) will be brought together and diffusion distances shortened. Indeed, reactants that were inaccessible to each other in the unfrozen cell may become far more intimately mixed after freezing. [5,9]

It has been reported by a number of authors that different species of fish have different susceptibilities to deterioration of texture attributes on frozen storage.[6,7,8,9] The reason for this is not clear, but a correlation between the body temperature of the fish and increased stability on frozen storage has been suggested. During storage in ice a number of changes may occur. These changes may be caused by enzymes present in the fish muscle or by the increase in microbial load on the fish surface. The changes may affect the initial flavor and texture of the fish and also the resistance of the fillets to changes during frozen storage. [5]

Rough handling may also cause loss of desirable properties. For example bruising of fish may induce an increased rate of rancidity development on subsequent frozen storage. Therefore, it has been recommended to use chilled sea water (CSW) rather than ice for reducing bruising and to improve flavor stability. Contamination of the fillets with blood or viscera, especially material from the kidneys, is also likely to increase the rate of textural change on frozen storage. [5,15,16]

The major losses in quality attributes tend to occur on frozen storage. During frozen storage of certain species of fish changes occur which result in deterioration of the textural attributes of the cooked fillet. The textural change has been described as a tendency to express liquid on initial compression in the mouth, and for the remaining material to be hard, dry and fibrous. [5,6,7,8,9,100]

Generally it is reported that the textural changes occurring during frozen storage are due ultimately to changes in the myofibrils, although the exact mechanism is not clear. Studies of the water–holding capacity of other meat systems have shown that most of the observed changes in water–holding capacity can be attributed

to changes in the water–holding capacity of the myofibrils. [5,10] The changes in water–holding capacity of fish muscle on frozen storage may be due to two events. The first is the pushing or collecting together of the myofibrils within the fibers as ice is formed externally to the myofibrils. The second involves changes within the myofibrils that render them increasingly unable to swell back up once the fish is thawed and/or cooked. It is likely that it is the changes that occur within the myofibrils that give rise to the texture changes observed on frozen storage. [5]

The site of ice formation and the size of ice crystals may have important effects on the structure of the muscle cells and their organelles. This in turn can impact upon the storage stability of the fish in the frozen state. In some cases the effects of different freezing regimes are reported but no measurements of ice crystal size and location are made. Thus, it is sometimes unclear whether different freezing or storage regimes have produced differences in the ice crystal structure or location. Therefore, although many authors report biochemical changes on frozen storage, how much of the observed change is driven by changes in the ice crystals is unclear. [5]

The development of rancid off–flavors, essentially the oxidation of unsaturated fats, is problematic in many fish types and seriously limits their shelf life. [5,11] Because of this problem much of the work studying flavor changes in frozen fish has focused on preventing the development of rancid off–flavors in pelagic species of fish which have a relatively high oil content. Low–fat species of fish such as cod (*Gadus morhua*) and haddock (*Gadus aeglefinus*), predominantly store lipid in the liver.

Susceptibility to rancidity depends not only on the amount of lipid present, but also the lipid composition and its location in the fish tissue. Fish contain high levels of highly unsaturated fatty acids and uniquely high levels of n–3 fatty acids, for example, eicosapentaneoic acid (EPA) and docosahexanoic (DPA). It is for this reason that they are susceptible to oxidative rancidity. [5,12]

It has also been suggested that lipid oxidation products can affect the color and nutritional value of food. Nutritionally important unsaturated fats, such as n–3 fatty acids, may become degraded in purified fish oils. However, the degree to which these molecules are degraded in whole fish fillets is still an area of some uncertainty.[5,13,14]

For many years attempts have been made to determine the shelf-life of frozen fish by a number of chemical, biochemical and physical methods but still today the gold-standard is sensory assessment by a well-trained panel. The best way of quality determination in food science is of course sensory evaluation, if it is performed properly. The sensory properties mainly decide whether a product will be accepted by the consumer or not. In the case of frozen fish, some sensory characteristics of spoilage of frozen fish, together with the reactions they are based on, are summarized in Table 14 and have been used in combination with different scoring schemes for quality assessment. [19, 20, 21, 22]

Table 14. Sensory description of thawed cooked fish flesh, and underlying chemical or physical reaction[19]

Aspect of quality	Underlying chemical or physical reaction
Appearance	
Dry	Protein denaturation
Gaping	Breakdown of connective tissue
Freezer burn	Sublimation of ice
Yellowish	Lipid oxidation; formation of formaldehyde
Odour	
Cold-store odour (cardboard)	Formation of carbonyls by lipid oxidation
Sour	Formation of carbonyls by lipid oxidation
Rancid	Formation of carbonyls by lipid oxidation
Amine	TMAO degradation into DMA and TMA
Flavor	
Cold-store flavor	Formation of carbonyls by lipid oxidation
Sour	Formation of carbonyls by lipid oxidation
Rancid	Formation of carbonyls by lipid oxidation
Soapy	Lipolysis
Amine	TMAO degradation into DMA and TMA
Texture	
Dry	Protein denaturation, loss of muscle structure
Firm, tough	Reaction between formaldehyde and protein

Soft, mushy	Proteolysis

TMAO: Trimethylamine N-oxide; DMA: dimethylamine; TMA: trimethylamine

A new approach for rapid assessment of quality characteristics of frozen fish is named QIM, the quality index method, which was originally developed for whole fresh fish.[23] Three different grading schemes have been used for cod, one for thawed whole fish, one for fillet from thawed cod, and one for cooked fillet. The grading schemes are based on parameters that vary considerably with frozen storage conditions. Each scheme consists of two parts, the quality parameters and the characteristics for each parameter. The characteristics are scored, '0' being the highest score. For example, in the case of cooked fillet from thawed cod, the quality parameter 'colour' is described by the characteristics 'white and opalescent' (score 0), 'loss of whiteness' (score 1), 'greyish, one small blood stain' (score 2), 'slightly yellow, a few more blood stains (score 3), 'light brown, discoloured with blood' (score 4). The scores for all single parameters are added to give the total quality index.

Biochemical indicators can be divided into three categories; those that indicate: *i*) *Extractable protein* (protein denaturation, like extractability, hydrophobicity, viscosity, electrophoretic pattern); *ii*) *Changes in enzyme activities* (a decrease or increase of enzyme activity, release of particle-bound enzymes) - Table 15; *iii*) changes in metabolite concentrations (e.g. amines, aldehydes, adenosine triphosphates (ATP) and related degradation products of nucleotides: adenosine monophosphate (AMP), inosine monophosphate (IMP), and hypoxanthine).[19]

Table 15. Enzymes tested as an indicator of quality of frozen fish [19,24,25]

Enzyme	Results and conclusions
Myofibrillar ATPase	Drop in activity was not correlated with protein solubility or toughness
Aldolase	Decline in soluble enzyme activity observed for cod and haddock stored at –14°C
Malic enzyme (ME)	Latent form of ME showed a decrease in activity when fish was stored for 5 months at –7°C, but no change at –29°C.
Sarcoplasmic ATPase	Rapid decrease during frozen storage
Cytochrome oxidase	Activity decreased during frozen storage of cod and it was possible to distinguish between frozen storage temperatures –9, –20, and –40°C.
Acid phosphatase	Activity decreased during frozen storage of cod at –30°C
5'-nucleotidase	Activity decreased during frozen storage of cod at –30°C
Phospholipase	Activity increased in the first weeks of frozen storage of cod at –30°C, then it declined to reach the original level

The denaturation of fish muscle proteins during frozen storage leads to a decreased water-binding capacity, and a dry, firm and tough texture, if the time-temperature profile of storage is unfavorable. The state of water in frozen-thawed fish has been determined as thaw drip (TD), water-holding capacity (WHC), water-binding capacity (WBC), or cooking loss (CL). The amount of water released during thawing (thaw drip) can be used as a simple method to get initial information on the properties of the product. [19]

Water-holding capacity of raw muscle is either measured by centrifugation[26] or by collecting the fluid released during texture measurement. Water-binding capacity is determined in a similar way, but here a defined amount of water is added to the sample before measurement. WHC was determined in most experiments to describe protein-water interaction during frozen storage of fish. Some examples are compiled in Table 16 showing the suitability for the technique for quality assessment and shelf-life determination of frozen fish. [19]

Table 16. Water holding capacity of frozen and thawed fish [19,27,28,29,30,31]

Fish species and type of product	Storage conditions	Results
Whole cod (*Gadus morhua*)	Different combinations of time and temperature	WHC was strongly negatively correlated with the chemical quality parameters DMA and FA
Fillets of Argentine hake (*Merluccius hubbsi*)	7 weeks at –7°C	WHC was affected by sex, size and sexual maturity of the fish
Blue crab meat (*Callinectes sapidus*)	32 weeks at –29°C	WHC was improved by cryoprotectants
Single- and double-frozen fillets of cod (*G. morhua*)	9 months at –22°C	WHC decreased considerably during storage of double frozen fillets, but only slightly for single-frozen fillets
Minced prawn flesh (*Penaeus spp.*)	90 days at –12°C	Initial WHC was very high; the slight decline during freezing was diminished by cryoprotectants

Texture measurement has been used in numerous studies as an objective method for evaluating muscle structure of frozen thawed fish. A short review of the relation between texture and technological properties of fish has appeared recently. [32] The influence of instrumental parameters (compression, speed) on the results of texture profile analysis (TPA) has been critically discussed. [33,34] The different phases of the diagram of force over time recorded during a TPA cycle can be correlated with the texture properties of hardness, springiness, cohesiveness, gumminess, chewiness, resilience and adhesiveness. A few applications of texture measurement of frozen thawed fish are listed in Table 17, demonstrating the suitability of this technique for quality determination. Other physical techniques, like electronic noses, color measurement [35] or differential scanning calorimetry[28,36,37,38] have been used only occasionally for characterization of frozen fish.

Table 17. Texture measurement of frozen and thawed fish[19,21,30,34,39,40]

Fish species and type of product	Storage conditions	Results
Different species of hake	Different temperatures: −12, −18, −40°C, several months	Texture was inversely correlated to viscosity
Fillets of cod	1 week at −15, then 2 weeks at −40°C	Firmness of cooked muscle was affected by method of catching and time of year
Blue crab meat (*Callinectes sapidus*)	32 weeks at −29°C	Texture was affected by storage time and cryprotectants
Fillets of cod	90 days at −12, −14, −22,−30°C	Texture was related to many other chemical and physical indices; peak force increased with time and temperature
Single- and double-frozen fillet and mince from saithe (*Pollachius virens*) and haddock (*M. aeglefinus*)	−24°C	Texture measurement was compared to sensory assessment; tensile force was affected by double freezing

A number of spectroscopic methods have been applied quite recently to measure the quality-determining properties of frozen fish. Nuclear magnetic resonance (NMR), infra−red (IR) and Raman spectroscopy may offer the chance for rapid evaluation of the state of water and protein in frozen fish. Some results from the application of these techniques are compiled in Table 18 Low resolution NMR and near IR may have the greatest potential in the future.

Table 18. New spectroscopic techniques for quality assessment of frozen-thawed fish [19,29,38,41,42,43,44]

Fish species, type of product, storage conditions	Spectroscopic method	Results
Whole cod, various storage conditions	Near infra-red (NIR) reflectance spectra of the skin	NIR reflectance measurement provided determination of WHC
Fillets of hake (*M. merluccius*) were stored at −10, −30 and −80°C	Raman spectroscopy	Changes in secondary protein structure were related to changes in viscosity and texture
Fillets of cod (*G. morhua*) and haddock (*M. aeglefinus*) were stored at −20 and −30°C	High-resolution NMR, magnetic resonance imaging (MRI)	NMR enabled measurement of metabolites (TMAO, TMA, DMA, creatine phosphate); by MRI changes in muscle structure were observed
Fillets of cod were stored at −10, −20 and −40°C	Low-field NMR relaxation	Transverse relaxation time of protons was related to time and temperature dependent deterioration
Minced red hake (*Urophycis chuss*)	Fourier transform NIR	Spectral region of 1530−1866 nm was significantly correlated to DMA concentration
Minced fillet of cod was stored at −10, −20 and −70°C for up to 4 months	Low-field NMR relaxation	Water proton relaxation time was correlated to instrumental and sensory texture scores and DMA concentration.

6. WEIGHT LOSS FROM FISH DURING FREEZING AND COLD STORAGE

6.1. 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.[63,118]

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: *i*) Type of freezer; *ii*) Freezing time; *iii*) Type of product (food surface); *iv*) Air velocity; *v*) Freezer operating conditions; and *v*) During storage (room temperature fluctuations). [63,118]

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. [63,118]

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. [63]

Time in a freezer, however, cannot be directly related to the weight loss since the rate of weight loss shown in Figure 14 is not directly proportional to time. More weight is lost at the start of a freeze than at the end. Some weight losses are given in Table 19. 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. [63]

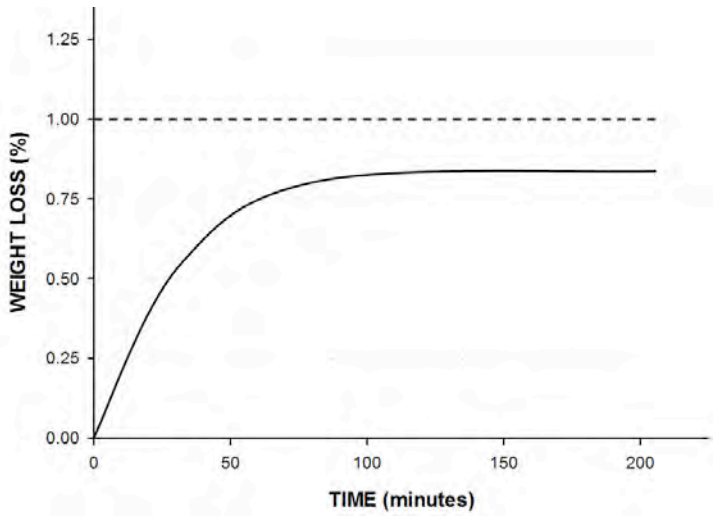


Figure 14. Dehydration weight loss from fish during freezing[63]

Table 19. Weight lost from fish during freezing[63]

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 14 would imply that freezing times would have to extend to many hours or even days for "freezer burn" to become apparent.

6.2. 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: *i*) Temperature; *ii*) Temperature fluctuation; *iii*) Humidity; *iv*) Heat transfer; *v*) Air flow over the product; *vi*) Radiation effects of lighting; *vii*) The product; *viii*) Shape and size of the product; and *ix*) Type of wrapper. [63]

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. 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. [63]

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. [63]

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. [63]

7. REGULATION AND LEGISLATION

7.1 Introduction

Most seafood legislation in the world will include definitions for fresh, frozen and chilled as well as regulatory limits in terms of prescriptive temperature requirements.

Some of the examples follow.

European Union

Temperature requirements are profusely referenced in the legislations, particularly in regulation Reg. 853/2004, some examples follow:

Temperatures under transport shall be so to minimize risk for growth of pathogenic bacteria, and deterioration by microbiological growth or enzymatic degradation. Criteria: "approaching that of melting ice", "melt water drain away", "at least -18 in all parts", "upward fluctuations max. 3 C",

Reference: Reg. 853/2004, Annex III, section VIII, ch. VIII-1, 2, 3, 4

Products shall be frozen rapidly to at least -18 C in the core and kept at at -18C or lower. Storage temperatures shall be monitored and documented. Reg. 853/2004, Annex III, section VIII, chapter III B (ref: section VIII, ch. 1 part 1, C1, C2)

Fresh fishery products (raw materials) shall be kept at temperature approaching that of melting ice and handled and stored to avoid contamination and or spoilage of the materials. Reg. 853/2004, Annex III, section VIII, chapter III A1, A4, A5 . Reg. 853/2004, Annex III, section VIII, chapter. VII-1, 2, 3

"Where freezing in brine of whole fish intended for canning is practised, a temperature of not more than -9 °C must be achieved for the product. Reg. 853/2004, Annex III, section VIII, chapter II, 7.

We need to insert something here before the importance of the seafood legislation...

Recommended International Code Of Practice For The Processing And Handling Of Quick Frozen Foods (CAC/RCP 8-1976 - Revision 1978, 1983, 2008)

Cold chain: A term embracing the continuity of successively employed means to maintain the temperature of foods, as appropriate, from receiving through processing, transport, storage and retailing.

Quick freezing process: A process which is carried out in such a way that the range of temperature of maximum ice crystallization is passed as quickly as possible.

Quick frozen food: Food which has been subjected to a quick freezing process, and maintained at -18°C or colder at all points in the cold chain, subject to permitted temperature tolerances.

Cold Store Design: The cold store walls, floor, ceiling, and doors should be properly insulated in order to help maintain appropriate product temperatures. It is important that the design of the cold store ensures that adequate refrigeration capacity provides and maintains a product temperature of –18°C or colder.

Frozen storage: Cold stores should be designed and operated so as to maintain a product temperature of –18°C or colder with a minimum of fluctuation. The temperature of the cold store may be an essential quality provision and/or a CCP to avoid a critical temperature abuse situation that may jeopardize food safety.

Transport: The transport of quick frozen foods should be carried out in suitably insulated equipment that ideally maintains a product temperature of –18°C or colder. The product temperature should be at –18°C or colder at the beginning of the transport.

Distribution: Distribution of quick frozen foods should be carried out in such a way that any rise in product temperature warmer than –18°C be kept to a minimum within, as appropriate, the limit set by competent authorities and should not in any case be warmer than –12°C in the warmest package to ensure quality of the products. After delivery, the product temperature should be reduced to –18°C as soon as possible.

Retail Sale: Quick frozen foods should be offered for sale from freezer cabinets designed for the purpose. Cabinets should be capable of maintaining and be so operated as to maintain a product temperature of –18°C. A rise in product temperature may be tolerated for short periods, with any rise warmer than –18°C kept to a minimum, within, as appropriate, the limit set by competent authorities, and should not in any case be warmer than –12°C in the warmest package.

Temperature management in the cold chain: Inadequate food temperature control is one of the most common causes of food borne illness. Inadequate food temperature control may also result in an adverse effect on product quality, including food spoilage. Temperature management systems should be in place to ensure that the temperature along the cold chain is controlled and monitored effectively.

Tolerances: Short term fluctuations of temperature of the product in the cold chain, within limits permitted in this Code and which do not affect safety and quality.

Recommended International Code of Practice for Frozen Battered and/or Breaded Fishery products (CAC/RCP 35-1985)

Freezer store: is an insulated and refrigerated room specifically designed for the storage of frozen products. Freezer stores have sufficient refrigerating capacity to maintain a temperature of –18°C (0°F) or lower for products already frozen, but are not designed to freeze products or to cool them down to storage temperature. (FR 2.21/mod.)

Frozen fish sticks, battered and breaded or fingers or portions: are clean, wholesome, uniform, unglazed masses of cohering pieces of fish flesh coated with batter and/or breading and presented either raw, partially cooked, or fully cooked which have been subjected to a freezing process sufficient to reduce the temperature of the product to a level low enough to preserve the inherent quality of the product and which have been maintained at this low temperature during transportation, storage and distribution up to and including the time of final sale.

Frozen fish blocks: are rectangular masses of cohering fish flesh which have been subjected to a freezing process sufficient to reduce the temperature of the whole product to –18°C (0°F) or lower to preserve the inherent quality of the fish and which have been maintained at this low temperature during transportation, storage and distribution up to the time of further processing.

Recommended International Code of Practice for Frozen Fish (CAC/RCP 16-1978)

Frozen fish: are fish which have been subjected to a freezing process sufficient to reduce the temperature of the whole product to a level low enough to preserve the inherent quality of the fish and which have been maintained at this low temperature during transportation, storage and distribution up to and including the time of final sale.

Freezer store: is an insulated and refrigerated room specially designed for the storage of frozen products. Freezer stores have sufficient refrigerating capacity to maintain a temperature of –18°C (0°F) or lower for products already frozen, but are not designed to freeze products or to cool them down to storage temperature.

Codex Standard for Quick Frozen Blocks of Fish Fillets, Minced Fish Flesh and Mixtures of Fillets and Minced Fish Flesh (CODEX STAN 165-1989, Rev. 1 - 1995)

The product after any suitable preparation shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution.
Codex Standard for Quick Frozen Finfish, Eviscerated or Uneviscerated (CODEX STAN 36-1981, Rev. 1 – 1995) The product, after any suitable preparation, shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution.
Codex General Standard for Quick Frozen Fish Fillets (CODEX STAN 190 – 1995) The product after any suitable preparation shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C (0°F) or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution.
Codex Standard for Quick Frozen Fish Sticks (Fish Fingers), Fish Portions and Fish Fillets - Breaded or in Batter (CODEX STAN 166 – 1989, Revisions 1995, 2004) The product after any suitable preparation shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution.
Codex Standard for Quick Frozen Lobsters (CODEX STAN 95 – 1981, Revisions 1995, 2004) The product, after any suitable preparation, shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution. Quick frozen lobsters shall be processed and packaged so as to minimize dehydration and oxidation.
Codex Standard for Quick Frozen Shrimps or Prawns (CODEX STAN 92-1981, REV. 1- 1995) The product, after any suitable preparation, shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution. Quick frozen shrimps shall be processed and packaged so as to minimize dehydration and oxidation.
Codex Standard for Quick Frozen Raw Squid (CODEX STAN 191 – 1995) The product after any suitable preparation shall be subjected to a freezing process and shall comply with the conditions laid down hereafter. The freezing process shall be carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C or colder at the thermal centre after thermal stabilization. The product shall be kept deep frozen so as to maintain the quality during transportation, storage and distribution.

FAO/WHO - CODE OF PRACTICE FOR FISH AND FISHERY PRODUCTS (2009).
Freezing process: A process that is carried out in appropriate equipment in such a way that the range of temperature of maximum crystallization is passed quickly. The quick freezing process shall not be regarded as complete unless and until the product temperature has reached –18°C (0°F) or lowers at the thermal centre after thermal stabilization.
Frozen fish: Fish that have been subjected to a freezing process sufficient to reduce the temperature of the whole product to a level low enough to preserve the inherent quality of the fish and that have been maintained at this low temperature as specified in the Standard for quick frozen finfish, uneviscerated and eviscerated (CODEX STAN 36-1981) during transportation, storage and distribution up to and including the time of final sale. For the purposes of this

Code, the terms "frozen", "deep frozen", "quick frozen", unless otherwise stated, shall be regarded as synonymous.
Frozen storage facility: A facility that is capable of maintaining the temperature of fish at or colder than –18°C, and with minimal temperature fluctuations. Severe fluctuations in storage temperature (more than 3°C) have to be avoided.
Transportation of end product: During all transportation steps, deep-frozen conditions should be maintained at –18°C (maximum fluctuation ±3°C) until final destination of product is reached. Cleanliness and suitability of the transport vehicle to carry frozen food products should be examined. Use of temperature-recording devices with the shipment is recommended.

8. SAFETY AND QUALITY ASSURANCE FOR CHILLED/FROZEN SEAFOOD PRODUCT

As mentioned earlier, controlled temperature of the product at 0°C is the key to trusting product quality without actual inspection of it. Inspection only once in the chain, onboard the vessel when gutting the fish will reduce the chain costs significantly. If the cold chain is broken the simple calculation indicating product quality of days elapsed (0°C) since catch will not be true and the product cannot be automatically used in the quality chain. Equipment and methods to ensure an intact cold chain are readily available. It is just a matter of implementing the right equipment and using robust procedures in each step in the chain to make it function. [2]

The most well known methods to manage quality and/or safety are: *i*) Good Hygienic Practices (GHP) / Good Manufacturing Practice (GMP) or Sanitation Standard Operating Procedures (SSOP) or prerequisite programmes; *ii*) Hazard Analysis Critical Control Point (HACCP); *iii*) Quality Control (QC); *iv*) Quality Assurance (QA) / Quality Management (QM) - ISO standards; *v*) Quality Systems; and *vi*) Total Quality Management (TQM).[98,99]

The primary concern of chilled food manufacturers is to produce a product that is both wholesome, i.e. it has all the fresh, quality attributes associated with a chilled food, and safe, i.e. free from pathogenic microorganisms and chemical and foreign body contamination. This is particularly important in this product sector as, due to the nature and method of production, many chilled foods are classified as high-risk products. [97] The main requirements for quality assurance systems are that it should be based on the Hazard Analysis Critical Control Points (HACCP) principles to ensure consumer safety, Good manufacturing practice (GMP) and Good hygienic practice (GHP) and it must be an active system that is continuously corrected, updated and developed according to input from customers and results of inspections. There must be: i) an intact cold chain in and in between all steps; ii) intact information flow in and in between all steps (traceability of the products); iii) an agreed standard method in the whole chain to measure fish quality on an objective basis (inspection method). [2,93,97,98,99]

Good manufacturing practice (GMP) covers the boundaries and fundamental principles, procedures and means needed to design an environment suitable for the production of food of acceptable quality. Good hygienic practice (GHP) describes the basic hygienic measures that establishments should meet and which are pre-requisites to other approaches, in particular HACCP. GMP codes and the hygiene requirements they contain are the relevant boundary conditions for the hygienic manufacture of foods and should always be applied. Generally GHP/GMP requirements cover the following: *i*) the hygienic design and construction of food manufacturing premises; *ii*) the hygienic design, construction and proper use of machinery; *iii*) cleaning and disinfection procedures (including pest control); *iv*) general hygienic and safety practices in food processing including the microbiological quality of raw materials, the hygienic operation of each process step and the hygiene of personnel and their training in hygiene and the safety of food. [66,93,98]

The Hazard Analysis Critical Point Control System (HACCP) is a food safety management system using the approach of identifying hazards and controlling the critical points in food handling and processing to prevent food safety problems. It is a system or approach that can be used to assure food safety in all scales and types of food manufacture and is an important element in the overall management of food quality and safety. The widespread introduction of HACCP has promoted a shift in emphasis from end-product inspection and testing to preventive control of hazards at all stages of food production, but especially at the critical control points (CCPs). As such, it is a management technique ideally suited to the manufacture of chilled foods, where many elements of the process contribute to safety and shelf-life, the shelf-life is restricted and any delay to await the results of microbiological testing uses-up shelf-life. [66,93,94,98,99]

HACCP involves: *i*) the identification of realistic (microbiological) hazards, such as pathogenic agents and the conditions leading to their presence, growth or survival (HACCP is also used for the control of chemical and physical hazards); *ii*) the identification of specific requirements for the control of hazards and

identification of process stages where this is achieved; *iii*) procedures and equipment to measure and document the efficacy of the controls that are an integral part of the HACCP system; and *iv*) the documentation of limits and the actions required when these are exceeded. [94,98,99]

Risk analysis encompasses identifying the hazards that may affect the quality or safety of the food product and controlling them at all stages of the process such that product contamination is minimized. In the food industry this is commonly referred to as Hazard Analysis Critical Control Point (HACCP). Such hazards are usually described as: *i*) biological (e.g. bacteria, yeasts, moulds); *ii*) chemical (e.g. cleaning chemicals, lubricating fluids); and *iii*) physical (e.g. glass, insects, pests, metal, dust). [93,94]

8.1.1. HACCP in chilling process

The schematic diagram shown in Figure 15, which is typical for all food factories, shows that the production of safe, wholesome foods stems from a thorough risk analysis. Indeed this is now a legal requirement. The diagram also shows that given specified raw materials, there are four major 'building blocks' that govern the way the factory is operated to ensure that the safe, wholesome food goal is realised. Hygienic design dictates the design of the production facility and equipment whilst process development enables the design of safe, validated processes. Hygienic practices and process control subsequently ensure the respective integrity of these two dependable.

Francisco, can you insert your experience here??

Not really, I come from the school that temperature control of part of pre requisite programmes and not of HACCP... we could not even talk about HACCP is temperatures issues are not sorted before. I personally would get this and the next sections out.

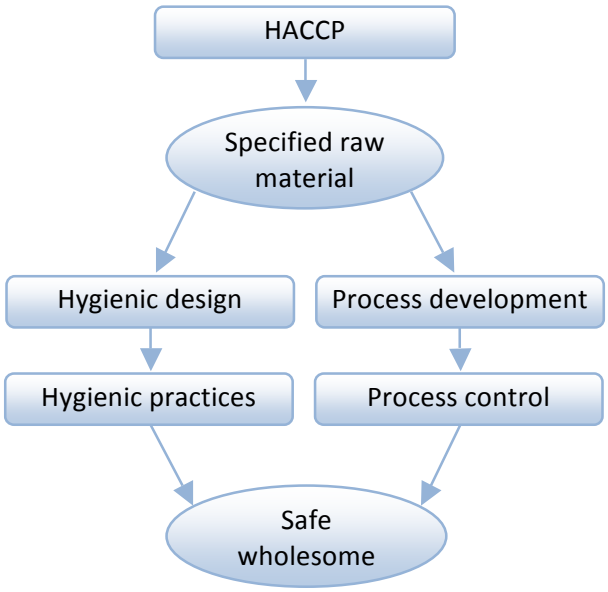


Figure 15. Schematic stages required to ensure safe, wholesome chilled products[97]

8.1.2. HACCP in freezing process

Francisco, can you insert your experience here??

CONCLUSIONS

Chilling and freezing are vital components in seafood value chain. The earlier temperature control starts, the better the edible quality and safety of the raw materials is to be. However, to obtain real benefits the

supply chain must be viewed in its entirety. Thus there may be little to be gained by controlling the quality of raw materials if inappropriate freezing and storage conditions are employed during processing and distribution.

It is hoped that this chapter gives the reader sufficient background information about factors that are likely to impact upon quality.

Maintaining the cold chain will maintain the edible quality along the different elements involved in delivering fish to the final consumer. Even small temperature variations do affect the products in different ways.

Not surprisingly there is a regulatory component associated to chilling and freezing that defines not ony the operations, but as well the temperature parameters involved.

The number of micro-organisms in food will decrease after freezing and storage, but freezing must not be regarded as a bacteria-killing process. In most cases, procedures resulting in better maintenance of sensory quality, i.e. rapid freezing and storage at a constant and very low temperature, also result in the best survival of micro-organisms. If a high number of micro-organisms are found in frozen foods, the reasons are probably as follows: *i*) a high microbial count in the raw materials; *ii*) delay before the freezing process is initiated; *iii*) slow or incomplete freezing process; and *iv*) temperature abuse with partial thawing (product temperatures above 0°C).

Shelf-life of a frozen product can be increased, depending on the quality of raw materials, pre-freezing treatment, rate of freezing, packaging film and storage conditions. Quality deterioration is accentuated by fluctuating time–temperature conditions during storage. High freezing rates and storage at low temperatures minimize deteriorative changes.

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