Low temperature preservation of fish products

Parvathy U
Fish Processing Division
ICAR- Central Institute of Fisheries Technology, Cochin

Introduction

Fish, being a rich source of all the nutrients viz., omega-3 fatty acids, quality and easily digestible proteins, essential minerals, and vitamins, has gained importance as a health food in human diet. These advantages offer considerable benefits to fish as a means to achieve nutritional as well as social security. Better awareness regarding this biomass as a potential source of nutrients has created increased interest in effective exploitation of these resources. However, their richness in nutrients as well as high moisture content increases its perishability, necessitating the processing and preservation of fish mandatory soon after harvesting. Among the various preservation methods available, low temperature preservation viz., chilling as well as freezing has attracted interest of many researchers on account of its minimal changes in the texture and other characteristics of fish upon proper processing and storage.

Chilling

Shelf stability of fish is very important for ascertaining its availability to a wide range of customers across the globe. This can be assured only by proper handling and preservation techniques. Among the various preservation techniques, chilling assures effectiveness in delaying bacterial growth and prolongs the shelf life of fish. Although chilling is effective in delaying the spoilage, it will not inhibit the spoilage completely as the enzymes and bacteria will be active at the chilled temperature. The objective of chilling is to cool the fish as quickly as possible to as low a temperature as possible without freezing. The storage life of chilled fish in different forms of ice like flake ice, slurry ice, ozone-slurry ice ranges from almost 4 to 20 days depending on the species. Studies have indicated that for every 10^0C reduction in temperature, the rate of deterioration decreases by a factor of 2-3. Hence higher and faster rate of temperature reduction upon capture assures better and prolonged stability of the seafoods.

The most common and cheapest means of chilling seafood is icing. Other means of chilling include: Air chilling; Use of alternative methods like chilled water viz., Refrigerated sea water (RSW), Chilled sea water (CSW), Chilled fresh water (CFW); Chilling of fish by dry ice (solid carbon dioxide), liquid nitrogen, cold ammonia or other refrigerants, etc. Chilling is a relatively short-term means of preservation when compared to other techniques like freezing, canning, salting or drying etc.

Icing is widely employed for chilled storage of marine as well as fresh water fishes as well as shell fishes. Fishes are kept in a chill store in insulated boxes with proper icing prior to pre-processing. The major advantage of using ice for chilling the fish is its high latent heat of fusion which facilitates the removal of large amount of heat from the object to be cooled. 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 ambient temperature of 30^{O}C to 0^{O}C. Hence theoretically about 30% of ice is needed to bring down the temperature from ambient conditions to 0ºC. However, ice is needed to maintain the temperature as well as to accommodate the heat from the environment and hence in tropical conditions, a 1: 1 fish to ice ratio is ideal for ice storage. Icing of fish is very easy as it does not involve sophistication or high level of skill. Further it's easy availability is an added advantage. However, due to lack of knowledge icing is not properly practiced during fish handling and preservation. The proper use of ice can substantially reduce post-harvest losses and improve the quality of fish. In general, icing of fish is done in three stages during the post-harvest supply chain: on board fishing vessel immediately after harvest; after landing in the landing centre or before transportation; during retail sale. For icing to be effective, standard protocols like use of good quality ice, cleaning, dressing and sorting of fish for icing, proper layering of ice and fish etc. should be ensured.

Ice is available in several forms such as blocks, plates, tubes, shells, soft, chip and flakes. To ensure maximum contact of ice with the fish, proper selection of the size of ice particles and good stowage practices are needed. Flake ice is the most popular form of ice 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. On being smaller in size and less thickness with smooth edges, it also causes minimum damage to the flesh.

Shelf life of iced fish

Shelf life of food is the time period during which the food can be stored and displayed whilst still maintaining an acceptable quality or specific functionality. For fish, shelf life is the time from when it is taken from the water until it is no longer fit for consumption. Shelf life of chill stored fish is limited and in general, range for few days between 4 to 20. The stability of fish is dependent on various intrinsic as well as extrinsic factors. Various research carried out in this aspect has derived at a few general observations which reports that under ice storage:
Non-fatty fishes, white fleshed fishes, freshwater fishes, tropical fishes, flat fishes, thick skinned fishes have better storage stability than their counterparts viz., fatty, dark fleshed, marine, temperate, round, thin skinned ones, respectively.

Quality Changes in chilled fish

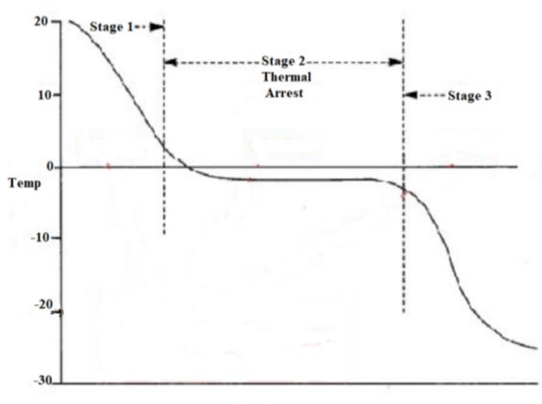
- *Weight loss:* The fish chilled with ice shows gradual weight loss upon storage. Losses which occur in iced fish are largely or entirely due to formation of free liquid drip. This is on account of quality changes viz., protein denaturation associated with the chilling and associated storage. Drip water carries with it a considerable percentage of soluble proteins, salts, other flavouring and nutritive components of the fish.
- *Discolouration:* Improper icing/chilling results in bruising, damage and consequent discolouration of flesh. Improper and delayed gutting of fish facilitate the powerful digestive enzymes to attack the viscera and belly walls resulting in belly burn or disruption at iced

temperature which also cause discolouration. It is well known that pelagic fishes with filled digestive tract may develop torn or burst bellies well before the signs of spoilage sets in.

- *Rancidity:* In case of fatty fishes, even at low temperature of 0 to 2ºC, rancidity may develop on account of fat oxidation and the rancid flavour becomes a limiting factor affecting its keeping quality during storage.
- *Shrinkage:* Shrinkage is a common phenomenon in fish packed with ice, particularly in the upper layers. The shrinkage in lean fishes are higher than that of fatty fishes as the subcutaneous layer of fat serves to reduce the evaporation of tissue moisture.
- *Weight gain:* Fish stored in refrigerated and chilled seawater exhibits the tendency to gain weight and uptake salt thereby limiting the application of this chilling system in seafoods.

Freezing

Low temperature preservation like freezing is the best method to retain the quality and freshness of fish and fish products for a long time. Freezing reduces the spoilage activity and extends the shelf life of the product. It represents the main method of processing fish for human consumption, and it accounted for 55.2% of total processed fish for human consumption and 25.3% of total fish production. Freezing involves the cooling down of food materials from ambient temperature conditions to a temperature below the freezing point. Generally the freezing process has three stages; first stage (pre-freezing stage) corresponds to removal of heat from the food, when the temperature is reduced from ambient to freezing point. The second stage which is the freezing stage, is the period of transformation of water to ice through the whole mass of food. The second stage is also referred to as the zone of maximum crystallization. Between the first and second stages there is a transitory super cooling period when the temperature falls below the freezing point which is not observed in all cases. In the third stage nearly 75% of the water in the muscle turns into ice which leads to further rapid drop in temperature, as the thermal diffusivity of ice being much higher than water.



Freezing Curve of fish

As the water in fish freezes out as pure crystals of ice, the remaining unfrozen water contains higher concentration of salts and other compounds which are naturally present in the fish muscle. The increasing concentration of the salts will depress the freezing point of the unfrozen water. Hence unlike pure water, conversion to ice will not occur at 0^0C but proceeds over a range of temperature. Thus, even at -30^0C, a portion of water in the fish muscle will remain in unfrozen state. Slow freezing produce ice crystals of comparatively larger size and few in numbers which may cause rupture of the cell walls and result in fluid loss and textural changes on defrosting. In contrast fast or quick freezing produce large number of small and uniform crystals, thus reducing the possibility of shrinkage or rupture.

The drip loss on thawing of fish occur mainly due to denaturation of protein during freezing which result in the loss of water binding capacity of the protein. The optimum range of temperature for denaturation is -1^0C to -2^0C; thus in order to reduce the thaw drip to minimum, the time spent in this temperature zone should be minimum. If the temperature of fish/fishery product is reduced from 0^0C to -5^0C in 2 hours or less, then it can be termed as a quick frozen product. During freezing process, the temperature of the fish should be lowered to -30^0C such that the thermal centre of the fish attains -20^0C prior to its removal from the freezer. The time taken to lower the temperature of the thermal centre to -20^0C is termed as the freezing time. Based on this, most of the commercial freezers operate at temperatures of -35^0C to -40^0C. The major factors which affect freezing time include: Freezer type, Freezer operating temperature, Refrigeration system and operating condition, Air velocity in an air blast freezer, Product temperature, Product thickness, Product shape, Product contact area and density, Product packing, Species of fish

Freezing Systems

Freezing techniques have evolved with different modes of operation and the first man made freezing system was reported to be freezing using ice-salt mixture; followed by the developments in mechanical refrigeration. Mechanical refrigeration can broadly be classified into two: direct and indirect system wherein the direct system, the refrigerant absorbs heat directly from the material to be cooled while in indirect/ brine system, the refrigerant absorbs the heat that brine absorbs from the material to be cooled.

Based on this mode of operation, they are further classified as:

- *Freezing in Air*
- *Indirect contact freezing*
- *Spray or Immersion freezing*
- *Cryogenic freezing*

Air freezing

Seafoods can be frozen in air at temperatures ranging from –18° to – 40°C.

Sharp Freezing

Sharp freezers are cold storage rooms especially constructed to operate at and maintain low temperatures. Freezing time generally ranges from 3-72 hours or more depending on the conditions and the size of product. In this method, the product to be frozen is placed in a very cold room, maintained at temperatures in the range of –15°C to –30°C. In this system, the air within the room will circulate by convection, with little or no provision for forced convection.

Hence foods placed at these low temperatures are frozen comparatively slow, taking several hours or even days for complete freezing.

Air blast freezing

In an air blast freezer, fish is frozen by circulation of a stream of high velocity cold air either in a batch or continuously, typically in a duct or tunnel at -18 to -34°C or lower, moving counter current to the product at a speed of 1-20 meter/sec.

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

Batch air blast freezers: Batch air blast freezers use pallets, trolleys or shelf arrangements for loading the product. The freezer is fully loaded, and when freezing is complete, the freezer is emptied and reloaded for a further batch freeze.

Air blast freezing is economical and is capable of accommodating products of different sizes and shapes. However it can result in excessive dehydration of unpackaged products if conditions are not carefully controlled, as well as undesirable bulging of packaged products which are not confined between flat rigid plates during freezing.

Modern designs of belt freezers are mostly based on the spiral belt freezer concept. In these freezers, a conveyor belt that can be bent laterally is used. The design consists of a self-staking and self-enclosing continuous belt for compactness and improved air flow control. The number of tiers in the belt stack can be varied to accommodate different capacities and line layouts. The products are placed on the belt outside the freezer where it can be supervised. Both packed as well as unpacked products are frozen and the freezer gives a large flexibility both with regard to product and freezing time. Both horizontal and vertical air flow can be applied and the latter is observed to be more efficient.

Fluidized bed freezing is a version of air blast freezing wherein marine products like small sized prawns, uniform sized fillets etc. can be frozen by passing through meshed belts where they are fluidized by a stream of forced cold air moving upward through the bed at a rate sufficient to partially lift or suspend the particles. Freezing by this method is rapid and a minimum air velocity of 2 meter/sec. or more is necessary to fluidize the particles and an air temperature of - 35°C is common. The bed depth depends on ease of fluidization and this in turn depends on size, shape and uniformity of the particles. A bed depth of slightly more than 3 cm is suitable for small prawns where as a depth of 20 to 25 cm can be used for non-fluidizable products such as fillets. Fluidized bed freezing has proven successful for many kinds and sizes of food products. The best results are obtained with products that are relatively small and uniform in size. Some fluidized-bed freezers involve a two stage freezing technique wherein the first stage consists of an ordinary air-blast freezing to set the surface of the product and the second stage consists of fluidized bed freezing. The advantages of fluidized bed freezing include more efficient heat transfer and more rapid rates of freezing and less product dehydration and less frequent defrosting of the equipment. Dehydration loses of about 1% have been reported during fluidized bed freezing of prawns. The short freezing time is apparently responsible for the small loss of moisture. The major disadvantage of fluidized-bed freezing is that large or non-uniform products cannot be fluidized at reasonable air velocities.

Contact Plate Freezing

Plate freezers consist of a vertical or horizontal stack of hollow plates, through which refrigerant is pumped at –40ºC. Fish products can be frozen by placing them in contact with these metal plate surface cooled by expanding refrigerants. This equipment consists of a stack of horizontal or vertical cold plates with intervening spaces to accommodate single layers of packaged product. The filled unit appears like a multi layered sandwich containing cold plates and products in alternating layers. When closed, the plates make firm contact with the two major surfaces of the packages, thereby facilitating heat transfer and assuring that the major surfaces of the packages do not bulge during freezing. Vertical plate freezers are also in use especially onboard fishing vessels. In this method the packages must be of uniform thickness. A packaged product of 3 to 4 cm thickness can be frozen in one to two hours when cooled by plates at -35°C. Freezing times are extended considerably when the package contains a significant volume of void spaces. Double contact plate freezers are commonly used for freezing foods in retail packages. This equipment may be batch, semi automatic or automatic. Advantages of this type of equipment include good economy and space utilization, relatively low operating costs compared with other methods, little dehydration of the product and therefore minimum defrosting of condensers, and high rates of heat transfer.

Spray or Immersion freezing

Immersion freezing is a method of commercially preparing frozen foods so that the product remains suitable for consumption over a long period of time. The process helps to lock in moisture as well as maintain the flavor and taste of the processed food. Liquid immersion freezing or direct immersion freezing is accomplished when a product is frozen by immersing or by spraying with a freezant that remains liquid throughout the process. Liquid immersion freezing can result in moderately rapid freezing. Freezants used for liquid immersion freezing should be non-toxic, inexpensive, stable, reasonably inert, and should have a low viscosity, low vapour pressure and freezing point and reasonably high values for thermal conductivity. Freezants should have a low tendency to penetrate the product, little or no undesirable effects on organoleptic properties and require little effort to maintain desired standards for sanitation and composition. Aqueous solutions of propylene glycol, glycerol, sodium chloride, calcium chloride and mixtures of sugars and salt have been used as freezant. The major advantages of liquid immersion freezing are rapid heat transfer, lower operating and investment costs and easy adaptability to continuous operations. Quick freezing preserves the texture of tissues more successfully and causes less dehydration during the freezing process. However it is difficult to derive freezants with suitable properties.

Cryogenic Freezing

Cryogenic freezing refers to very rapid freezing by exposing food products to an extremely cold freezant undergoing change of state. The fact that heat removal is accomplished during a change of state by the freezant is used to distinguish cryogenic freezing from liquid immersion freezing. The most common food grade cryogenic freezants are boiling nitrogen and boiling or subliming carbon dioxide. The rate of freezing obtained with cryogenic methods is much greater than that obtained with conventional air-blast freezing or plate freezing, but is only moderately greater than that obtained with fluidized bed or liquid immersion freezing. Currently liquid nitrogen is used in most of the cryogenic food freezers. Usually liquid nitrogen is sprayed or dribbled on the product or alternatively very cold gaseous nitrogen is brought into contact with the product. Freezing with carbon dioxide as well as using freon are all other means employed. Carbon dioxide is absorbed or entrained by the product in this method. This entrapped CO_2 should be removed before it is packaged in an impervious material. Further used of refrigerants like freon, though economic is being withdrawn by the industry on account of the concerns with regard to its role in ozone depletion.

Advantages of cryogenic freezing include: improved baseline production rates by reducing the amount of time required to remove heat from a product; marked increase in product yield due to less product dehydration; improved product safety and minimum product degradation due to the short freezing time; better texture retention due to formation of smaller internal ice crystals; low labor costs through reduced product handling and quicker cleanup and consistent production rates.

Crusto Freezing is a combination of cryogenic freezing system and air blast freezing system. The equipment utilizes the possibility of a fast and efficient crust freezing of extremely wet, sticky products which can then be easily handled in a spiral belt freezer or a fluidized bed freezer without deformation or breakage.

Quality changes associated with freezing and frozen storage

The quality of frozen-thawed cooked fish is influenced by a number of factors including species, composition, size, harvesting conditions, 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. Effective pre-freezing and freezing techniques are available for controlling many of these problems. Reasonable control of toughening and loss of juiciness can be accomplished by storing fish for a minimal time and / or at temperatures at -18°C or lower. Undesirable oxidative changes in fish can be minimized by (1) eliminating oxygen (2) avoiding contamination with heavy metals (oxidative catalysts) (3) adding antioxidants and (4) by using low storage temperature. Dehydration can be avoided by applying glaze and suitable protective coatings.

Cooling seafoods is among the most effective methods for preserving their quality. From a choice refrigerant, it can be chilling which facilitates short term preservation to freezing at sub-zero temperatures leading to extended storage life for months and even years, depending on temperature employed. Application of these preservation techniques with standard operating protocols can ensure superior quality seafoods to the customers.

Suggested Readings

1. Balachandran, K. K. (2001). *Post-harvest technology of fish and fish products*. Daya Books.
2. Connel, J.J. (1995). *Control of Fish Quality*. Fishing News Books, London, England p 245.
3. Garthwaite, G.A. (1997). *Chilling and Freezing of Fish. In: Fish Processing Technology* 2 nd Edition (Ed.Hall G.M) , Springer (India) Pvt.Ltd, New Delhi , pp 98-108.
4. George Ninan (2014). *Freezing and Frozen Storage of Fish and Shellfish Products. In: Training manual on "Modern Food Processing Technology"* (George Ninan, Venkateswarlu Ronda and A.Jeyakumari Eds), ICAR-CIFT, Kochi, pp. 40-53.
5. Gopakumar, K. (2002). Textbook of fish processing technology. Indian Council of Agricultural Research, 491p.
6. Hardy, R. (1986). Fish processing, Proc. R. Soc. Edinburg, 87B, 201.
7. Huss, H.H. (1995*). Quality and quality changes in fresh fish*, FAO Fisheries Technical Paper No. 348. Rome. 195 p.
8. Johnston, W. A. (1994). *Freezing and refrigerated storage in fisheries* (Vol. 340). Food & Agriculture Org.
9. Ronsivalli, L. J. and Baker, D. W. (1981*). Low temperature preservation of seafoods: A review*. Marine Fisheries Review, 43(4), 1-15.
10. Subsinghe, S. (1996). Handling and marketing of aquacultured fish, Infofish Int.,3,p 44.
11. Venugopal, V. and Shahidi,F (1998) Food Rev. Int. 14.p 35.
12. Venugopal, V. (2006). *Bulk handling and Chilling, In Seafood Processing: Adding value through quick freezing, retortable packaging and quick chilling*, CRC Press , Taylor & Francis Group, Boca Raton, FL., p 485
13. Zugarramurdi, A., Parin, M.A. and Lupin,H.M. (1995). *Economic engineering applied to the fishery industry*. FAO Fisheries Technical Paper No.351, FAO,Rome,Italy.