# Chilling, Freezing and Cold Storage of Aquatic Food Products

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Low temperature preservation is the best method to retain the quality and freshness of fish and fish products for a long time. Among them, chill storage i.e., keeping the fish in the unfrozen condition has only limited shelf life and it will vary between 4 and 20 days depending on the condition and species of fish. In frozen storage also the shelf life is restricted but it varies from few weeks to years. The various factors that affect the frozen storage shelf lives are condition of fish at the time of catch, handling, processing and product development, packaging and glazing of the product, freezing method adopted, frozen storage temperature, stacking methods and transportation techniques. These factors can be put together and can be termed as 'Product, Processing and Packaging' (PPP) and 'Time Temperature Tolerance' factors (TTT).

**Good Handling Practices**

The type of handling the fish receive on land during preprocessing and processing will determine the quality of the final product. Every stage from capture, handling and processing, and eventually to sale, to the consumer, involves some loss of quality. Different raw material specifications are used for each product. For example, chilled fish for immediate sale on the local market may not be perfectly fresh but may still be acceptable to the consumer. But in the case of a product such as frozen fillets, fresh raw material will be required as it will have to withstand the rigors of the freezing process and extended cold storage before it reaches the consumer. Hence during pre-processing stage raw material is graded according to the suitability for various processing methods. Handling the fish (raw material) during processing varies with type of the fish, the processing methods and the intended final product. However, there are some important good practices to be followed in general, which are described below:

- *As far as possible, every precaution should be taken to avoid the warming of fish, as this will favour the action of enzymes and bacteria.*
- *Avoid mishandling of the fish. This will damage the skin and flesh and accelerate the process of bacterial contamination and enzymatic action.*
- *Cool the fish as quickly as possible by any convenient method. Whatever be the method, it is important to cool the entire fish.*
- *The fish, which are caught at different times, have to be kept apart since they will be at different stages of spoilage.*
- *Small fishes have to be kept separately from large fishes, as they tend to spoil more rapidly than the latter.*

- *Soft-bellied fishes are to be kept separately and if the guts are being removed or the belly has burst, the body cavity has to be washed to remove any traces of the gut.*
- *The containers used for the transportation of fish should be cleaned after every use. Chlorinated water should be used, whenever possible for every fish washing operation.*
- *Do not put fish on the ground; it can be kept on simple concrete / wooden platforms, which, if frequently cleaned, will reduce contamination.*
- *Fish handlers at every pre-processing and processing stage should learn about and adopt good hygienic practices.*

**Chilled storage**

Chilling is an effective way of reducing spoilage in fish if it is done quickly and if the fish are kept chilled and handled carefully and hygienically. Immediate chilling of fish ensures high quality products (Connel, 1995: Huss, 1995) .For every 10 $^0$C reduction in temperature, the rate of deterioration decreases by a factor of 2-3 (Hardy, 1986). The objective of chilling is to cool the fish as quickly as possible to as low a temperature as possible without freezing. Chilling cannot prevent the spoilage together but in general, the colder the fish, the greater the reduction in bacterial and enzyme activity.

The important chilling methods of fish and fish products at non-freezing temperature are:

- *Iced storage.*
- *Chilled seawater (CSW) storage.*
- *Chilled freshwater (CFW) storage.*
- *Mechanically Refrigerated seawater (RSW) storage.*
- *Cold air storage.*

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

Ice is available in several forms such as blocks, plates, tubes, shells, soft and flakes. Of these, flake ice is the most popular form for industrial use because of its cooling efficiency. It is also relatively dry and will not stick together to form clumps when stored. Cooling capacity is more for flake ice due to a large surface area for heat exchange. It also cause minimum damage to the flesh To ensure maximum contact of ice with the fish, proper selection of the size of ice particles and good stowage practices are needed. The rate of chilling is governed by:

- *The size, shape and thickness of fish;*

- *The method of stowage;*
- *Adequate mixing of ice, water and fish (in ice slurries);*
- *Adequate contact of ice with the fish;*
- *The size of the ice particles.*

Icing is widely employed for chilled storage of freshwater fish in the country. The dressed and cleaned fish is kept in a chill store in insulated boxes with proper icing prior to preprocessing. The major advantage of using ice for chilling the fish is that it has a high latent heat of fusion so that it is capable of removing large amount of heat as it melts without changing the temperature at 0 $^{O}$C. During transition from ice to water 1 kg of ice absorbs 80 k cal of heat and this will be sufficient to cool about 3 kg of fish from 30 $^{O}$C to 0 $^{O}$C. Hence theoretically about 30 % of ice is needed to bring down the temperature from ambient conditions to 0°C. However, ice is needed to maintain the temperature as well as to accommodate the heat from the environment. Hence in tropical conditions a 1: 1 fish to ice ratio is ideal for ice storage. Fish of the same size and species are placed in the same boxes. It is always recommended to add about 12-20% extra ice to the fish in order to compensate for water loss from melting and bad handling (Zugarramurdi, et. al, 1995). The effectiveness of chilling by temperature exchange depends on the thickness of the layers of fish and the distribution of ice.

**Chilling versus freezing of fish**

There are many factors to be considered when considering the differences between chilling and freezing of fish products for various markets. Both chilling and freezing operations can produce stable products and the choice of one or the other depends on many factors.

**Advantages and disadvantages of chilling and freezing ***

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

* Shawyer, M.; Medina Pizzali, A.F. (2003) The use of ice on small fishing vessels. FAO Fisheries Technical Paper. No. 436. Rome, FAO, 108 p.

## Freezing Characteristics

The water present in fish products are converted to ice during freezing i.e., a change from the liquid phase to the solid phase. The change of water from liquid to solid phase results in increase in volume and a consequent decrease in density, increase in thermal conductivity and thermal diffusivity, and decrease in heat capacity. The volume increase on freezing of water is by about 9%, thermal conductivity 4 times and thermal diffusivity 11 times. Heat capacity is found to reduce from one cal/g to 0.5 cal/g. A proportional change in these properties may also observed in food products. Since water is the major component undergoing changes during freezing, knowledge of the effect of pressure and temperature on the phase diagram of water is necessary. Various combinations of temperature and pressure on two or three states of water in equilibrium are given in Fig. 1.

Point A is the critical point of water i.e., 374°C and 218.6 atmosphere pressure. Above this temperature water cannot be condensed to liquid whatever be the pressure applied. Various lines in the figure represent conditions under which two phases exist in equilibrium. Line AO represents the transition between liquid and vapour and is known as vapour pressure curve or boiling point curve. Line OB shows the transition between solid and vapour i.e. the sublimation curve. OC is the solid liquid curve or melting point curve and OD is the curve for the super cooled water and water vapour. Super cooled water has a greater vapour pressure than ice at the same temperature. Line OC has slight inclination to the left of the vertical indicating that increased pressure stabilizes liquid state, i.e. ice has less density than water.

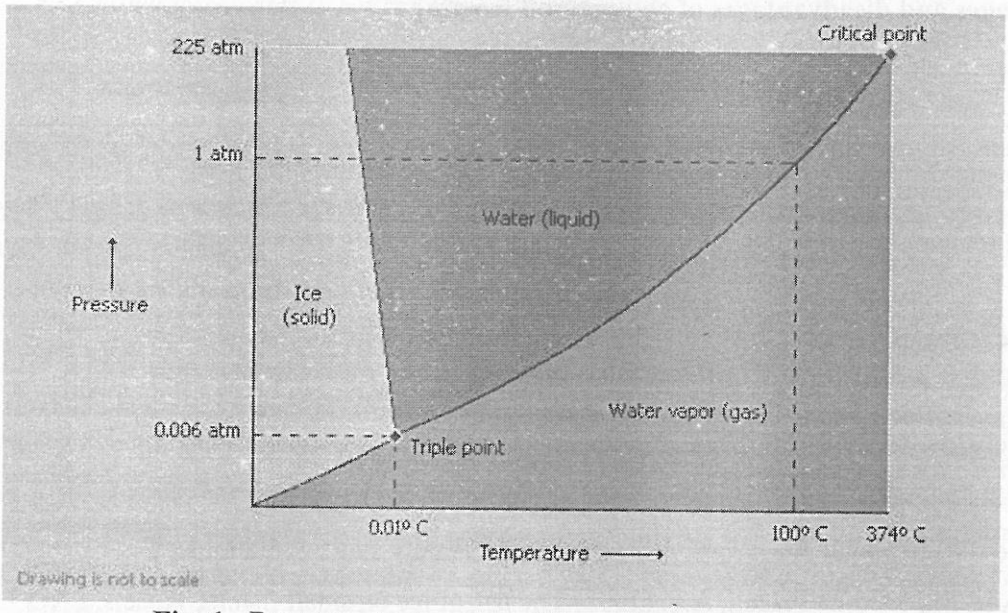


**Fig. 1. Pressure temperature phase diagram of water**

The extent to which pressure affects freezing point can be calculated. The normal atmospheric pressure lowers the freezing point of water by 0.0075°C. The dissolved air at one atmospheric pressure depresses the freezing point of water by 0.0024°C. Thus at 4.578 mm Hg pressure the freezing point of water is 0.0099°C greater than that at one atmosphere. This point is called triple point where all three phases of water exist in equilibrium.

**Freezing Curve for Pure Water**

The freezing curve of pure water is given in Fig. 2. During the early stages of cooling i.e. cooling from ambient temperature to 0°C ($T_1$ to $T_2$) the sensible heat amounting to 1cal/g °C is removed. Point S represents super cooling. Super cooling is needed to remove sufficient quantity of heat so as to get stable ice nuclei for crystal growth. On crystallization of ice at S the heat of crystallization is released and the temperature of the system rises to 0°C ($T_2$) from S.

The temperature remains at 0°C until all the water is converted to ice. This period is called thermal arrest period.79.8 cal of heat must be removed for each gram of ice formed. The water-ice transformation usually involves a long period. On completion of solidification further heat removal is faster and about 0.5cal/g of heat is removed for the decrease by every 1°C.

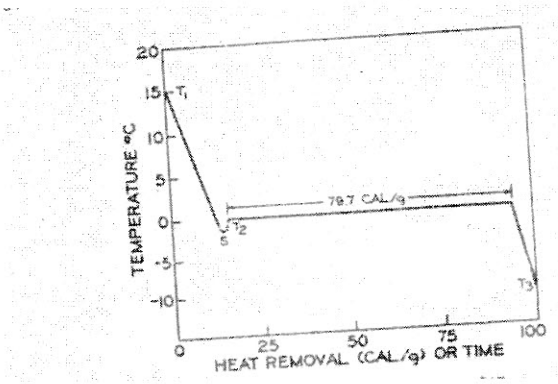


**Fig.2. Freezing curve for pure water**

***Freezing Curves for Water in Fish***

Solid liquid equilibrium in food is usually depicted by means of time temperature plots. Time temperature plots (Fig. 3) derived under moderately slow freezing gives only an approximate indication of the true equilibrium prevailing in complex systems such as food at subzero temperatures. In very rapid freezing, the time temperature curves bear little relationship to the true equilibrium conditions.

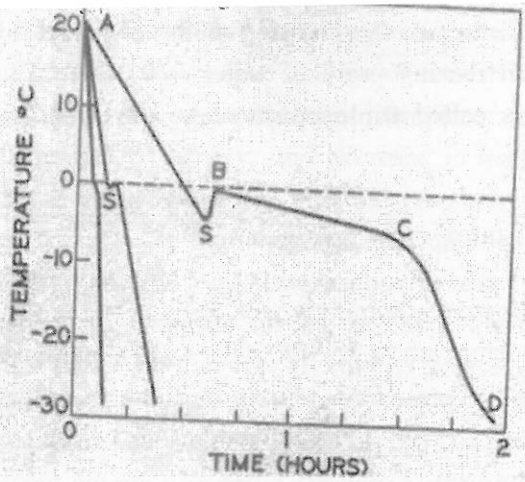


**Fig. 3. Freezing curve for water in fish**

The most striking feature of Fig.3 is its simplicity. The curve ABCD is obtained under lowest freezing conditions and represents most nearly an equilibrium situation. Cooling from A to S involves removal of sensible heat. Super cooling occurs to some extent although it is not always apparent. Following the onset of crystallization at point S, the released heat of crystallization causes the temperature to rise promptly to initial freezing point B. The initial freezing point, which is determined by the amount of dissolved substances in the food, differs surprisingly little among various types of natural foods. Section BC of the curve represents the period during which major portion of the water in food is crystallized. Heat generated from ice formation constitutes the bulk of energy that is to be removed during freezing. Ice formation during this period results in a moderate increase in concentration of solutes in the unfrozen water. These changes results in slight decrease in freezing temperature as freezing progresses. So the curve BC is not a plateau parallel to the time axis but has a slight negative slope. During early stages of BC water separates as pure or nearly pure ice crystals. During the later section of BC and beyond the possibility of eutectic mixture of crystals of solute and ice exists, in addition to complex solids of unknown structures and composition.

By reaching point C almost 80% of water in fish is frozen. Each successive gram of ice formed beyond C causes a large increase in concentration of the dissolved substances in the unfrozen water. Furthermore, removal of a given amount of heat will cause a much greater reduction in temperature during CD than during AB. Even at D, the fish will contain some freezable water. Table 1 gives the approximate amount of water frozen at various freezing temperatures. It can be seen that at a temperature of -30°C about 8% of water remains unfrozen.

Tab: Percentage of water frozen at various temperatures in a typical fish fillets with 80% $H_2O$

| | |
|---|---|
| 0 | 0 |
| -1 | 10 |
| -2 | 55 |
| -3 | 69 |
| -4 | 76 |
| -5 | 80 |
| -10 | 81 |
| -20 | 91 |
| -30 | 92 |

As seen from Fig. 3 increased rates of heat removal as in the case of quick freezing causes the various stages of cooling and freezing to become less distinct. At very high rates of heat removal, which occurs in cryogenic freezing using liquid $N_2$, the curves become undistinguishable. This does not represent conditions of stable equilibrium. The freezing point of water in fish is not at 0°C, but is around -1°C depending on the concentration of solutes in fish muscle.

**Crystallization**

Crystallization during freezing is the formation of a systematically organized solid phase from a solution or liquid. It consists of two phases viz. nucleation and crystallization. During removal of heat, water molecules tend to combine into an ordered manner in the form of a particle. When the size of the particles is sufficient to survive and serve as a site for crystal growth, it is called nucleus. The process of formation of nucleus is called nucleation. When the size is not sufficient for the growth it is called embryo. During crystal growth an enlargement of the nucleus takes place by an orderly addition of water molecules.

Ice and water will be in equilibrium at 0°C when heat is neither added nor removed. On removal of heat, water molecules will add to the existing ice and become totally solid at 0°C. If ice is absent from the system a different pattern is followed for nucleation and crystal growth. Nucleation must precede crystal growth. On cooling, the temperature falls below 0°C (super cooling) before nucleation and solidification. The size of these nuclei depends on the cooling rate. The greater the cooling rate or super cooling the smaller the size for the nuclei and the larger the number of nuclei formed. Nucleation takes place both intracellular and extracellular with minimum dislocation of water at greater cooling rates. This is the reason for the formation of large number of ice crystals and maintenance of high quality during quick freezing.

In pure water, homogeneous nucleation takes place. In pure water, a tiny droplet of water with less than 1μ in diameter can be super cooled up to -41°C and this is accepted as the limit of super cooling. In food systems where water is not ultra-pure, heterogeneous nucleation takes place in preference to homogeneous nucleation. Here the water molecules aggregate in a crystalline arrangement on nucleants such as cell walls and any suspended particles. Heterogeneous nucleation is predominant in foods.

Rate of nucleation will remain very low and nearly independent of sample temperature when the degree of super cooling is small. As the temperature is lowered to some critical value characteristics of the system, rate of nucleation will suddenly increase from almost negligible to a very high value.

Physical disturbances will generally enhance the rate of nucleation or will cause nucleation to occur at a higher temperature than is normally possible. Such nucleation is referred to as dynamic nucleation. For example a small sample of water under static conditions may nucleate homogeneously at -40°C, heterogeneously at -4°C, and heterogeneously at dynamic stimuli at about -0.5°C.

**Crystal Growth**

The second phase of crystallization consists of crystal growth. It requires some super cooling usually less than 0.1°C. The crystal growth occurs by the systematic addition of molecules to the crystal surface. Crystallization of water from a solution containing different solutes is limited by mass transfer and heat transfer. Water molecules move from the liquid phase and attach to this sites where the energy is sufficiently low to provide stability. At the same time the solute must diffuse away from the vicinity of the interface towards the interior of the liquid phase. The latent heat of crystallization must be removed to sustain crystallization.

Water molecules are small, highly mobile and usually present in abundance under most circumstances in food. Hence it is likely that the transfer of water molecules to the crystal surface would limit the rate of ice crystal growth. During the final stages of freezing, viscosity of the liquid phase is high and a little unfrozen water remains. In the above instance, transport of water is retarded or stopped and hence the growth of ice crystals.

Foods are abundant in dissolved substances, suspended matter and sometimes membranes. Small solutes migrates short distances. They are concentrated between crystals. Suspended matter and membranes are unable to migrate. So ice crystals form around them or push them aside. The transfer of solutes and other mono-crystallizing matter can reduce the rate of crystal growth as compared to pure water. However, transfer of solute is not considered to be the rate limiting factor, except during the later stages of freezing.

Inorganic substances are less effective retardants than organic compounds. Membranes also act as effective barriers to ice crystal growth.

**Crystal Size**

Rapidly frozen food contain ice crystals which are small and numerous. But similar specimens, which have been frozen slowly, contain ice crystals of large size. The sizes of the completed crystal vary inversely with the number of nuclei formed. Even though freezing conditions are held constant, large differences in crystal size are sometimes noticed among different substances, different samples of the same substance and even within the same sample. Fish frozen in pre-rigor contain smaller and more numerous ice crystals than that in post rigor under similar conditions. This is attributed to the greater amount of bound water in the pre rigor samples than post rigor samples. These bindings retard the migration of free water in pre-rigor muscle and thereby encourage formation of more nucleuses.

**Morphology of Crystals**

The external appearance of individual crystals is influenced by factors that alter the flow and attachment of the crystallizing substance to the crystal surface. Some of these factors are thermal conditions, composition of the crystallizing medium, surface conditions and inherent growth characteristics of the crystals. The morphology is also affected by the rate of freezing. Slow freezing generally produces continuous smooth interface. Under moderate super cooling continuous irregular interface occurs. In this type the cells have profound influence on the nature of the ice structures. The parallel, elongated and cylindrical structures of the cell in fish muscle frequently cause ice to form long parallel spheres. Under great super cooling abundant formation of crystals with discontinuous interface occurs. The heat removal is rapid with much lower super cooling. A variety of ice crystals are formed and the major types of structures are of hexagonal forms. In cryogenic freezing at extra rapid rate of heat removal a sequence of eutectic structures similar to that reported above are produced. At rates of heat removal usually encountered in commercial practice hexagonal types of eutectics are most likely to develop.

**Location of Ice Crystals in Tissue**

The location of ice crystals in tissue is a function of freezing rate, specimen temperature and the nature of the cells. Slow freezing of fish muscle generally causes ice crystals to form exclusively in extracellular areas. Although uncommon, intracellular ice crystals have been observed in some slowly frozen specimens e.g. pre-rigor cod and tissue frozen for a second time. Conditions leading to preferential extra-cellular ice crystals result in large ice crystals, maximum dislocation of water and a shrunken appearance of cells in the frozen state.

All kinds of tissues exhibit a uniform distribution of ice crystals both intracellurlarly and extracellurlarly when frozen very rapidly. In tissue, uniform crystallization is essentially synonymous with intracellular crystallization. The rate of freezing needed to produce uniform crystallization generally increases as cell size decreases. Conditions which produce intracellular crystallization result in numerous small ice crystals with minimum dislocation of water and a frozen appearance similar to the original unfrozen appearance. The food quality is usually superior than that obtain by slow freezing.

Cells contain a greater concentration of non-diffusible ions like protein than the surrounding fluids. Diffusible ions exist in unequal concentration on opposite sides of the cell membrane and the concentration of the ionic particles is greater inside the cell than outside. On this basis a lower freezing point is expected for the cell contents than the surrounding fluids. Regardless of freezing rate, crystallization is initiated primarily in the extra cellular fluid. However, crystallization of systems containing limited quantity of extracellular fluid such as pre rigor cod begins in intracellular areas.

**Selecting a Method for Freezing Fish/Prawns**

The selection of a method for freezing aquatic foods is based on the cost of freezing and operations and quality considerations for the product. These should include cost of equipment, operating temperature, operating costs, space requirements, product quality considerations and similar factors. It is quite possible that a product with the lowest retail price may be rejected by the consumer for a product of better quality which has been achieved by using a superior but more costly processing method. On the other hand, it is possible that some products processed by the most economical methods may have qualities which are only slightly inferior to products processed by more expensive methods. To properly assess the effect of freezing methods on product quality, the product must be evaluated following a treatment similar to that which it will receive commercially. To assess the quality of frozen fish products, the product must be evaluated after the following sequence of events:

- *Pre-freezing treatments such as chilling, addition of chemicals etc.*
- *Freezing,*
- *Frozen storage for a commercially realistic time and temperature.*
- *Thawing and also cooking.*

Quality information can be combined with data on freezing cost to determine which method of freezing is best for the product under consideration. The rate of freezing can exert some influence on the final thawed quality. It is observed that the attainment of a product temperature of -18°C or lower in a period of two hours or less will produce satisfactory results.

Plate freezing is used exclusively for orthorhombic packages of fish. Air-blast freezing is used for many kinds of fish and shell fish when packaged individually. Excessive dehydration can occur during air-blast freezing of unpackaged items unless the freezing time, air velocity and temperature differential are maintained at suitably low value. Liquid immersion freezing is used for freezing fish and shrimp at sea and sometimes for freezing shrimp on shore. Freezing fatty fish by immersion in brine is undesirable because it accelerates oxidation of lipids during frozen storage.

Expensive liquid nitrogen freezing is used to a limited extent in western countries for freezing fish and other sea-foods. Cryogenic methods are particularly advantageous when production is small or varied, when it is important to minimize capital investment or when cryogenic method is being used to supplement conventional freezing. Freezing by means of liquid $CCl_2F_2$ could be of greater importance in future because it is the least expensive cryogenic method.

**Pre-freezing and Freezing Considerations**

The quality of frozen-thawed cooked fish is influenced by a number of factors including species, composition, size, how and where caught, elapsed time between harvest and freezing, the state of rigor and quality when frozen and the details of freezing process and frozen storage.

The major problems encountered during the freeze-processing of fish are oxidative deterioration, dehydration, toughening, loss of juiciness and excessive drip. Fish are subject to deterioration by microorganisms and by autolysis when it is unfrozen. So great care must be taken to follow good sanitary practices. It is necessary to promptly cool the fish to near 0°C for preprocessing operations and to freeze without undue delay. Effective pre-freezing and freezing techniques are available for controlling many of these problems except toughening and loss of juiciness. Reasonable control of toughening and loss of juiciness can be accomplished by storing fish for a minimal time and /or at temperatures of -18°C or below.

Undesirable oxidative changes in fish can be minimized by eliminating oxygen, avoiding contamination with heavy metals (oxidative catalysts), adding antioxidants and by using low storage temperature. Dehydration can be avoided by applying glaze and suitable protective packaging.

**Physical Changes during Freezing**

The volume change in pure water at 0°C on conversion to ice at 0°C is about 9%. Most foods expand on freezing but to a lesser extent than pure water. The various factors that contribute to volume change upon freezing of food are:

- *Cooling of specimen prior to freezing causes contraction*
- *Ice formation during freezing causes expansion*
- *Cooling of ice crystals causes contraction*
- *Solute crystallization causes contraction or expansion depending on the type of solutes.*
- *Cooling of solute crystals present in eutectics causes contraction.*
- *Solidification and cooling of non-solutes such as fat causes contraction.*

The effect of ice formation predominates during freezing. A consequence of the increase in volume during freezing of food is the development of mechanical stress and hence freezing damage to food. The dislocation of water that accompanies slow freezing and re-crystallization may also cause mechanical stress. Mechanical damage to the texture of tissues during freezing is marginal in muscles because of its pliable consistency and parallel arrangement of cells. Sample size, freezing rate and final temperature of the tissue appear to influence the intensity of stress. In large tissues, outer surface freezes to solid before freezing commences in inner areas. On further freezing, the inner areas get frozen leading to considerable internal stress. The rate of freezing also influences the severity of stress. Slow freezing results in unusually great damage due to detrimental size and location of ice crystals. Rapid freezing coupled with low temperature will result in severe cracking of tissues containing large percentage of water.

During freezing of tissues, nearly all the non-aqueous constituents concentrate in a diminished quantity of unfrozen water. The extent of concentration is influenced mainly by the final temperature, and to a lesser extent by the eutectic temperatures of the solutes present, agitation and rate of cooling. Agitation of the fluid phase during freezing aids formation of pure ice crystals by minimizing accumulation of solutes at the solid liquid interface. Slow removal of heat results in a smooth, continuous solid liquid interface, maximum crystal purity and concentration of solutes in the unfrozen phase. Rapid freezing results in an irregular and discontinuous interface, considerable entrapment of solutes by growing crystals and less than maximum concentration of solutes in the unfrozen phase. During freezing, the unfrozen phase changes significantly in properties such as pH, acidity, ionic strength, viscosity, freezing point, surface tension, interfacial tension, and oxidation reduction potential. Freezing forces the macromolecules like proteins to come closer making interactions between molecules more probable. pH changes occur because of increasing concentration of solutes in the unfrozen phase during freezing. The effect of eutectics on pH is governed by the type of solutes that crystallize during freezing.

The freezing process is considered complete when most of the water at the centre of the food product has been converted into ice. At -15°C, more than 80% of total water is transformed into ice. The system is segregated into a crystalline phase of pure water and an amorphous domain, which contains solutes and residual water. As the temperature

decreases, the viscosity of the interstitial fluid increases rapidly as a result of both increase in concentration and decrease in temperature. When the viscosity reaches a very high value (~1011 – 1012 PaS), solidification (vitrification) occurs, and the concentrated phase surrounding the ice crystals becomes a glass. The temperature at which this transition takes place is called the glass transition temperature of the maximally freeze concentrated system. The freezing of water is stopped at this temperature; water still unfrozen is often called "un-freezable water".

**Physical Changes during Frozen Storage**

The major physical changes during frozen storage of fish are freezer burn and re-crystallization. Freezer burn is a surface phenomenon which occurs in improperly packed products. Freezer burn appears as an opaque dehydrated surface. It is caused by the sublimation of ice on the surface of the muscle. The sublimation takes place when the vapour pressure of ice on the surface of fish muscle is higher than the vapour pressure of the cold store. Other factors contributing to freezer burn are air velocity in the cold store, cold storage temperature and post mortem condition of the muscle. It can be prevented or reduced by glazing the product in chilled water and air tight packaging with water impermeable packaging materials.

The ice crystals in the frozen muscle undergo transformations during frozen storage causing changes in number, size and shape. This phenomenon is called re-crystallization. During frozen storage, the ice crystals in rapidly frozen samples are found to grow slowly. The sizes of the ice crystals between rapidly frozen and slow frozen samples have almost the same size after a long storage. There are many reasons for the changes in size and shape. During storage, the reorientation of the ice crystals takes place to give a stable shape with a compact structure having smaller surface to volume ratio and lower surface energy. In frozen products, the large ice crystals may grow at the expense of small crystals. This may be caused by melting-diffusion-refreezing or sublimation-diffusion-refreezing. The net result is an increase in average crystal size, decrease in the number of crystals and decrease in surface energy of the crystalline phase. Fluctuating temperature and associated vapour pressure gradients enhance this type of re-crystallization. Also contacting crystals fuse together resulting in an increasing crystal size, decrease in number of crystals and decrease in surface energy. Each frozen product exhibits a critical temperature below which re-crystallization does not occur at a significant rate. Low and uniform temperature of frozen storage can minimize re-crystallization.

**Drip**

Drip is the exudates coming out from a frozen product on thawing. Fish after freezing, frozen storage and thawing often exudates a considerable amount of drip. Drip

may amount to 1 to 5% or much more. Drip loss may cause sizable financial loss. On thawing, if the drip loss is high, the frozen products appear somewhat dry and stringy. However, the relationship between texture and drip loss need not be linear upto moderate drip loss, but at high drip loss, the loss of texture is directly related. Though factors like internal pressure developed during freezing, freezing rate, size and location of ice crystals may influence thaw drip, the major factors are the quality of the raw material, abuse of frozen storage and the extent of resultant denaturation. When the quality is poor and the frozen product is stored especially at a higher frozen storage temperature for a long duration the amount of drip is found high and is almost proportional to the storage period. Very slow freezing and the development of large extracellular ice crystals also have some influence. In quick freezing the cell dehydration during freezing is minimum due to the formation of uniform intracellular and extracullular ice crystals. This causes minimum damage to the cell and consequently expects a low drip (Jul, 1984).

**Temperature Fluctuation**

In good cold storage it is rare that temperature fluctuation in storage rooms exceed more than ±2°C. Temperature fluctuation has little effect on quality when the storage temperature is below -18°C. Very high temperature fluctuation may have an adverse effect on product quality.

**Quality Changes**

Most of the quality changes normally attributed to the freezing process are indeed unrelated to that process. In fact, except for cases where texture is adversely affected by freezing, the frozen product is often practically indistinguishable from the fresh product when thawed immediately. However, after few months of storage, depending on product, process, packaging and storage temperature, changes are noticed. These changes are due to changes during frozen storage. The drip is very much increased by warm freezer storage temperatures. The explanation generally offered is that the high ionic strength of the solution causes rapid denaturation of proteins with poor binding of water as a consequence. This effect is not pronounced at colder freezer storage temperature because of reduced reaction rates.

The most important adverse effect on freezing and frozen storage on nutritive value may be a loss of vitamins, mostly the more labile ones such as ascorbic acid, thiamin and riboflavin vitamins are water soluble and hence some losses occur in the drip.

**Time Temperature Tolerance**

Longer keeping times are recorded at colder temperatures in frozen storage shelf life studies. Many chemical reactions such as lipid oxidation, lipid hydrolysis and protein

denaturation and the resultant sensory changes in texture and flavour are temperature dependant. Time temperature tolerance studies for quality changes during frozen storage showed a logarithmic relationship of storage time vs. temperature of the storage. Various studies indicated that the frozen storage temperature has pronounced influence on quality and shelf life. In general, the retention of the qualities will be better at lower temperatures and an inversely proportional shelf life.

**Freeze/Thaw Stability**

Most frozen food will suffer some physical deterioration if they are subjected to thawing and refreezing. There are often textural changes brought about by the formation and reformation of ice crystals. Fish and meat both suffer under these circumstances and cause protein denaturation. It is possible to give some protection against damage from freeze/thaw cycles by using certain stabilizers. Polysaccharides such as sucrose, sorbitol, carrageenan and modified starches exhibit such cryoprotective properties.

**Cold Storage**

Cold stores are an integral part of food freezing industry. There are different types of cold stores such as single storied and multistoried. The size, type and nature of cold storages are determined by the storage temperature, type of food stored, stacking conditions, movement of material inside cold store like palletisation and quality requirements. Manual system of handling and stacking is adopted in small rooms with low height where the stacking height does not exceed 3-4.5 m. In large cold storages palletized systems are used. Palletisation consists in the indivisibility of a load representing a transport; handling and storing unit. Considerable savings in handling time and labour are obtained by palletisation. In large cold storages the dimensions are multiples of storage pallets considering spaces between pallets, between pallets and walls and space for gang ways, which is determined by the type of fork left trucks used. The present trend is for large cold storages which make palletisation, handling and stacking very convenient. Pallets are loaded with goods amounting to 1 to 2 $m^3$ and can be moved about and stacked by means of a fork lift truck.

Two systems may be applied in palletized storage viz.

*i) Self-supporting stacks of pallets piled one on top of the other and*
*ii) Laying the pallets on the shelves of a steel frame structure.*

Self-supporting stacks has the draw back that only the top pallet is directly accessible and does not lent itself to complete mechanization and automation. The loading factor in palletized storage is lower than manual storage; but palletisation is cost effective. Palletized storage in shelved racks avoids the disadvantage of self-supporting stacking system, but has a

higher installation costs. This system is advantageous for a wide range of products with high turnover. Several variants of this system are available. The layout of the cold store room is based on the pallet module and the required width of the gangway together with type of handling. The width of the stacking module is decided by the width of the gangway and the depth of pallets stacked on each side of the gangway. Gangway in side cold stores are a necessity for the normal day to day operation. The width of gangways has steadily reduced with the decrease in the size of the fork truck used. Originally the gangways have a minimum of 3.75m, but it has been reduced to 2.60m and still further at present. Air distribution within the cold store is now almost entirely through the use of either long throw fans with the air cooling equipment or through directing. The airflow in the room should be distributed in such a way that the temperature difference is uniform at all points.

Many cold stores in the past were built with a large anteroom or corridor before entering the main cold store. This room was held at an intermediate temperature between the ambient and the operational temperature of the cold store. This system is not considered useful in most cases today. At present the automatic doors allow quick loading and unloading and thereby reduce heat penetration into the store. In many stores the entrance is sealed by an air lock. However anterooms and cold stores may be useful in areas of high ambient temperature and humidity.

**Cold Storage Space**

If the required capacity is known, the corresponding refrigerated space is determined if the loading factor (storage density) of each commodity is known. The space actually used for storage (net effective capacity) is smaller than the refrigerated space since passages should be provided for air circulation and goods movement. Normal spacing requirements in self-supporting pallet storage are:

| | | |
|---|---|---|
| i. | Between stacks | 10-30cm |
| ii. | Floor clearance | 10-15cm |
| iii. | Ceiling clearance | 40-100cm |
| iv. | Below air bucks | 15-30cm |
| v. | Under ceiling coils | 20 cm |
| vi. | From walls | 30-60cm |
| vii | Passage ways for palletized stacking | 150-200cm |
| viii | For right angled turns for fork lift trucks | 300-400cm |

These information's are required to find out the utilization factor. The effective capacity of a cold store is determined by using the formulae

$$V_u = KV_B,$$

where Vu is the effective capacity, VB the gross capacity i.e. the geometric volume of the room and K is the utilization factor. The utilization factor K for various storage rooms vary depending on the size of the cold storage. For small cold storages with less than 100m2 area and less than 4m height the K value is 0.56 in manual storage system. For large cold storage above 250m2 area and more than 4m height under manual operation, the K value is 0.68. The values for K in cold storages of varying sizes under different types of operation are given in Table 2.

**K value for cold storages of different size under manual and palletized operations**

| Floor area | Height m | Storage system | K |
|---|---|---|---|
| <100 | <4 | Manual | 0.56 |
| 100-250 | <4 | Manual | 0.60 |
| >250 | >4 | Manual | 0.68 |
| | >4 | Manual | 0.68 |
| 100-250 | <4 | Palletised | 0.56 |
| | >4 | Palletised | 0.68 |
| >250 | >4 | Palletised | 0.68 |

For calculating effective capacity, the intrinsic density of goods also should be taken into considerations. The intrinsic density is the average mass of a package of goods divided by the geometric volume. In case of packages of non-geometrical shape the intrinsic density is determined by measuring the mass and volume of the complete pallet in which the packages have been arranged. Based on all these factors the stowing density of frozen aquatic food in a cold store is approximately calculated as 300-350kg/$m^3$ but higher values are reported in certain cases. The general design of a cold store is determined by storage capacity, facilities for reception and delivery of goods, interior operating space, maintenance of low temperature and economic constructional and operational techniques.

**Maintenance of Cold Storage Temperature**

Considerable amount of heat is penetrated into the cold storage because of the difference in temperature between the cold storage and outside. Other than this there are many factors which may cause an increase in temperature inside the cold storage. To reduce the penetration of heat into the cold storage some precautions are necessary. Care should be taken to ensure that the doors of cold storages are left open for a minimum time. It is necessary to use air curtains, strip curtains and air locks (vestibules) to reduce air infiltration. The product stored is another source of heat gain. Hence the temperature of the product brought into the cold storage should be reduced to that of the cold storage. For this purpose the product is cooled to the temperature of the cold storage before storing it to reduce additional heat load

to the storage. Generation of heat by products is applicable only to live products like fruits and vegetable which undergo respiration.

As is the case of food products, care should be taken to avoid heat transfer from packing materials, pallets, trays, and shelves, which are not pre-cooled. So the packaging materials should be cooled to the storage temperature. It should be noted that if some packaging materials like wood and carton are moist, the water gets frozen and the latent heat of fusion may be significant. Heat gain takes place from the technical equipment like fans and pumps, lighting of the refrigerated space, heat elements and other electrical motors and electronic equipment in the cold store. Heat gain from people, trucks and transport, loading and unloading equipment in the cold store is significant. The defrosting of evaporators and equipment is another source of heat gain. Since the ambient temperature is very high compared to cold storage temperature significant quantity of heat is penetrated through the walls to the cold storage. This can easily be calculated from the surface area A, the overall heat transfer coefficient of the insulation materials k and the estimated temperature difference $\Delta T$ between outside and cold storage using the formula

$$\text{i.e., } Q_T = k.\ A.\ \Delta T$$

The usage load can be estimated from experience and will greatly depend on the use of store and external conditions. The total heat gain into a cold storage can be calculated and greatly depend on the environmental conditions and use of the cold storage. Proper cold storage management can considerably reduce the heat ingress and hence the efficiency of the cold storage.

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