

FOOD SCIENCE AND TECHNOLOGY

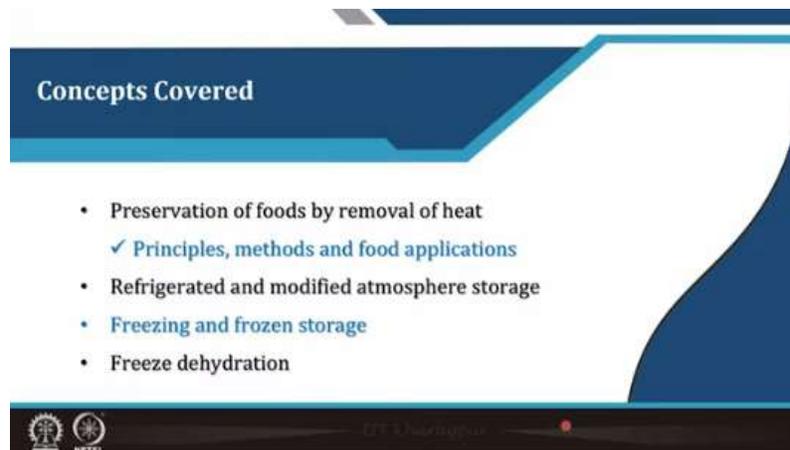
Lecture45

Lecture 45: Low-Temperature Preservation of Foods

Hello everyone, Namaskar.

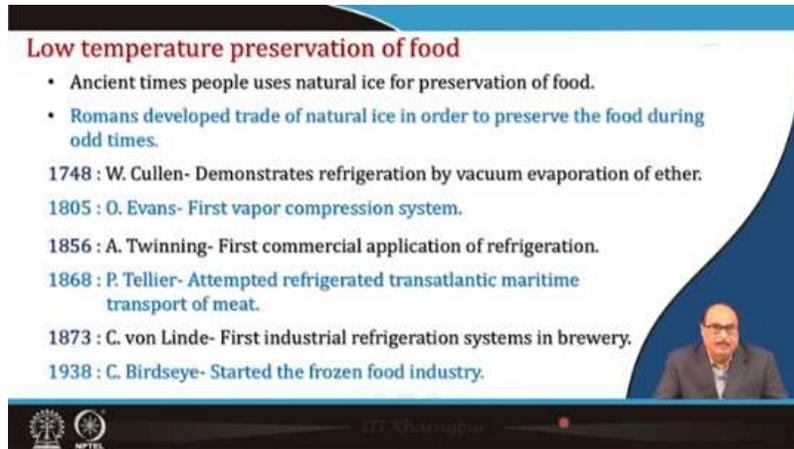


In this lecture today, in the next half an hour or so, we will talk about the preservation of food by the removal of heat. Earlier, we discussed how to preserve food by adding heat or other energy, maybe pressure, microwave, or other things.



In today's class, we will talk about how we can preserve food by removing heat; in other words, you can say low-temperature food preservation. This class will discuss the

principles and methods of low-temperature preservation of food, as well as refrigerated and modified atmosphere storage. freezing and frozen storage, and finally, we will also touch upon freeze dehydration as the main point.



Low temperature preservation of food

- Ancient times people uses natural ice for preservation of food.
- Romans developed trade of natural ice in order to preserve the food during odd times.

1748 : W. Cullen- Demonstrates refrigeration by vacuum evaporation of ether.

1805 : O. Evans- First vapor compression system.

1856 : A. Twining- First commercial application of refrigeration.

1868 : P. Tellier- Attempted refrigerated transatlantic maritime transport of meat.

1873 : C. von Linde- First industrial refrigeration systems in brewery.

1938 : C. Birdseye- Started the frozen food industry.

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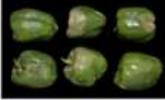
So, if you look at the history of low-temperature preservation of food, you will know that since ancient times, people have used natural ice for food preservation. Even Romans developed the trade of natural ice to preserve food during odd times. In the year 1748, W. Cullen demonstrated refrigeration by vacuum evaporation of ether. In 1805, O. Evans developed the first vapour compression system. In 1856, A. Twining demonstrated the first commercial application of refrigeration. In 1868, P. Tellier attempted refrigerated transatlantic maritime transport of meat. In 1873, C. Von Linde first developed an industrial refrigeration system in a brewery. In 1938, C. Birdseye started the frozen food industry.

So, you can see now that low-temperature preservation and even cold chain and frozen storage are the state of the art in the food preservation industry. Refrigeration in the food industry is not limited to preservation only. It is also applied for several other purposes, such as hardening materials like fatty foods, such as butter and other fats, and material handling to ensure proper handling. It can also be used; that is, refrigeration can concentrate heat-sensitive materials to avoid their thermal degradation. It can also be used for drying at lower temperatures for better physical structures of the food, as well as air conditioning, which includes air dehumidification.

Low temperature preservation of food (Contd..)

- Use of refrigeration in the food industry is not limited to preservation.
- Refrigeration is applied for a number of other purposes such as
 - ✓ Hardening of fatty foods such as butter and fats for material handling.
 - ✓ Concentration of heat sensitive materials/avoid thermal degradation.
 - ✓ Drying at lower temperature for better physical structure.
 - ✓ Air conditioning including air dehumidification.










So, these are the various other purposes, of course. All these methods, in some way or another, directly or indirectly, help extend the shelf life or improve the other characteristics, maybe functionalities, etcetera, of the food.

□ Effect of low temperature on microbes

- Temperature plays a vital role in influencing the enzymatic activity, membrane fluidity, and overall metabolic processes of microbes.
- Only few microbes can sustain at lower temperature.
- Low temperature can be lethal to microbial cells and only 10% are being killed.
- Freezing reduces the solvent concentration in food and subsequent solute concentration will increase.
- This effect can change several parameters in food, such as
 - ✓ pH of food increases affecting microbial DNA, RNA, enzyme and cell wall.
 - ✓ Alter colloidal status of the food and interfere with salt balance of microbes.
 - ✓ Denature proteins and stop biological cell repair.
 - ✓ Increase viscosity by freeze concentration altering flowability of nutrients.

Classification	Growth range (°C)	Optimum (°C)
Psychrophiles	-20 to 20	~15
Psychrotrophs	0 to 30	20-30
Mesophiles	20 to 45	~37






If you recall, in earlier classes, we also briefly discussed how low temperature affects microbes and enzymes, etcetera. So, basically, the principle of this low-temperature preservation is based on the fact that the low temperature brings down the temperature in such a way that it is in the range which creates stress over the microorganisms, and then microorganisms stop growing; they are not able to manage that stress created by the temperature changes, and their biological processes, etcetera, are adversely affected, and ultimately, their activity stops. So, low temperatures can become lethal to microbial cells, and only about 10% are killed, particularly if, in the stationary phase growth phase, the microorganisms are kept for a longer period of time, then some of them may die. Freezing reduces the solvent concentration in food, and subsequently, the solute concentration will

increase, which is also because of the increase in the solute concentration. There is an osmotic concentration that creates an unfavourable environment for microbial growth. So, the effect, particularly the solute concentration changes in the freezing process, can affect or cause several parameter changes in several parameters of the food, such as the pH of food, which increases, affecting microbial DNA, RNA, enzymes, and cell walls. They can alter the food's colloidal status and affect microbes' salt balance. They can denature proteins and stop microbial cell repair, and also, there may be an increase in viscosity due to freeze concentration, altering the flowability of the nutrients.

Effect of low temperature on enzymes

- pH changes in the food and microbial cells during freezing may lead to the inactivation of enzymes.
- DNA and RNA damage in the microbial cell hamper enzyme synthesis and affect the microbial metabolic activities under frozen condition.
- Increase viscosity interfere with enzyme transfer in the food.
- Cell lysis due to freezing causes leaching of enzymes with cytoplasm.

Enzyme activity against temperature

Similarly, you can see the effect of low temperature. particularly on the enzymes that are the pH changes in the food and microbial cell which might take place during the freezing process may lead to the inactivation of the enzyme, may lead to the denaturation of the body or enzyme cell protein systems, DNA and RNA damage in the microbial cell hampers the enzyme synthesis and affects the microbial metabolic activities under frozen conditions. there is an increase in the viscosity during the freezing process. This increase in the viscosity interferes with the enzyme transfer in the food, and cell lysis takes place due to freezing mainly because of the leaching of the enzyme with the cytoplasm, and other stresses might be created.

So, what is refrigeration? You now know that most pathogens stop growing at less than 5 °C. A few pathogens grow slowly under refrigeration, even if that further lowers the temperature; pure water freezes at around 0 °C. However, foods may freeze even at less than 0 °C, or sometimes, they may even freeze at less than 0 °C, and this depression in the freezing point of the food material is mainly because of the pressure of various solutes in the food.

Refrigeration

- Most pathogen growth is stopped at $< 5^{\circ}\text{C}$.
- A few pathogens grow slowly under refrigeration.
- Pure water freezes at 0°C but foods freeze at $< 0^{\circ}\text{C}$.
- No organism (pathogen or spoilage) grows below 0°C .

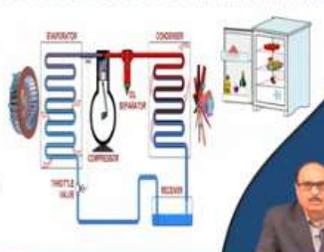
Refrigeration also

- ✓ Slows down spoilage microorganism growth, and
- ✓ Slows chemical reactions that can lead to off-flavors.

Refrigerated storage
 0 to 8°C

Freezer storage
 0 to -23°C

Every 10°C lowering in temperature makes the shelf-life almost double.




So, these solutes decrease it, resulting in freezing point depression. Refrigeration also slows down the growth of spoilage microorganisms and slows down the chemical reactions that can lead to off flavours. So, when we talk about refrigerated storage, it generally means storage from 0 to 8°C . In contrast, frozen storage involves freezing the food and storing it at 0 to -23°C , probably at -18 or -23°C . So, here, the rule of thumb is that every 10°C lowering in temperature makes the material's shelf life almost double. So, this is a general rule. There may be a little bit of variation from food to food. One of the most commonly used low-temperature refrigeration or refrigeration is now very popular in every home-scale refrigeration system. In the home, there is a freezer compartment where the temperature is around 0°C ; in the other chamber refrigeration chamber, the temperature may be 0 to 8°C . So, in the refrigeration facility, you who have seen towards the back side of the refrigerator will find a compressor and compression unit that is the same unit in the bigger scale you can go. So, this compressor unit contains an evaporator and condenser. This is a compressor unit that contains a receiver and thermo light bulb. So, this compressor unit removes the heat and evaporates the material, then cools down and brings down the temperature in the facility. So, when you put any material, depending upon the size of the how much you want to store in the food, what is the quantity of the material, what is the initial temperature, and what is the final temperature you want in the storage facility?

Refrigeration load

- It is the amount of heat removed by the refrigeration system
- Heat of respiration = Total weight (kg) × Heat of respiration of produce (J kg⁻¹ s⁻¹)
- Heat removed from containers = $\frac{\text{No. of containers} \times \text{Container weight} \times C_p \text{ of container} \times T \text{ difference}}{\text{Time required}}$
- Heat evolved by operators and light = Heat produced by operator and bulbs per second
- Heat loss through walls and roofs = $\frac{k_{\text{insulation}} \times \text{Area} \times (T_{\text{ambient}} - T_{\text{chiller}})}{\text{Insulation thickness}}$
- Heat loss through floor = $\frac{k_{\text{concrete}} \times \text{Area} \times (T_{\text{soil}} - T_{\text{chiller}})}{\text{Floor thickness}}$

Total heat load = Sum of all above five heat loads

So, one can calculate the size of the refrigeration load so that the load may be in a steady or unsteady state. The total load is the amount of heat you can see the refrigeration system has removed. So, when the material is kept inside the storage facility, the material continues to expire. So, there is a heat of respiration. So,

Heat of respiration = Total weight of the material (kg) × Heat of respiration of produce (J kg⁻¹ s⁻¹).

So, that is the total heat of the supposed 100 kg. You have put 100 kg in a potato, 100 kg in a tomato, etcetera. So, what is the heat of respiration of the tomato multiplied by 100 kg? So, that will be the heat of respiration. Then, you can one have to calculate the heat removed

$$\text{from containers} = \frac{\text{Number of containers} \times \text{Container weight} \times C_p \text{ of container} \times T \text{ difference}}{\text{Time Required}}$$

So, if you want to reduce the temperature from 45 to 8 °C, what is that temperature and what time is required? So, this gives a total heat removed from the container. Similarly,

The heat evolved by operators and light = Heat produced by operator and bulbs per second

Then, heat loss through the walls and roofs; although proper insulations, etcetera, are provided inside the facility, there may be some heat loss. So you can one can calculate

$$\text{Heat loss through walls and roofs} = \frac{k_{\text{insulation}} \times \text{Area} \times (T_{\text{ambient}} - T_{\text{chiller}})}{\text{Insulation thickness}}$$

Similarly, heat loss through the floor of the storage facility will be

$$\text{Heat loss through floor} = \frac{k_{\text{concrete}} \times \text{Area} \times (T_{\text{soil}} - T_{\text{chiller}})}{\text{Floor thickness}}$$

So, the total heat load will be the sum of all these five loads. So, now and for this, one can calculate that if x kg of the material is put in a storage environment, how much will the refrigeration load be, and accordingly, power, etcetera, can be calculated.

Refrigerated storage

Raw material → Sorting → Grading → Cleaning → Blanching → Packaging → Storage

- Refrigerated storage is crucial for preserving food by slowing the growth of bacteria, molds, yeasts, and the chemical reactions that cause spoilage.
- Refrigerated storage facility is maintained between 4 to -2°C . It is used to store perishable foods for a short term say 3-5 days.
- For longer period, other preservatives can also be added to food.
- The storage period is based on the sensitivity of the commodity towards lower temperature.
- Minimally processed fruits and vegetables can be stored in cold storage.
- Maintains taste, texture, and nutritional value of perishable items.
- Helps in reducing food waste by preserving products for longer periods.

The slide also features a small inset image of a man speaking and logos for IIT Bombay and NPTEL at the bottom.

So, refrigerated storage involves raw materials, particularly perishable materials. They are sorted, graded, cleaned, blanched, and packed, and finally, they are put into the storage environment and okay. So, this is particularly useful for preserving perishable foods. This low temperature is very important. A good refrigeration facility may be kept between 4 to -2°C or 0°C depending on the type of commodities, respiration rate, etc. It is generally used to store perishable food for a short term. The period maybe 3 to 5 days, or some commodities may be stored in bigger storage facilities for longer periods. Other preservatives can also be added along with temperature control, such as humidity or atmosphere control (O_2 , CO_2), which we will discuss later. So, the storage period is based on the sensitivity of the commodity toward lower temperatures, and minimally processed fruits and vegetables can be stored in cold storage, maintaining the taste, texture, and nutritional value of perishable items, helping to reduce food waste by preserving products for longer periods.

So, the first principle of refrigerated storage we have already discussed is temperature control: you bring down the storage facility temperature to an unfavourable level where microorganisms cannot grow, and enzymes cannot act. Their undesirable activities and undesirable chemical reactions are stopped. Then, when you control the temperature, there is a reduction in microbial growth, slowing down the enzymatic activity and temperature. We can also control the humidity to maintain optimal food conditions and reduce microbial preservation and minimal moisture loss during refrigerated storage.

Principles of refrigerated storage

- **Temperature control:** The temperature of storage is reduced between -2°C and 4°C .
- **Reduction of microbial growth:** Reduction in temperature interfere with optimal microbial activity and reduces the microbial multiplication.
- **Slowing enzymatic reactions:** Refrigeration slows enzymatic processes responsible for ripening, browning, and spoilage.
- **Humidity control:** Controlling humidity to maintain optimal conditions for various food to reduce the microbial prevalence and minimal moisture losses during the refrigerated storage.
- **Air circulation:** Good air circulation helps maintain an even temperature throughout the storage area.
- **Insulation:** Refrigerated storage units should be well-insulated to maintain the internal temperature.




So, if you control the humidity, the food material maintains its freshness in the storage facility. Similarly, good air circulation helps maintain an even temperature throughout the storage area, and proper insulation is necessary. If there is adequate insulation, refrigerated storage units should be well insulated to keep the internal temperature. There will be little heat loss, which may help maintain the desired conditions and minimize energy wastage.

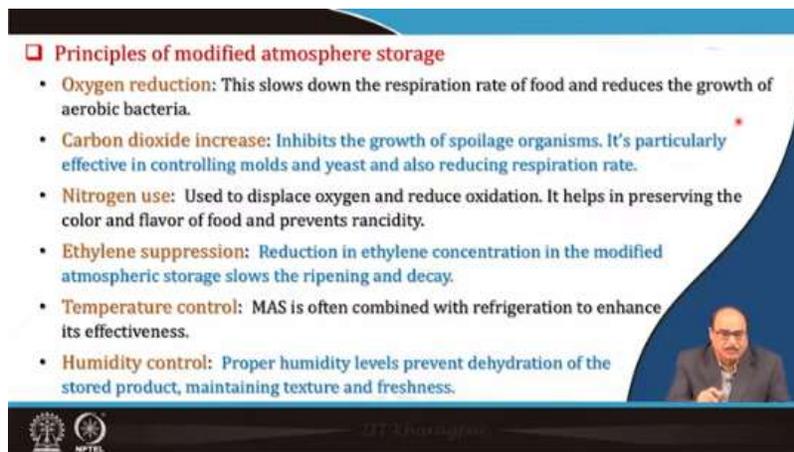
Modified atmosphere storage

- Refrigeration slows, but does not completely halt, the respiration of fresh produce eventually leading to moisture losses during storage period.
- Modified atmosphere technologies are used to reduce the rate of respiration, reduce microbial growth, and retard enzymatic spoilage by changing the gaseous environment surrounding the food product.
- This is achieved by reducing the concentration of oxygen (O_2), which is required in respiration, or by adding an inhibitory gas such as carbon dioxide (CO_2) or carbon monoxide (CO).
- Generally, an atmosphere of 3-6% O_2 and 2-10 % CO_2 achieves microbial control and extends the shelf-life of various fresh-cut products.
- Other gases such as helium, argon and xenon (noble gases) and nitrous oxide (N_2O) have been used in MAP applications to reduce microbial growth and maintain product quality.




Now, we see the modified atmosphere storage. So, modified atmosphere storage is the same principle in the same storage facility as refrigerated storage. We just lower the temperature. However, in the modified atmosphere storage, along with the temperature, we also lower the gaseous composition in the storage facility. Typically, oxygen concentration is lowered, and carbon dioxide gas is increased. These perishable materials, such as fruits, vegetables, milk, or other perishable foods, when kept inside the storage room, continuously respire, and the material is good as long as it is respiring aerobically. Once aerobic respiration is stopped, anaerobic respiration will take over, and the material will

spoil. Therefore, the basic principle of this storage preservation is low-temperature preservation, in which you manipulate the storage facility environment to lower the temperature, increase the oxygen, increase the carbon dioxide, and all those things. So, the material's respiration rate is slowed down to the greatest possible extent. So, in the modified atmosphere storage, generally, an atmosphere of 3 to 6% oxygen may be from 2 to 10% or 5 to 10% carbon dioxide; it achieves microbial control and extends the shelf life of various fresh-cut produce, and accordingly, one has to, of course, depending upon the type of the fruit, vegetable, and other commodities, even it is a variety, etcetera. So, the O₂ and CO₂ conditions might vary. So, other gases such as helium, argon, and xenon, that is, the noble gases, etcetera, nitrous oxide, and N₂O have been used in modified atmosphere packaging applications to reduce microbial growth and maintain product quality.



Principles of modified atmosphere storage

- **Oxygen reduction:** This slows down the respiration rate of food and reduces the growth of aerobic bacteria.
- **Carbon dioxide increase:** Inhibits the growth of spoilage organisms. It's particularly effective in controlling molds and yeast and also reducing respiration rate.
- **Nitrogen use:** Used to displace oxygen and reduce oxidation. It helps in preserving the color and flavor of food and prevents rancidity.
- **Ethylene suppression:** Reduction in ethylene concentration in the modified atmospheric storage slows the ripening and decay.
- **Temperature control:** MAS is often combined with refrigeration to enhance its effectiveness.
- **Humidity control:** Proper humidity levels prevent dehydration of the stored product, maintaining texture and freshness.

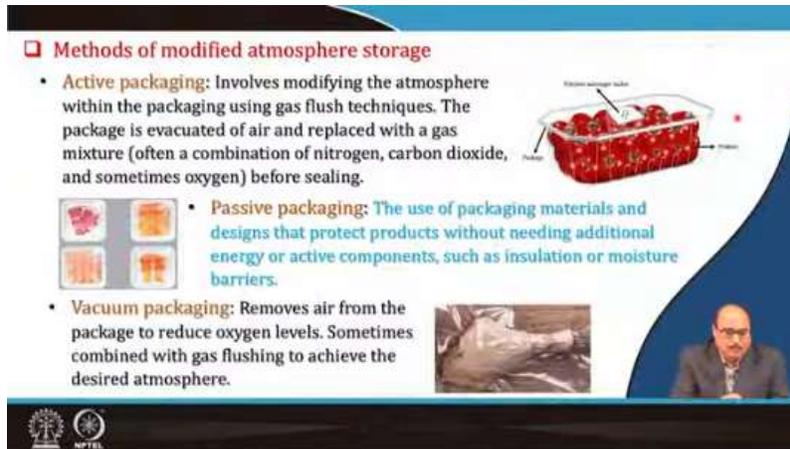
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So, here again, if you talk about the principle that is oxygen reduction when you lower the oxygen, it not only slows down the respiration process, but it also helps reduce the oxygen or oxidation or other chemical reactions as well as the growth of the aerobic bacteria and all those things. Then carbon dioxide increases, which inhibits the growth of spoilage microorganisms. It is particularly effective in controlling moulds and eats and reducing respiration. Then nitrogen uses nitrogen. It is sometimes even smaller oxygen level if they are in some particularly highly sensitive material, which may result in oxidation. So, sometimes, this oxygen is eliminated by flushing the nitrogen into the facility, which helps preserve the colour and flavour of the food material and prevents oxidation or rancidity in fatty foods. Then, ethylene suppression, that is, the reduction in the ethylene concentration in the modified atmosphere storage facility, slows down the ripening and delays the decay of the food material. Temperature control is often connected with refrigeration to enhance

its effectiveness. So, refrigeration facilities, that is, temperature and humidity control, and apart from that, O₂, CO₂, and ethylene control are done to get the desired effect.

Methods of modified atmosphere storage

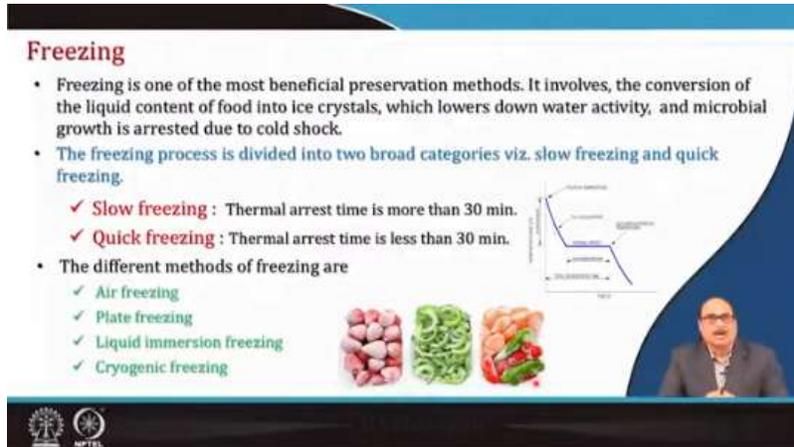
- **Active packaging:** Involves modifying the atmosphere within the packaging using gas flush techniques. The package is evacuated of air and replaced with a gas mixture (often a combination of nitrogen, carbon dioxide, and sometimes oxygen) before sealing.
- **Passive packaging:** The use of packaging materials and designs that protect products without needing additional energy or active components, such as insulation or moisture barriers.
- **Vacuum packaging:** Removes air from the package to reduce oxygen levels. Sometimes combined with gas flushing to achieve the desired atmosphere.



So, these various methods, that is, of the modified atmosphere storage and modified atmosphere packaging, include one, which is active packaging, which involves modifying the atmosphere within the packaging using gas flux techniques. The package is evacuated of air and replaced with a gas mixture, often a combination of nitrogen, carbon dioxide and sometimes even oxygen, to maintain the balance of the gases inside the system, and then the material is sealed. So, all these things are kept, and the material is sealed by suitable instrumentation by suitable flushing of the desired gases: O₂, CO₂, and N₂. So, that becomes the active packaging. Passive packaging uses packaging materials and designs that protect products without needing additional energy or active components such as insulation or moisture barriers. So, here, insulation is proper insulation that gives a moisture barrier. Then comes the vacuum packaging, which removes air from the package to reduce oxygen level and sometimes combines with gas flushing to achieve the desired components. So, as I told you earlier, there are materials like coffee powder, fruit powder, fruit juice powder, etcetera, and even fruit chips etcetera. All those things are solid or perishable food materials with other properties. So, when you completely evacuate oxygen inside packaging material, that is, by using mechanical machines, systems, etc., it squeezes the package. Another reason is that if there is a small proportion of oxygen in some sensitive foods, like coffee powder, etc., oxidation may cause changes in the colour, flavour and all those things. So, this is now nitrogen flushing. You can say now that there are various ready-to-eat products, such as powder premixes, and all those things packed by nitrogen flushing. So, nitrogen gas is inserted by completely removing air.

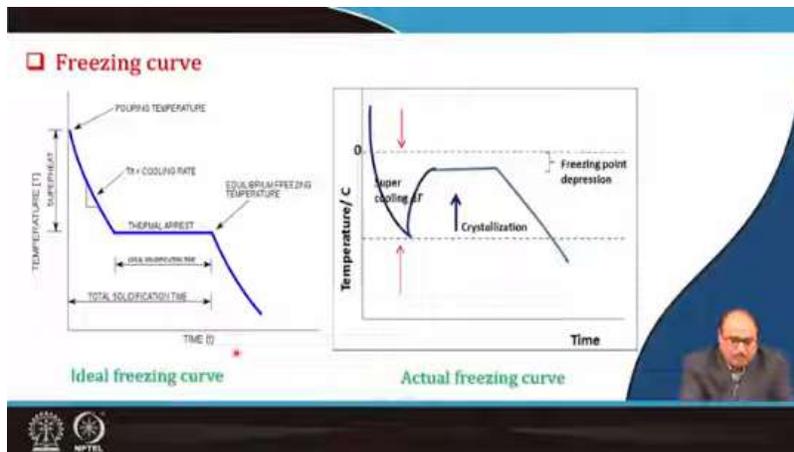
Freezing

- Freezing is one of the most beneficial preservation methods. It involves, the conversion of the liquid content of food into ice crystals, which lowers down water activity, and microbial growth is arrested due to cold shock.
- The freezing process is divided into two broad categories viz. slow freezing and quick freezing.
 - ✓ **Slow freezing** : Thermal arrest time is more than 30 min.
 - ✓ **Quick freezing** : Thermal arrest time is less than 30 min.
- The different methods of freezing are
 - ✓ Air freezing
 - ✓ Plate freezing
 - ✓ Liquid immersion freezing
 - ✓ Cryogenic freezing

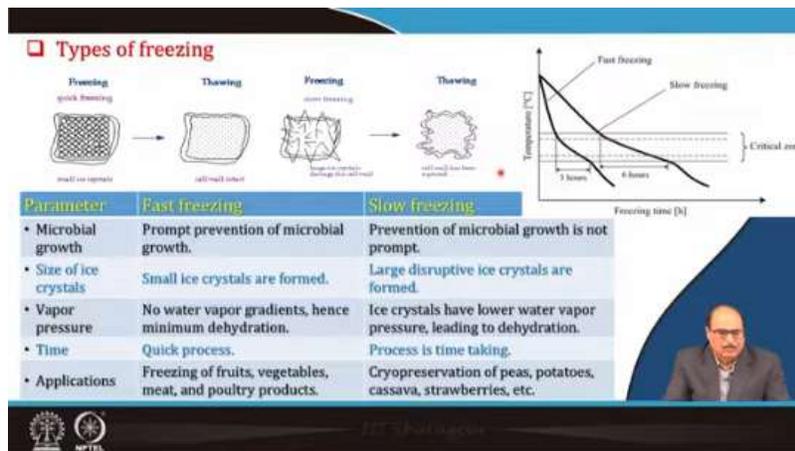


The slide includes a graph showing the temperature profile of a food item during freezing. The y-axis represents temperature and the x-axis represents time. Two curves are shown: a steeper curve for 'Quick freezing' and a shallower curve for 'Slow freezing'. Both curves show a 'Thermal arrest time' where the temperature remains constant during the phase change from liquid to solid. Below the graph are three images of frozen food products: a tray of frozen tomatoes, a bag of frozen green beans, and a bag of frozen mixed vegetables.

Now, we talk about freezing. So, freezing is again one of the most beneficial preservation methods. It involves converting the liquid content of the food into ice crystals in the food in earlier classes; we discussed that it has some free water and some bound water. So, in the freezing process, temperature is brought to such a level that almost all or most of the majority of free water is converted into ice crystals, and because of this, water activity slows down, and microbial growth is restricted due to this cold shock. So, the freezing process can be divided broadly, that is, by the process by which it is conducted. There may be two categories: slow freezing and quick freezing. Slow freezing is where the material is here, and you can bring it out; there is a temperature, and when the freezing starts, the freezing starts until almost all free water is completely frozen. So this is called thermal arrest time thermal arrest. So, if a thermal arrest time of more than 30 minutes is slow freezing and a thermal arrest time of less than 30 minutes is quick freezing. So, the different methods of applying this process may be air freezing, plate freezing, liquid immersion freezing, cryogenic freezing, etc.



So, in the last slide, you saw that figure that this is here a little bigger than what is happening that is the ideal freezing curve, that is, if you put the material inside, there is a lowering that may be a room temperature 20 or 25°C. So, you give that to cool it down at a specific rate, such as the material temperature, when you put it into a cold room and in a freezer environment, even the refrigerator in the frozen freezer compartment. So it takes some time. Its material comes here, and then here, the conversion of ice water into ice takes place. Then there is an equilibrium freezing temperature at which at that point at which is almost all the further temperature decreases. So, this is the ideal case, but in the actual food case, this does not happen because of the presence of various solutes, etcetera. So, the material freezes down and comes very lower to even less than 0. It cools down depending on the material and its solutes, which is called supercooling. So, super cooling here comes, and then after the supercooling material temperature increases a little bit, and maybe the nucleus crystal might be at supercooling, that is, crystal formation, etcetera takes place, and then it will go again it will. So, this is the now the crystals. in various cases, the nucleation starts at the supercooling. Then the temperature increases, and then comes this point, which is the point where crystal formation will take place. All the water will convert into ice, and its temperature will finally go down until it reaches a eutectic point. So, this is the actual freezing curve. So, it comes to a normal temperature of less than 0 super cooling, which is the thermal arrest time, which means there is less than 30 minutes. It is a quick freezing. So, these are the various methods we will discuss now that are used to utilize this time conversion of ice in water into ice.



So, this is freezing, and that is the type of freezing. Interesting that is freezing is that you can say quick freezing or slow freezing. Here, the water is quick, the number of ice crystals may be larger, and the size of the ice crystals may become smaller. There is not much structural dislocation and quality. So, after thawing, the reverse of freezing occurs; before consumption, the material from the frozen stage is brought to the normal stage. So, once the ice is again converted back into the water, you get the internal structure of the frozen material that is as good as its natural counterpart. In the case of slow freezing, there may be large ice crystals number fewer ice crystals, but the larger the growth crystal growth is in this period, there is also crystal growth. So you get because of the large crystal size, the structure, etcetera of the material gets disturbed, and then when you thaw it, then there may be a structural change, and others say that the material you get ruptures itself wall and all those things. So, quality sometimes may get particularly textural characteristics, etcetera. So, a comparison of slow and fast freezing, for example, microbial growth in fast freezing, is needed. There is prompt prevention of microbial growth, whereas, in slow freezing, the microbial growth is not promptly prevented. Size of ice crystal: as I told you, small ice crystals are formed; in the slow freezing, large disruptive ice crystals are formed; vapour pressure in the fast freezing is quick freezing with low water vapour gradient there is minimum dehydration, but in the slow freezing ice crystals have lower water vapour pressure and lead to which leads to dehydration time. Quick freezing lasts less than 30 minutes and is processed quickly, whereas slow freezing takes longer. The application typically uses quick freezing to freeze fruits, vegetables, meat, and poultry products. In contrast, slow freezing may be used to cryopreservation peas, potatoes, cassava, and strawberries.

Effect of freezing on food ingredients

- **Water:** The water in food forms into ice crystals and liquid converts to solid reducing free water content in food.
- **Carbohydrates:** Some of the sugars may leach out due to damage to structural integrity. Starch might undergo retrogradation depending on freezing rate. Slow freezing causes higher retrogradation.
- **Protein:** The tertiary and quaternary structure of protein get damaged due to denaturation.
- **Lipids:** Lipids and fats get oxidized during freezing. Though the rate of oxidation is very slow; prolonged storage increases the amount of fat oxidized.
- **Vitamins and pigments:** Vitamin undergoes oxidation during frozen storage resulting into vitamins degradation. Similarly, the color degrades during storage due to pigment degradation.
- **Cell structure:** Ice crystal formation damages plant tissues; larger crystals causes higher tissue damage.




So, the effect of freezing on food ingredients like water in the food forms into ice crystals, and the liquid converts into solids, reducing free water content. Even in carbohydrates, some of the sugars may leach out due to damage to structural integrity, particularly in the case of slow freezing. Starch might undergo retrogradation depending on the freezing rate; slow freezing causes higher retrogradation. Then, proteins: the tertiary and quaternary structures of proteins get damaged due to denaturation; the protein may be denaturation. Lipids and fats oxidise during freezing, though the oxidation rate is slow. However, prolonged storage increases the amount of fat oxidized. Vitamins and pigments: If you see the freezing effect, vitamins undergo oxidation during frozen storage, resulting in vitamin degradation. Similarly, the colour degrades during storage due to pigment degradation. Cellular structure ice crystal formation damages plant tissues. Larger crystals cause greater tissue damage.

Air freezing

- Packaged or unpackaged non-fluid foods can be frozen in air at temperatures ranging from -18° to -40° °C and further divided into three types.
 - ✓ Still air sharp freezing
 - ✓ Air blast freezing
 - ✓ Fluidized bed freezing
- **Still air sharp freezing**
 - It consists of placing products in a very cold room, maintained at temperatures in the range of -15° °C to -29° °C.
 - Sharp freezers are cold storage rooms especially constructed to maintain low temperatures.
 - Freezing time is generally 3-72 hours or more depending on the conditions and the size of the product.
 - No fan is used for this type of freezing.




So, methods of the freezing air freezing. Here, packaged or unpackaged non-fluid foods

can be frozen in the air at a temperature ranging from -18 to -40 °C and further divided into three types: still air sharp freezing, air blast freezing, or fluidized bed freezing. Still, air-sharp freezing here consists of placing the product in a very cold room maintained at a temperature of -15 to -29 °C. Sharp freezers are cold storage rooms especially constructed to maintain low-temperature freezing time, generally 3 to 72 hours or more, depending on the conditions and the product size, and no foil is used in this type of freezing.

The slide is titled "Air blast freezing" and "Fluidized bed freezing". It contains the following text and diagrams:

- Air blast freezing**
 - Products are placed on trays, either loose or in packages and the trays are placed on freezing coils in a low-temperature room with cold air blowing over the product.
 - In this freezing method fan is used for air circulation.
 - The temperature of the air is usually between -28 °C to -46 °C and air velocity is 15 m/s.
- Fluidized bed freezing**
 - Fluidized bed freezing is a modification of air-blast freezing.
 - Solid food particles ranging in size from peas to strawberries can be fluidized by forming a bed of particles 1-5 in.
 - Deep on a mesh belt (or mesh tray) and then forcing air upward through the bed at a rate sufficient to partially lift or suspend the particles.

Diagrams include a cross-section of a freezing chamber with labels for "AIR BLAST FREEZING" and "FLUIDIZED BED FREEZING". A small video inset shows a person speaking.

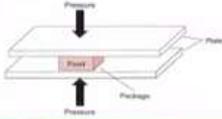
Air blast freezing, you can say the products are placed on trays either loose or in packaged form, and the trays are placed on freezing coils in a low-temperature room with which the air blows, and the air is blown on the top of the product's surface. So, a fan is used for air circulation in this freezing method. The temperature of the air is usually between -28 to -46°C. Air velocity is around 15 m/s, depending upon the material being frozen, various frozen thicknesses of the material layers, and all the thermal conductivity of the layer. Then, fluidized bed freezing, as you can see here, is a modification of air blast freezing. Solid particles ranging in size from peas to strawberries can be fluidized by forming a bed of particles about 1 to 5 inches deep on a mesh belt or mesh tray and forcing the air upward, as you can see here. So, they float in the air, which is material, and then cold air is blown over there. So, it improves heat transfer properties, etcetera, and the ice crystal formation occurs because the particles are suspended.

❑ Plate freezing

- In the plate freezing method, the product is compressed between metal plates using pressure for maintaining good contact between food surface and metal plate.
- This method can only be used for regular-shaped materials. After freezing is completed, the hot liquid is used to dissolve the ice.
- The refrigerant is allowed to expand within the plates to provide temperatures of -30°C or below.
- This method can be used for meat, fish, dairy, and other products where agglomeration of the food particles is not a concern.

■ Advantages of plate freezing

- ✓ Uniform freezing
- ✓ Reduced freezer burn
- ✓ Efficient use of space




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Then it becomes plate freezing. You can see here the plate; the full material is pressed between two plates, and this method can only be used for regularly shaped materials. After freezing, the hot liquid dissolves the ice for thawing purposes, etcetera. The refrigerant can expand within the plates to provide a temperature of -30°C or below. So, this method can be used for meat, fish, dairy, and other products where agglomeration of the food particles is not a concern because, in this case, the material is compressed between two plates using pressure and good contact. So, heat is applied from there. Thus, these plates are cooled. So, with this, the material food also gets cooled. So, the advantages of plate freezing are that it is uniform freezing, reduces freezer burn, and makes efficient use of space.

❑ Liquid immersion freezing

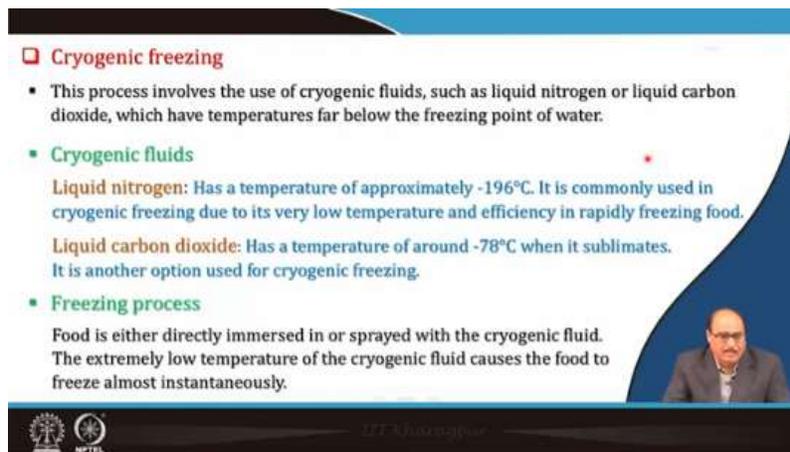
- Immersion freezing is a method of freezing food by submerging it in a very cold liquid and valued for low freezing time.
- **Liquid nitrogen immersion freezing:** Food is submerged in liquid nitrogen, at extremely low temperature of around -196°C .
- **Liquid CO_2 immersion freezing:** Food is submerged in a solution of liquid CO_2 , which has a temperature of around -78°C when it sublimates.
- **Brine immersion freezing:** Food is submerged in a chilled brine solution, typically made from water and salt, which lowers the freezing point of the solution. The temperature of the brine is usually around -10°C to -20°C .
- **Direct immersion freezing:** Food is placed directly into a very cold liquid (often a brine or glycol solution) that is chilled to freezing temperatures.




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Then the other method is liquid immersion freezing. Immersion freezing is the method of freezing food by submerging it in a very cold liquid and is valued for its low freezing times. So, you can see it is a liquid refrigerant; the product flows and is immersed in the material for the desired period. So, the food is submerged in liquid nitrogen, which is maintained at

an extremely low temperature, maybe $-196\text{ }^{\circ}\text{C}$ or liquid carbon dioxide immersion freezing, where the liquid carbon dioxide is maintained at around $-78\text{ }^{\circ}\text{C}$. Even brine solution can be used simply as a brine or salt solution; its temperature may be $-10\text{ }^{\circ}\text{C}$ to $-20\text{ }^{\circ}\text{C}$ or even direct immersion freezing, meaning food is directly placed into a very cold liquid. Often, a brine or a glycol solution is chilled to freezing temperatures. Of course, the method to be used should depend on the immersion liquid in which it should be immersed, and that will depend upon the type of material processed and other characteristics, such as the food characteristics.



Cryogenic freezing

- This process involves the use of cryogenic fluids, such as liquid nitrogen or liquid carbon dioxide, which have temperatures far below the freezing point of water.
- **Cryogenic fluids**
 - Liquid nitrogen:** Has a temperature of approximately $-196\text{ }^{\circ}\text{C}$. It is commonly used in cryogenic freezing due to its very low temperature and efficiency in rapidly freezing food.
 - Liquid carbon dioxide:** Has a temperature of around $-78\text{ }^{\circ}\text{C}$ when it sublimates. It is another option used for cryogenic freezing.
- **Freezing process**

Food is either directly immersed in or sprayed with the cryogenic fluid. The extremely low temperature of the cryogenic fluid causes the food to freeze almost instantaneously.

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Cryogenic freezing is, again, a process that involves cryogenic fluids such as liquid nitrogen or liquid carbon dioxide, which have temperatures far below the freezing point of water. So, as mentioned in the earlier slide, liquid nitrogen typically has a temperature of $-196\text{ }^{\circ}\text{C}$. So, it is used in cryogenic freezing due to its very low temperature and high efficiency, resulting in very fast freezing. Liquid carbon dioxide has a temperature of around $-78\text{ }^{\circ}\text{C}$ when it sublimates, and it is another option for cryogenic freezing. So, the food is either directly immersed in this refrigerant, which is the liquid nitrogen or liquid carbon dioxide, or the material refrigerant or freezers is spread over the material. So, this extremely low temperature of the cryogenic fluid causes the food to freeze almost instantaneously.

Frozen storage

- A food preservation technique that involves cooling food to temperatures below its freezing point, typically between -18°C and -25°C or lower, to preserve it by inhibiting spoilage and decay.

- **Mechanism**

Temperature reduction: The food is rapidly cooled to a temperature below freezing.

Ice crystal formation: The formation of ice crystals within the food helps to immobilize moisture, thereby preventing the growth of microorganisms and slowing enzymatic reactions.

Microbial inhibition: At low temperatures, the metabolic activity of microorganisms is significantly reduced, preventing their growth and reproduction.

Storage conditions: The food is stored at a consistently low temperature to maintain its frozen state, ideally in a freezer at -18°C or lower.



Then comes the frozen storage, the frozen storage, which is the again after the freezing of the food, then kept they are kept in an environment that is either -18°C , -25°C or lower, depending upon the type of food. To allow for no temperature, these ice crystals formed should not melt or be kept under frozen conditions. So, the mechanism here is a temperature reduction during the frozen storage; of course, there are some recrystallization phenomena, but no new ice crystals are formed. So, microbial inhibition and storage conditions, etc. So, the main thing is that that is after freezing, the material is put into the conditions -18 or -25°C , where the material is maintained under the frozen environment without any effect, that is, without any recrystallization or any crystal change in its orientation, its characteristics, etcetera.

Freeze drying

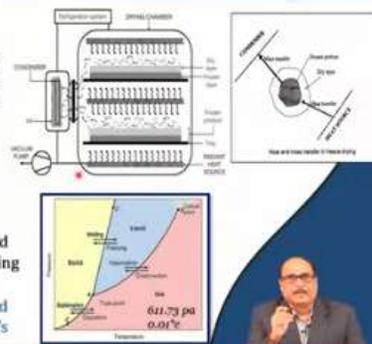
- Freeze drying is a preservation method that removes moisture from food by freezing it and then sublimating the ice into vapor, leaving the food dehydrated. This process helps retain the food's structure, flavor, and nutrients.

- **Principles**

Freezing: The food is first frozen at very low temperatures, typically below -40°C . This process forms ice crystals within the food.

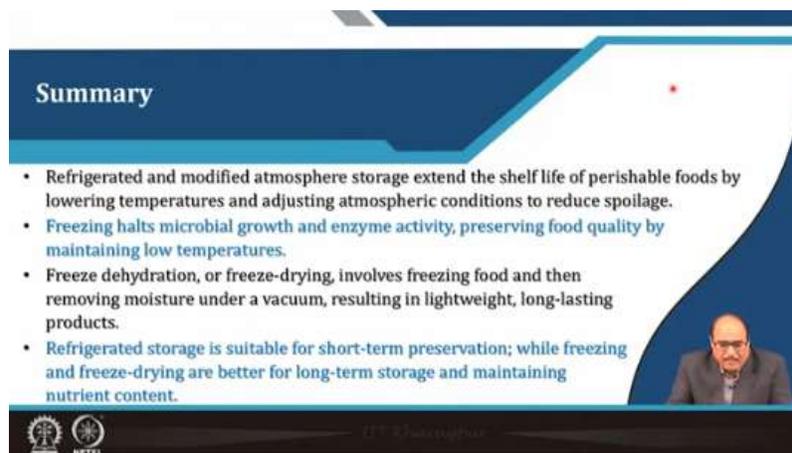
Sublimation: In a vacuum, the frozen ice in the food is converted directly into water vapor without passing through the liquid phase.

Desorption: The remaining water vapor is removed from the food, further drying it and ensuring that it's completely devoid of moisture.



Now, we will briefly talk about freeze-drying. So, freeze-drying is a drying and preservation method that removes the moisture from the food by freezing and then sublimating. So, there are two steps in the freeze-drying process: freezing, as we discussed

earlier. So, after freezing, it is put into certain conditions, and the material, ice, forms directly without converting into water; it sublimates and vaporizes. So, here you see that it is a triple point, that is, the phase diagram of water. If you look at this, it is the A, a triple point, the pressure and temperature. So, this is the triple point at a pressure of about 611.73 Pascal and a temperature of around 0.01 °C. So, this condition maintains pressure above this and this temperature. So, that solid will go directly into the vapour phase. Otherwise, if your temperature is higher, the pressure is higher, and the temperature is higher. Above this triple point, the material will solidify and go into liquid. Then it will go into the water, and this is. So, this is melting, evaporation, condensation here, and sublimation, and these are the basic things I am sure you must have all been taught in your school. So, here we go for the sublimation. So, the principle is that the food is frozen at a very low temperature, typically minus 40 °C or so, and then in a vacuum, the ice in the food is converted directly into water vapour without passing through the liquid. And then finally, desorber the remaining water vapour is removed from the food. and further drying it and ensuring it is completely devoid of moisture. So, the freeze drying is a simultaneous heat and mass transfer operation. You can say that if you have a food material here, there is a frozen product in the form of ice, a condenser and a heat source. When you apply heat, the material absorbs it, and then at low temperatures, etcetera, the mass transfer takes place. Water evaporates, and you get the dried material, which is how the sublimation process works. So, this is a brief explanation of freeze drying.



Summary

- Refrigerated and modified atmosphere storage extend the shelf life of perishable foods by lowering temperatures and adjusting atmospheric conditions to reduce spoilage.
- Freezing halts microbial growth and enzyme activity, preserving food quality by maintaining low temperatures.
- Freeze dehydration, or freeze-drying, involves freezing food and then removing moisture under a vacuum, resulting in lightweight, long-lasting products.
- Refrigerated storage is suitable for short-term preservation; while freezing and freeze-drying are better for long-term storage and maintaining nutrient content.

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So, now I will summarize that refrigerated and modified atmosphere storage extends the shelf life of perishable foods by lowering the temperature and adjusting atmospheric conditions to reduce spoilage. Freezing halts microbial growth and enzyme activity, preserving food and its quality by maintaining low temperatures. Freeze dehydration or

freeze drying involves freezing the food and removing the moisture under a vacuum, resulting in a light, long-lasting product. This is the sublimation process, which involves freezing and sublimation. Refrigerator storage is suitable for short-term preservation while freezing and freeze-drying are better for long-term storage. Although there are refrigeration conditions, if you go with the modified atmosphere, then the shelf life of the material can be increased. It may be kept for a comparatively longer period of time if the temperature and atmospheric conditions, gases, etcetera, are also maintained.



These are the references which were used in this lecture with this.



Thank you very much for your patience while listening. Thank you.