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An Investigation on Impact of Freezing Time over Meat Products

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Abstract

Freezing process is the one of the most advantageous methods of food preservation techniques for high quality of food for long storage. The cold storage follows both chilling and freezing processes for the preservation of vegetables from between -18^{0}c and -35^{0}c to avoid the physical, microbiological and chemical activities that causes deterioration in foods. To preserve the food material various freezing equipment's are followed like blast freezer, plate freezer, contact freezer, immersion freezer, cryogenic freezer, individual quick freezer etc. The choosing of the freezing system is depending upon the type of food products moisture content, nature of products and pre-treatments etc. sometimes low temperature can cause the damage to cells of meat by ice crystal growth, even though, freezing retains characteristic and nutritional of commodities.

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Freezer, Refrigerant, Freezing time, Storage period, Storage temperature, Relative humidity.

Introduction

Freezing is one of the most preferable methods of preservation of meat products and inhibit microbiological growth and help to preserve the original sensory and nutritional qualities. The fundamentals of freezing are normally required to produce products with high quality for quick freezing and storing at a constant sub – freezing temperature. In cold storage, the ready - to - eat meals are normally quick – frozen to a temperature near -15°C to -20°C (Evan, 2008) using cryogenic technique. The above method controls ice nucleation in the way that water can transform into small ice crystal (Kennedy, 2000). In additional to freezing techniques, ice formation (i.e., ice nucleation and growth) is effected by characteristics of food being frozen like mass (Degner *et al.*, 2013). In freezing operation the temperature of usually reduce to - 18^{0}c or less (Fennema *et al.*, 1975). Low temperature freezing system delays the chemical and biological processes in food and reduces the quality loss. During the preservation of meat products, there is various options to choose the refrigeration system and efficiency is accomplished by the tonnes of food and refrigeration system. The refrigeration works based in the refrigerant is a heat carrying medium which during their cycle (i.e. Compression, condensation, expansion and evaporation) in the refrigeration system and discards the heat so absorbed to a higher temperature system. In 1834, ether, ammonia, sulphur-di-oxide, methyl chloride and carbon dioxide came into use as refrigerants in compression cycle refrigeration machines. In present days, new refrigerants including halo-carbon compounds, hydro-carbon compounds are used for refrigeration applications. The suitability of a refrigerant for a certain application is determined by its physical, thermodynamic, chemical properties and by various practical factors. There is no one refrigerant which can be used for all types of applications. i.e. there is no ideal refrigerant. If one refrigerant has certain good advantages, it will have some disadvantages also. Hence, a refrigerant is chose which has greater advantages.

And refrigerant may broadly be classified into following two groups:

1. Primary refrigerants and

2. Secondary refrigerants.

The refrigerant which directly take part in the refrigeration system are called primary refrigerant whereas the refrigerant which are first cooled by primary refrigerants and then used for cooling purposes are known as secondary refrigerant.

The primary refrigerant is further classified into following four groups:

Halo – Carbon or organic refrigerant

Azeotrope refrigerants

Inorganic refrigerant

Hydro – carbon refrigerant

Methods of Freezing

The freezing methodology of meat products is by using the air – blast freezing used under high velocity air at about -30^{0}c is blown over food products, contact freezer is used where the packaged and un packaged food is place by conduction methodology. In immersion freezer, the food is placed at low temperature and cryogenic freezing, where food is placed in ultra-low temperature. When the food products are to be preserved in its original fresh state for longer periods, then they are usually frozen and stored approximately at – 15^{0}c or below. Such storages are known as frozen storages. They differ from the cold storages in their size and temperature range. The size of frozen storages is considerably smaller than cold storages and temperature used for cold storages. The food products which are commonly preserved in frozen storage meat products. The high quality products in good condition should only be frozen and meat products do not require any special processing before freezing. They are directly taking them into frozen storages after washing.

There are various methods available for food freezing system, these include: air-blast freezers (batch and continuous), fluidized bed freezers, impingement freezers, liquid immersion freezers, plate freezers, liquid nitrogen freezers and carbon dioxide freezers. In air blast freezer, the significant specialty in application for use, the air is flow at low viscosity fluid it has flow across around irregular surface geometries, thus providing a more uniform freezing rate over the whole product. Other freezing methods such as plate freezing (contact freezing) offer faster cooling times, but can only be used with products of a suitable geometry (Hessami, 2004). Many food products may be stored at variable temperature above the freezing point. The storage may be short term storage and long-term storage depends upon the delivery of food system and product feature. The storages which are used for short term storage purposes are known as cold storages. The short – term storage is usually meant for retail establishment where rapid turnover of the product is normally expected. The period for short term storages ranges from one to two days or to a week or more in some cases, but not more than fifteen days under any circumstances. The long-term storage is usually carried out by wholesalers and commercial storage warehouses. The storage period depends on the type of product stored and its condition on entering the storage. The maximum storage period for long term storage ranges from seven to ten days for some sensitive products and up to six or eight months for more durable products such as smoked meat. When perishable food are to be stored for longer period, they should be frozen and stored in frozen storages.

In general the condition required for short term storage are more flexible than those required for long term storage temperature are tolerable for short term storage.

The following procedures are kept in mind while storing the Meat products:

Storage temperature

Most of the foods for short term storage are stored at a temperature slightly above their freezing point. The products are stored at incorrect storage temperature, its lowers the quality of the stored products**.**

Relative humidity and air motion

The relative humidity and air motion are major criteria which must be controlled in the storage of all perishable food in their natural state**.** The issues are necessary in order to prevent excessive loss of moisture from the product (dehydration). It may be noted that low relative humidity and high air velocity causes excessive dehydration. The loss of excessive amount of moisture from the meat products causes a shrinkage and discoloration.

Condition of products at the time of entering storage

The condition of product at the time of entering the storage is one of the important factors for determining the storage life of a refrigerated product. It may be noted that refrigeration only arrests or retards the natural processes of deterioration. But the already deteriorated products cannot be restored to good condition.

When the products subjected to dehydration are to be chilled, then the humidity should be kept at a peak level. Some extremely sensitive products, such as poultry meat and fish are frequently chilled in ice to reduce moisture losses during chilling stage. When the products packed in ice are placed in refrigerated storage, the slowly melting ice keeps the surface of the product moist and prevents excessive dehydration.

Freezers used for Perishable Food Commodities

Contact Freezers

In contact freezer, the meat products are frozen by placing in contact with system and cooling is achieving by heat conduction. The direct contact between the product and medium used for reduction of product temperature is appropriate and effective. In this type of system, there is no barrier between the product surface and medium utilized for product freezing. Contact freezer operates between the ice nuclei and observed number of concentration of ice crystal (Avramov *et al.*, 2011). Several detailed reviews on ice nucleation have been published. The plate freezer has flat hollow refrigerated metallic plates and arranged in parallel manner. The food products are placed in between metallic plates and pressure is applied over the contact for proper freezing. The ice nucleation occurs in the region next to the refrigerated border and is controlled by the magnitude of supercooling reached in this zone.

Plate freezers are freeze only the regularly shaped food objects and items are placed in horizontal and vertical planes (Horizontal plate and vertical plate freezer). The food item are packaged and placed in trays before the freezing operation. To ensure the heat exchange the hydraulic system for movement. In vertical plate freezer, a refrigerant runs through all plates arranged vertically. This direct contact method of freezing method makes the vertical plate freezer as suitable for quick freezing of meat products, which increases energy saving and lower freezing time (Heap, 1997).

Air Blast Freezer

In this method of quick freezing, the food products are freeze by the contact with cold air by convection process. The air blast freezing is widely used because it provides excellent quality of the food among all other types. In this method, a very low temperature air is circulated with a very high velocity around the various parts of the products kept in insulated tunnel type storages. The temperature of -20°C to -40°C are commonly used for this method of freezing. The velocity of air varies from 30m/min to 120m/min according to the type of food to be freeze. It may be noted that dehydration of the product may occur in freezing unpacked whole or dressed fish in blast freezer unless the velocity of air is kept to about 160m/min and the period of exposure of air is controlled. The blast freezers are provided with blower to circulate the air towards the food at rapid rate and produce ice crystals over the surface. The micro-organism is not able to survive in the extremely cold condition of blast freezer**.** The air blast freezers are extensively used throughout the world to freeze the various products of packaged or unpackaged of any shape and size. Hence, this type of freezer's are mostly used to preserve the meat products. In air blast freezer, the temperatures are maintained at -35°C for 48hrs (Dempsey, 2010). In quick freezing, the ice crystals are formed at the higher nucleation points to maintain the quality (Dempsey *et al.*, 2012). The air blast freezing is mainly used for freezing fishery products like meat, shrimp, fish fillets steaks, scallops or pre cooled products packed in small packages.

Immersion Freezer

In this method of quick freezing, the food products are immersed into low temperature liquids. Since the liquids are good conductors of heat and in good thermal contact with all the products, therefore the heat transfer is rapid and the product is completely frozen in a very short time. The liquid medium, used for freezing the foods should be non-toxic and should not produce any bad effect on the immersed foods. The liquids used for this purpose are sodium chloride, brine (Robertson *et al.*, 1976), sugar brine and propylene glycol. The fish and shrimp are the two animal products which are most frequently frozen by immersion.

This freezing method produces a thin coating of ice on the surface of the product resulting in prevention of dehydration of unpackaged products during the storage period. The only disadvantage of this system is the extraction of the juices from the products by osmosis resulting into contamination and weakening of the freezing solution. This defect can be avoided by freezing the products in canned or packaged forms.

Immersion freezing systems are extensively used in on the ship freezing of fish but its industrial use on other products has been limited. There are two advantages of immersion freezing over air blast freezing.

Overall, energy consumption is reduced by 25% in immersion freezing. It is one of the fastest freezing techniques, because heat transfer coefficient is higher in the liquid phase than in air (Robertson *et al.,* 1976). Immersion freezing causes less product dehydration and a higher quality final product is obtained (Lucas *et al.,* 1996).

In this type of freezing system, using a liquid coolant as a heat-transfer medium (Lucas *et al.*, 1996), can radically increase freezing speed (Ribero *et al.,* 2009) due to the high thermal coefficient of liquid medium. This results in an immediate and even nucleation throughout foods achieved and small ice crystals are formed (Anese *et al.*, 2012; Zhu *et al.*, 2004).

Individual Quick Freezer

Individual quick-freezing technique is designed to freeze each and every piece of food products. Generally, smaller pieces of food products, such as meat, poultry, shrimps, small fish etc., There is no formation of swellings in product, creates smaller ice crystals and less mechanical damage of whole cells of the food. Quick frozen products have better taste, flavour, aroma, colour appearance and freshness than slow frozen products.

Darke *et al.,* (1981) compared the Individual quick freezing and air blast freezing for vegetables and found that vegetables in individually quick frozen were higher quality compare to common blast frozen vegetables, particularly with regard to reduced drip loss.

Effects of Freezing Systems and Storage Temperatures on Overall Quality of Perishable Food Commodities

Usually, foods can be stored safely at a temperature of -18°C, however, this low temperature storage and/or for long period of time can cause vitamin losses and adverse quality effects on color and flavor of the product at retail level. However, during frozen storage the losses in vitamins depends on the type of product, packaging used and additives or sugar used (Fennema, 1982).

Frozen Food Properties

The freezing process has impact on the thermal properties of the food product. Because of the significant amount of water in most foods and the stimulus of phase change on properties of water, the properties of the food product change in a proportionate manner. The water within the product changes from liquid to solid, the density, enthalpy, thermal conductivity, and apparent specific heat of the product change gradually as the temperature decreases below the initial freezing point for water in the food.

Weight loss

Some foods exhibit particular quality advantages as a result of rapid cooling. In meat, the pH starts to fall immediately after slaughter and protein denaturation begins. The result of this denaturation is a pink proteinaceous fluid, commonly called “drip,” often seen in prepackaged cuts of meat. The rate of denaturation is directly related to temperature and it therefore follows that the faster the chilling rate, the less the drip. Investigations using pork and beef muscles have shown that faster rates of chilling (e.g. reducing the deep leg temperature of a pig in 10 hours to 5°C compared with 14°C) can halve the amount of drip loss.

Density

The density of ice is less than the density of liquid water. As same as, the density of a frozen food will be less than the unfrozen product. The gradual change in density is due to the gradual change in the proportion of water frozen as a function of temperature and this shows the influence of temperature on density. The magnitude of change in density is proportional to the moisture content of the product.

Thermal Conductivity

The thermal conductivity of ice is approximately a factor of four larger than the thermal conductivity of water. This relationship has a similar impact on the thermal conductivity of a frozen food. Since the change of phase for water in the product is gradual as temperature decreases, the thermal conductivity of the product changes in a manner. In major food products of the thermal conductivity increase occurs within range of 10°C below the initial freezing temperature for the food product. If the product happens to contain a fibrous structure, the thermal conductivity will be less when measured in a direction perpendicular to the fibers.

Enthalpy

The enthalpy of a frozen food is one of the properties in computations of refrigeration of freezing the product. The heat content is normally zero at -40°C and increases with increasing temperature. Major changes in enthalpy occur at 10°C just below the initial freezing temperature, when maximum of the phase change in water occurs.

Specific heat

The specific heat for a food product is a function of temperature. This statement shows that the specific heat of a frozen food at a temperature greater than 20°C below the initial freezing point is not meaningfully different from the specific heat of the unfrozen product. The specific heat profile clearly shows the range of temperature where most of the phase changes for water in the product occurs.

Thermal Diffusivity

The density, thermal conductivity, and specific heat of a frozen food are combined to calculate thermal diffusivity. The relationship shows that thermal diffusivity increases gradually as the temperature decreases below the initial freezing point. The magnitudes of the property for the frozen product are expressively larger than for the unfrozen food.

Freezing time of Meat products

Freezing, also known as solidification, is a phase transition where a liquid turns into a solid when its temperature is lowered below its freezing point. The definition, freezing means the solidification phase change of a liquid or the liquid content of a substance, usually due to cooling. Some criteria on freezing system are differentiating solidification from freezing as a process where a liquid turns into a solid by increasing the pressure, the two terms are used interchangeably. For most substances, the melting and freezing points are the same temperature; however, certain substances possess differing solid–liquid transition temperatures.

Crystallization

Most liquids freeze by crystallization, formation of crystalline solid from the uniform liquid. This is a first-order thermodynamic phase transition, which means that as long as solid and liquid coexist, the temperature of the whole system remains very nearly equal to the melting point due to slow removal of heat when in contact with air, which is a poor heat conductor.

Because of the latent heat of fusion, the freezing is greatly slowed and the temperature will not drop anymore once the freezing starts but will continue dropping once it finishes. Crystallization consists of two major events, nucleation and crystal growth.

"Nucleation" is the step wherein the molecules start to gather into clusters, on the nanometer scale, arranging in a defined and periodic manner that defines the crystal structure. "Crystal growth" is the subsequent growth of the nuclei that succeed in achieving the critical cluster size. The thermodynamics of freezing and melting is a classical discipline within physical chemistry, which nowadays develops in conjunction with computer simulations. Due to the freezing of food meat products

Freezing involves removal of both sensible and latent heat

Freezing of water reveals high transitions between the different freezing periods, whereas with foods, the transitions are more gradual

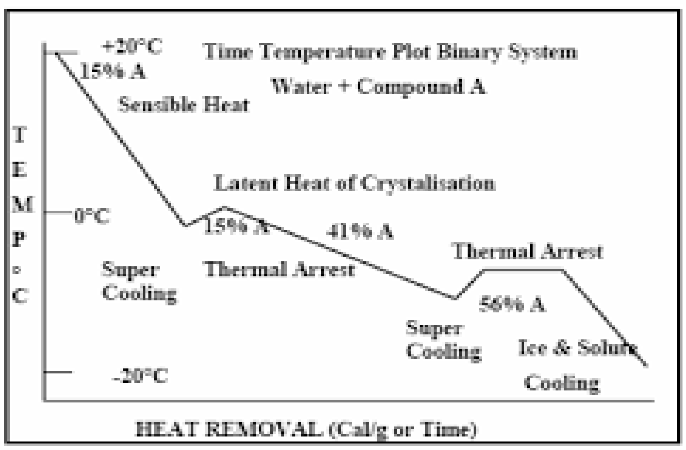
During the reaching out of peak point temperature for freezing foods, the frozen food may still have some water present as a liquid.

Freezing time requirements help to design the refrigeration capacity. The Plank’s equation is simple with some limitations and Pham’s method is completely on physical aspects of process.

Table.1 Recommended storage condition of Meat products

S. No.	Food products	Short term storage	Long term storage	Air circulation	Forced air circulation	Freezing point in ^{0}c Celsius	Composition in % water	Maximum storage period
1.	Poultry (fresh)	-2.2 to -1.1	-2.2 to -1.1	84	87	-2.8	74	10 days
2.	Poultry (Frozen)	-9.4 to -6.7	-17.8 to -15	85	85	-2.8	74	10 months
3.	Pork (fresh)	1.1 to 3.3	-1.1 to 0	80	85	-	57	15 days
4.	Pork (smoked)	4.4 to 7.2	-2.2 to -1.1	80	85	-	57	15 days
5.	Beef (fresh)	1.7 to 4.4	-1.1 to 0	84	87	-2.8	68	3 weeks
6.	Fish (fresh)	1.1 to 3.3	-1.1 to 0	85	85	-2.2	70	15 days
7.	Fish (frozen)	-9.4to -6.7	-15 to -12.2	80	80	-	70	6months
8.	Sausage (fresh)	1.7 to 4.4	-6.1 to -2.8	80	85	-3.3	65	15 days

Fig.1 Heat removal Vs Temperature



Plank's equation methods

The plank's equation is for predicting freezing time was proposed by Plank (1913) and adapted to food by Ede (1949). This equation defines only the phase change period of the freezing process. Planks for calculating the freezing time of food material is

$$tF=\frac{\rho H_L}{T_F - T_\infty}\left(\frac{P'a}{h_c}+\frac{R'a^2}{k}\right)$$

t_f = freezing time of food

ρ_f is the density of the frozen material,

H_L is the change in the latent heat of the food (kJ/kg)

T_F is the freezing temperature (°C),

T_a is the freezing air temperature (°C),

h is the convective heat transfer coefficient at the surface of the material (W/[m 2°C]),

a is the thickness/diameter of the object (m), k is the thermal conductivity of the frozen material (W/[m°c]),

P and R are used to account for the influence of product shape

Pham's Method to Predict Freezing Time

Pham (1986) coined a method for predicting food freezing and thawing times. This method can be used for regular size objects and irregular shapes by approximating them to be similar to an ellipsoid. This method is used to determine the freezing time of one-dimensional infinite slab. The following assumptions are used in developing this method:

The initial and final temperatures are constants and newton's law of cooling used for convective heat transfer rate.

$$T_{fm} = 1.8 + 0.263T_c + 0.105T_a$$

$$t_F = \frac{d_c}{E_f h}\left[\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2}\right]\left(1 + \frac{N_{Bi}}{2}\right)$$

d_c is a characteristic dimension, either shortest distance

h is the convective heat transfer coefficient (W/[m 2 K])

E_f is the shape factor, an equivalent heat transfer dimension.

E_f =1 for an infinite slab, E_f =2 for an infinite cylinder, and E_f = 3 for a sphere.

ΔH_1 is the change in volumetric enthalpy (J/m^3) for the precooling period

$$\Delta H_1 = \rho_u c_u (T_i - T_{fm})$$

c_u is the specific heat for the unfrozen material (J/[kg K]),

T_i is the initial temperature of the material (°C).

ΔH_2 is the change in volumetric enthalpy (J/m 3) for the phase change and post cooling period

$$\Delta H_2 = \rho_f[Lf + cf\ (T_{fm} - T_c)]$$

c_f is the specific heat for the frozen material (J/[kg K]),

L_f is the latent heat of fusion of food (J/kg),

ρ_f is the density of frozen material.

The temperature gradients ΔT_1 and ΔT_2 are obtained from following equations

Freezing as a preservation process to obtain a high-quality product for consumption, the quality is partial by the freezing process and frozen-storage conditions. The freezing rate or time allowed for the product temperature to be decrease from above to below the initial freezing temperature will impact product quality. For some products, rapid freezing is required to ensure formation of small ice crystals within the product structure and without damage to the product. Some food products have geometric shapes and sizes that do not allow rapid freezing. The storage temperature conditions influence frozen food quality in a significant manner. An increase in product storage temperature tends to reduce the preservation quality of the process, and fluctuations in storage temperature tend to be even more detrimental to product quality. The freezing process depends on the product characteristics. The various freezing systems are available, each designed to achieve freezing of a particular product at maximum quality by freezing time prediction. To attain freezing of a food product, the product must be exposed to a low-temperature medium for short time to remove sensible heat and latent heat of fusion from the product. Removal of the sensible and latent heat can decrease in the product temperature as well as a conversion of the water from liquid to solid state (ice). In some cases, approximately 10% of the water remains in the liquid state at the storage temperature of the frozen food.

The freezing process can be achieved by using either indirect or direct contact systems. The type of freezing system used will depend on the product characteristics, both before and after freezing is completed.

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