

Types of freezer, Methods of protective treatments, Calculation of freezer refrigeration load

3.3.1. Introduction

The three basic methods of freezing fish are:

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

3.3.1.1. Air blast freezers

The advantage of the blast freezer is its versatility. **It can cope with a variety of irregularly shaped products and whenever there is a wide range of shapes and sizes to be frozen, the blast freezer is the best choice.** Before going on to describe the various types of air blast freezer, it is necessary to deal with some of the basic principles of air blast freezer design and operation.

Designing air blast freezers

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

Frost build-up on the cooler is also more prolific on the upstream coils; therefore a cooler with a large frontal area will be able to operate longer before a defrost is necessary.

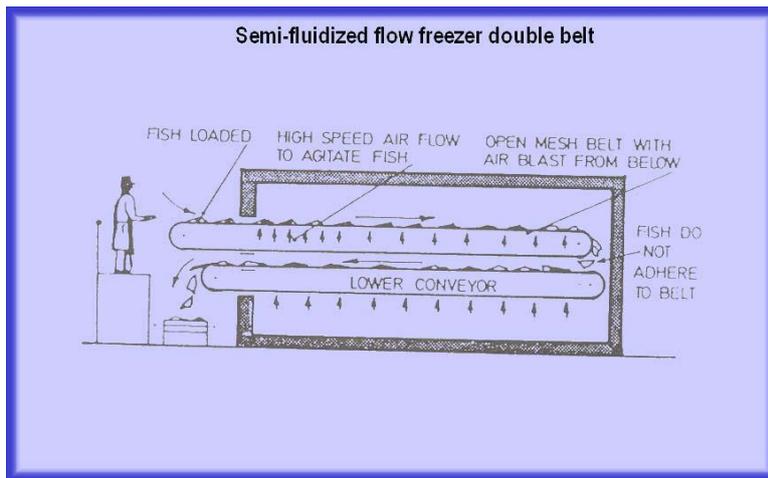
Continuous air blast freezers

The belt has to be flexible, easily cleaned, non corroding, suitable for use in direct contact with food and should not interfere unduly with either the freezing time or adversely affect product quality. Stainless steel mesh link belts or chain link belts are mainly used for this purpose but they have certain disadvantages. Apart from being expensive, they affect the appearance of the product. If fish are loaded directly on the belt, the crinkled or indented appearance of the frozen product is not always acceptable. Open mesh belts can also give rise to difficulty when removing the product after freezing and some weight loss may be incurred due to slight physical damage. Skin-on fillets can usually be removed quite easily but skinless fillets and fish portions can stick to the belt and cause unacceptable weight losses.

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

Fluidized and semi-fluidized freezers

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 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.



3.3.1.2. Plate freezers

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

Horizontal plate freezers

At present in India all the processing plants have HPF. Capacity of this freezer varies between 500kg to 1ton/load. Each plates are connected with pressure resistant hose on both ends, i.e. suction line and discharge line. A hot gas defrost arrangement is the quickest method to defrost an HPF, but even with this method, it may take 30 min or more. The defrosted plates must be completely free from frost or ice and dried before the freezer is used again.

Vertical plate freezers

The main advantage of this type of freezer is that fish can be frozen in bulk without the requirement to package or arrange on trays. This type of freezer is therefore particularly suitable for bulk freezing and it has also been extensively used for freezing whole fish at sea. The maximum size of block made by this method is usually 1070 mm x 535 mm. Other dimensions however, can be produced in which the thickness can vary from 25 to 130 mm, and it will depend on the fish to be frozen. The maximum weight and dimensions are also limited by the physical effort required from the operator to lift the block, and by the ease with which it can be handled so that damage to the fish is kept to a minimum.

In most cases, fish can be loaded between the plates without wrappers and water need not be added either to strengthen the frozen block or improve the contact with the plates. Fish such as cod and haddock produce compact blocks with a block density of approximately 800 kg/m³. It has certain operational disadvantages.

Defrost is essential to prevent fish sticking to the plates which are at a temperature below 0°C, and thus failing to form a compact block. Freezing times are longer due to the poor contact being made with the plates and because of the lower block density, more storage space is required for a given quantity of fish.

3.3.1.3. Liquid nitrogen freezer

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

The main advantage of the liquid nitrogen freezer LNF is that freezing is very quick and the physical size of the freezer is correspondingly small. **The freezer is operated without the need for compressors, condensers or coolers; therefore maintenance requirements are minimal and the power required to operate the freezer is very low.** Liquid nitrogen must be retained in a vacuum insulated pressure vessel with continuous venting to keep the contents cool and the internal pressure down. It is found that 0.5 percent of the stored contents is lost each day by this method. In addition, about 10 percent has been estimated to be lost during the transfer of liquid from the tanker to the storage vessel. This method of freezing is more expensive than most others. **It is four times more costly than conventional air blast freezing.** Although the freezer is small and there is no refrigeration machinery requirement, storage space and access is required for the liquid nitrogen tank. The main disadvantage of this type of freezer in most developing countries like India is that delivery of nitrogen could be expensive and there may be no guarantee of regular supplies.

3.3.1.4. Carbon dioxide freezer

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

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

3.3.1.5. Immersion freezers

In this method a liquid refrigerant is used for the removal of heat from a product. Favourable freezing rates can be achieved. Liquid can remove more heat per unit volume than gas (eg. air) but, like gas, a stagnant boundary layer is form which slows the transfer of the heat. Liquids used for heat transfer must therefore be circulate over the product. Difficulties due to high viscosity often arise when a low temperature liquid is used.

Chapter 4: Methods of protective treatments

3.4.1. Brining

To minimize drip loss, fillets/steaks of fish are immersed in brine for a short time and this process is known as firming of fillets/steaks. There are several advantages in this type of firming.

1. When fish fillets are dipped in strong brine, the proteins in the outer surface of the fillet gets coagulated due to which firming takes place.
2. The layer of salted out proteins insulates the muscle tissues from the negative influence of outside factors.
3. It favours the retention and preservation of natural extractives and flavour compounds.
4. It minimized drip loss.

Effect of salt concentration in brine and brining time

The treatment of fish fillets with brine is a precision operation. When the salt concentration is less than 5% proteins get solubilized and lost in salt solution. If it is more than 15%, tissue proteins coagulate due to “salting out” of the proteins and the texture becomes tough. If the duration of dip treatment is more, the product becomes salty. Therefore, brining treatment should be done in right concentration for a brief period of time.

Method of brining: Before the treatment with brine, the fillets are washed properly, because brine treatment on a clean surface is more effective. Salt concentration in brine should be 10-12% (sp. gr. 1.07 to 1.09). Brining temperature should be less than 15°C. In dip treatment the brining time is 1 to 2 min. However, there is scope to change the salt concentration and duration of time for treatment depending on species of fish. The brine should be changed after every dip treatment. Addition of antimicrobials such as sodium benzoate, benzoic acid, parabens, sodium nitrite and antioxidants like ascorbic acid can be added to brine in order to maximize its effectiveness. However in **fatty fish bringing promotes fat oxidation in it and hence the results are not**

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3.4.2. Advantages of brine treatment

1. Treatment with brine destroys the microorganisms present on the fish fillet to a great extent. However, salt should not contain Ca^{++} and Mg^{++} impurities which are responsible for salt odour and bitter taste.
2. Prevention of belly bursting by brine treatment: During chilled storage and during freezing and thawing, belly bursting is observed in sardines (poor appearance, viscera comes out) which is a major problem in small fish such as sardine. If sardine is dipped in 15% brine for 30 min and then frozen, the problem of belly bursting can be minimized. By this method, due to coagulation of proteins the belly wall becomes tough. However the treatment promotes oxidation of fat and hence the shelf life in frozen storage gets reduced.

Phosphate treatment : Poly PO_4 treatment minimizes drip loss in frozen fish and fishery products. Poly PO_4 (Polyphosphate) treatment may be given separately or along with brine treatment. In cod fillets drip treatment in **0.0844 < (4%) poly PO_4** solution minimized significant amount of drip loss.

Role of Polyphosphate in minimizing drip loss :

In frozen fish, water holding capacity of tissues comes down due aggregation and protein denaturation and hence results in increased drip loss. The important reasons for drip loss are given below.

1. Freezing changes ionic environment of fish muscle.
2. Reduction in pH due to production of lactic acid.
3. Degradation of nucleotide which contains active phosphorus.
4. Formation of actomyosin from actin and myosin.

The role of polyphosphate in minimizing driploss and preservation of quality of fish is explained as follows.

1. Balanced action of tripoly PO_4 , organic phosphate such as ATP and other phosphates leads to break down of the complex protein actomyosin to constituent proteins actin and myosin resulting in increased water holding capacity of muscle.
2. Cell fluids of fish (salted) dipped in brine require -22°C for complete freezing due to increase in salt concentration. Therefore liquid present in such cell fluids remain unfrozen and atmospheric oxygen dissolve in such a liquid and penetrates inside the tissues. This accelerates oxidation process. However, if 12% tripoly PO_4 is mixed with brine, the freezing point of tissue fluids will only be -3°C . Therefore proportion of unfrozen liquid will be greatly reduced and also concomitant oxidation. This is very much useful in fatty fishes.
3. Polyphosphate acts as a chelating agent and chelate prooxidant metal ions, thereby minimizing catalytic action of metal ions in fat oxidation.

3.4.3. Use of Polyphosphate in freezing of fish

Dip treatment in phosphate solution prior to freezing gives better results. In prawns, in addition to dip treatment in phosphate solution, it may be mixed with glaze water.

Quantity of poly PO_4 to be used

Fairly high proportion of phosphate ion is required for breakdown of complex acto-I-myosin into its constituent proteins. Among various phosphates, tripoly PO_4 and pyropoly PO_4 gives the best results.

Use of tripolyphosphate solution of 0.16 M ionic strength (8%) and 4.5% pyropolyPO₄ along with salt to increase the ionic concentration to 0.4 M and 0.35 M respectively increases the water holding capacity of muscle tissues effectively. Among the above, tripoly phosphate is extensively used but its effect depends on the species of fish. Though tripolyPO₄ solution and brine can be used separately, fish and fillets are treated with pyropolyPO₄ and brine together very good effect was observed.

Polyphosphate should be used in such a way that it is absorbed quickly into fish muscle. It has been found that the enzymes and digestive juices convert the polyPO₄ in to orthoPO₄ in the body and hence it does not pose any health hazard. However it is better to take proper care while using depending on its desired effect on the product.

Antioxidant treatment

Rancidity is the commonly observed storage problem in fatty fish. To minimize the problem of rancidity, antioxidants which are commonly used in edible oils and fats have to be used in fish. Rancidity in oils and fats is controlled by following methods.

1. Removal of pro-oxidant chemical compounds or inactivation of these factors.
2. Packaging of fish so that oxygen is prevented from coming into contact with fish surface and subsequent penetration inside the tissues.
3. Before or after freezing fish may be treated with antioxidants. Enzymes responsible for fat oxidation may be inhibited.

Phenolic antioxidants, even though very effective, they are not soluble in water. Some of the methods used for application of antioxidants for frozen fish and fillets are as follows.

1. Water soluble antioxidants such as ascorbic acid penetrates the tissues of fish through tissue fluids and helps in arresting oxidation process. It is effective against salmon, trout, herring and tuna during frozen storage. It is also effective against colour change in pomfrets. Ascorbic acid also acts as a synergist when used along with BHA, tocopherol and hydroquinone. Ascorbic acid in glaze increases the shelf life of mackerel and pomfret during chilled and frozen storage.
2. Glaze containing ascorbic acid and citric acid mixture is effective against fatty fish and onset of rancidity can be delayed for a long time.
3. Oil soluble antioxidants are useful in minimizing rancidity in fatty fishes. This is because the oil of fish is on the surface and the antioxidants dissolve quite easily into such oil and penetrates into the tissues. The antioxidant power of BHA and Ascorbic acid double when used as a mixture.

3.4.4. Methods of using antioxidants

1. **Dip treatment prior to freezing**
2. **In glaze water**

Water soluble antioxidants can be easily dissolved in water and can be directly used. However, oil soluble antioxidants are first emulsified in small quantity of oil in water type and used. When gallates are used there should be no contact with Fe⁺⁺ and pro oxidant metal ions may be bound by chelating agents and make them unavailable in oxidation reactions. Nitric acid, phosphoric acid, sodium phosphate citrates, tartarates and ethylene diamine tetra acetic acid (EDTA) are some of the important chelating agents. These may be used separately or along with anti oxidants.

Commonly used antioxidants

Antioxidants are of 2 types 1) Water soluble and 2) Oil soluble.

Antioxidants used in fish processing are as follows

	Compound	Nature	Max. Percentage used
1)	BHA	Oil	0.02
2)	Salts of gallic acid		
	a) Propyl gallate	Water	0.01
	b) Octyl gallate	Oil	0.01
	c) Do decyl gallate	Oil	0.01
3)	Nor-dihydrogui acetic acid	Oil	0.01
4)	Ascorbic acid	Water	0.25-2

5)	Sodium ascorbate	Water	0.25-2
6)	Sodium sulphide	Water	0.25-2
7)	Tocopherols	Oil	0.03
8)	Amino acids (cystine, histidine, tryptophan)	Water	0.03
9)	Synergist (citric acid, sorbitol)	Water	0.03

As antioxidants break the chain of free radical formation, oxidation is prevented. However, this is easy in the case of almost pure oils but in the case of fish it is quite difficult because the action of antioxidant depend on several factors such as

1. Property of oil in the tissues.
2. Penetration of antioxidants into tissues .
3. Presence of Pro-oxidant materials.

Therefore some antioxidants are effective only against certain species of fish. Some problems associated with the use of antioxidants in fish are

1. Determination of an antioxidant for a particular species of fish.
2. Medium and method of application of the antioxidant.

Chapter 5: Calculation of freezer refrigeration load

3.5.1. Calculation of freezer refrigeration load

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

Load calculation

I. Number of freezer

$$20 \text{ t/day} = 20,000 \text{ kg/day}$$

$$20,000 \div 10 = 2,000 \text{ blocks/day}$$

$$24 \div 2 = 12 \text{ cycles/day}$$

$$2,000 \div 12 = 167 \text{ blocks/cycle}$$

II. Fish load

$$20,000 \div 24 = 833 \text{ kg/h}$$

$$\text{Enthalpy at } -30^{\circ}\text{C} = 4.6 \text{ kcal/kg}$$

$$\text{Change in enthalpy} = 81.3 \text{ kcal/kg}$$

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

a) Specific heat of fish above freezing, 0.9 kcal/kg°C

b) Latent heat of the fish, 60 kcal/k

c) Specific heat of fish below 0°C, 0.4 kcal/kg°C

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

Heat to remove on cooling to 0°C

$$833 \times 0.9 \times 10 = 7497 \text{ kcal/h}$$

Latent heat to remove $833 \times 60 = 49980 \text{ kcal/h}$

Heat to remove on cooling to -30°C

$$833 \times 0.4 \times 30 = 9996 \text{ kcal/h}$$

Total heat to remove from fish = 67473 kcal/h

Total refrigeration requirement with allowances:

$$\text{Add } 30\% = 142681 \text{ kcal/h}$$

The calculation of fish load gives refrigeration requirement to freeze the fish only. Depending on the type of freezer used, other heat loads such as fan heat, pump heat from circulating pump, heat leak through freezer insulation, heat load due to pallets, trays, trolleys, defrost procedure, air infiltration, internal lighting etc. have to be taken into account and added to this value to determine the total refrigeration requirement.

3.5.1.1. Freezing time

Following are the Variables which affect freezing time

1. Freezer type
2. Freezer operating temperature
3. Refrigeration system and operating condition
4. Air speed in an air blast freezer
5. Product temperature
6. Product thickness
7. Product shape
8. Product contact area and density
9. Product packaging
10. Species of fish

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.

Air speed in blast freezers: Freezing time is reduced as the air speed increased.

Product before freezing: The warmer the product, the longer it will take to freeze. Fish should therefore be kept chilled (+4°C) before freezing both to maintain quality and reduce freezing time and refrigeration requirement.

Product thickness: The thicker the product, the longer is the freezing time.

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.

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 a greater influence on the freezing time than the resistance of the wrapping material itself.

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. Correspondingly freezing time will be less.

3.5.1.2. Calculation of freezing times

The more general form of Plank's equation for calculation freezing time is:

$$L \quad P D \quad R D^2$$

$$\text{Freezing time} = \frac{L}{V} \left\{ \frac{P}{D} + \frac{R D}{f k} \right\}$$

$$V \quad D \quad f k$$

Where

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

V = Specific volume of fish (m³/kg)

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

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

f = Surface coefficient of heat transfer (including effect of packaging) (kcal/h.m °C)

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

P and R= Constants which depend on shape

Values for shape constants P and R

Shape	P	R
Sphere	0.167	0.042
Infinite Cylinder	0.167	0.042

Infinite Slab	0.500	0.250
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Calculated freezing time – Example 1: What is the freezing time if all other conditions remain the same but the operating temperature is -25°C .

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

$$200 \times 34 \div 24 = 283 \text{ min or } 4\text{h } 43\text{min}$$

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

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

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

3.5.1.3. Coding, Packing and Storage

A code slip bearing the marking of the numerical code of the processor, abbreviation of the name and type of products, year, month and date of production shall be embedded on the frozen block. In the case of individually Quick frozen (IQF) packs the code slips shall be placed in the primary containers.

An illustration of the coding is given below:

520 FSPD

11A10

Where in the above illustration

520 – the numerical code of the processor/ exporter

FS – Name of the product (Frozen shrimps)

PD – Type of the product (Peeled and Deveined)

11 – Year of processing (here 2011)

A – Month of processing (here January)

10 – Date of processing (here tenth day of the month)

The following abbreviations shall be used for the months of the year:

January - A

February - B

March - C

April - D

May - E

June - F

July - G

August - H

September - J

October - K

November - L

December - M

The frozen products shall be packed in primary container other wise known as wax coated board or duplex carton and such primary containers shall be packed in seaworthy fibre board cardboard cartons of 5 ply minimum or any other better type of cartons. In the case of Individually Quick Frozen products the pieces shall be arranged/wrapped in moisture proof film. As per the specific requirements of the buyer the packing of frozen fish and Fishery products without primary container/Duplex cartons shall be permitted. In such cases the products shall be placed in a master poly bag and placed inside the master carton. The frozen material shall be stored in a room maintained at or below a temperature of minus 18° C.