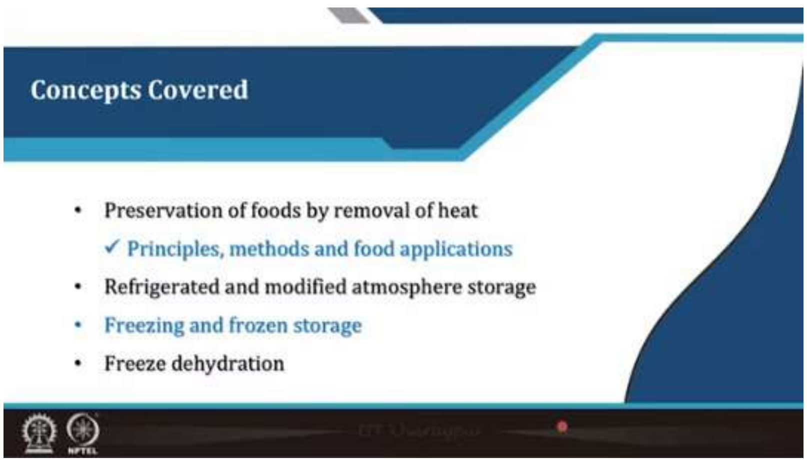
FOOD SCIENCE AND TECHNOLOGY

Lecture45

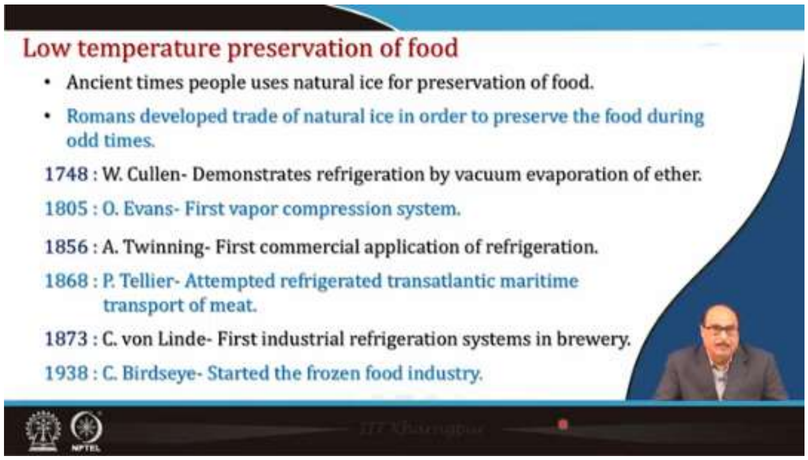
Lecture 45: Low-Temperature Preservation of Foods

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.



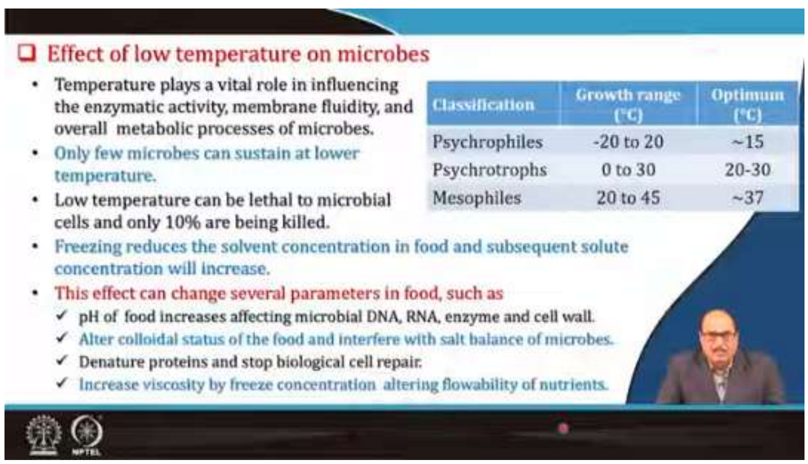
In today's class, we will talk about how we can preserve food by removing heat; in other words, you can say low-temperature food preservation. This class will discuss the principles and methods of low-temperature preservation of food, as well as refrigerated and modified atmosphere storage. freezing and frozen storage, and finally, we will also touch upon freeze dehydration as the main point.



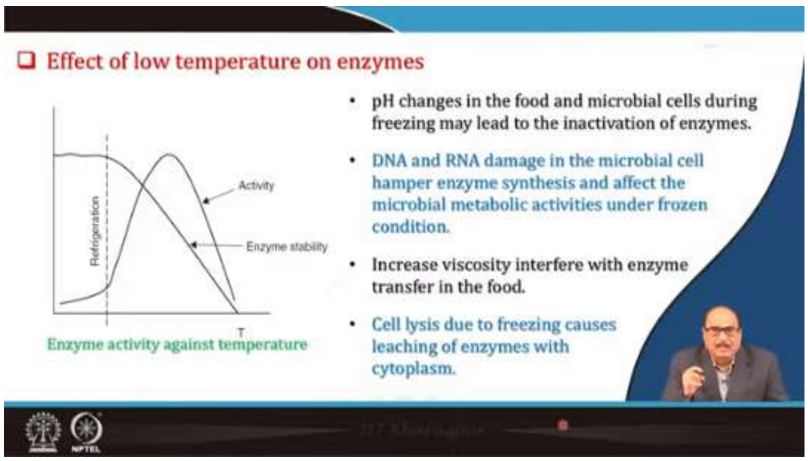
So, if you look at the history of low-temperature preservation of food, you will know that since ancient times, people have used natural ice for food preservation. Even Romans developed the trade of natural ice to preserve food during odd times. In the year 1748, W. Cullen demonstrated refrigeration 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.

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.

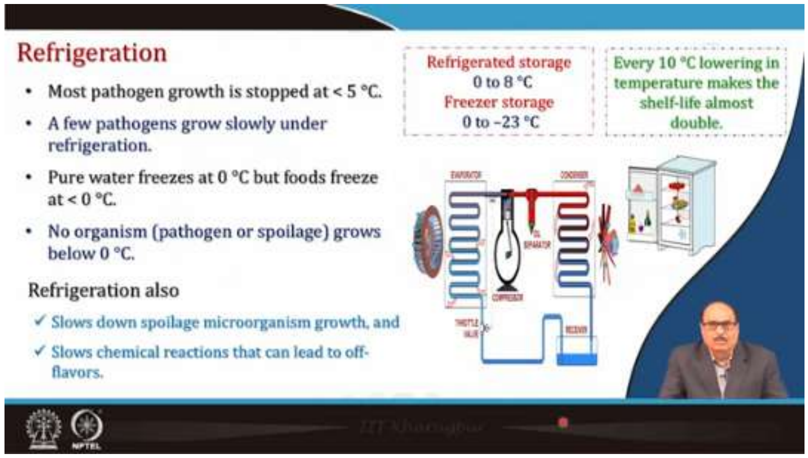


If you recall, in earlier classes, we also briefly discussed how low temperature affects microbes and enzymes, etcetera. So, basically, the principle of this low-temperature preservation is based on the fact that the low temperature brings down the temperature in such a way that it is in the range which 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.

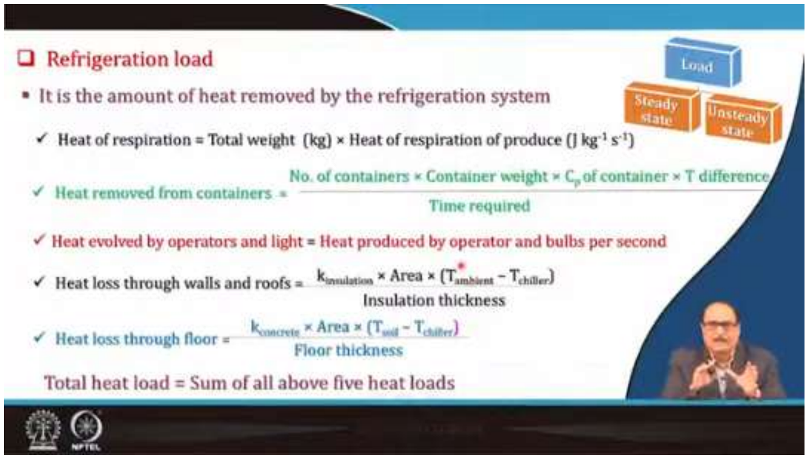


Similarly, you can see the effect of low temperature. particularly on the enzymes that are the pH changes in the food and microbial cell which might take place during the freezing process may lead to the inactivation of the enzyme, may lead to the denaturation of the body or enzyme cell protein systems, 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.



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 0 °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?



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 ($Jkg^{-1}s^{-1}$).

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

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

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

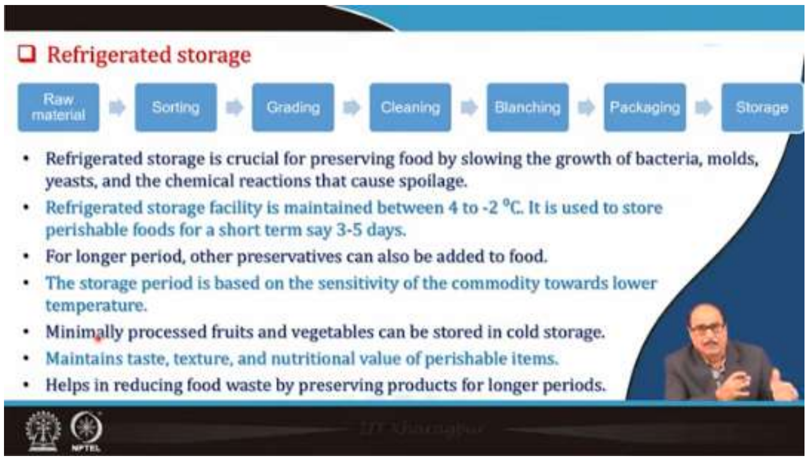
Then, heat loss through the walls and roofs; although proper insulations, etcetera, are provided inside the facility, there may be some heat loss. So you can one can calculate

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

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

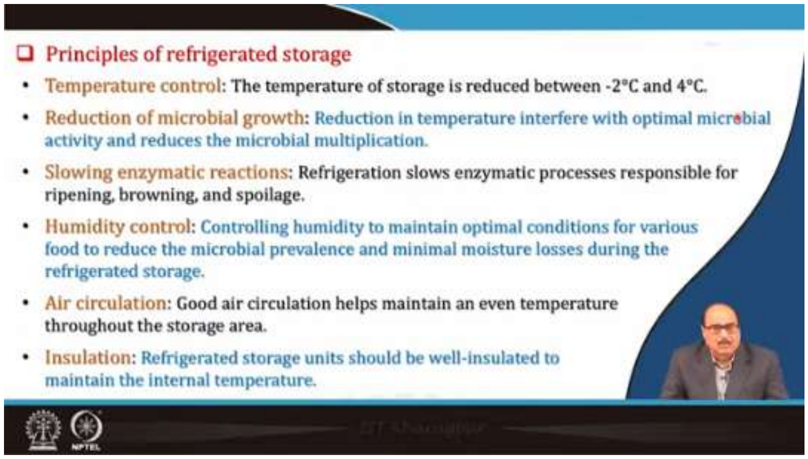
Heat loss through floor = $\frac{\mathrm{K_{concrete}} \times \mathrm{Area}\ \times (\mathrm{T_{soil}} - \mathrm{T_{chiller}})}{Floor\ thickness}$

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.

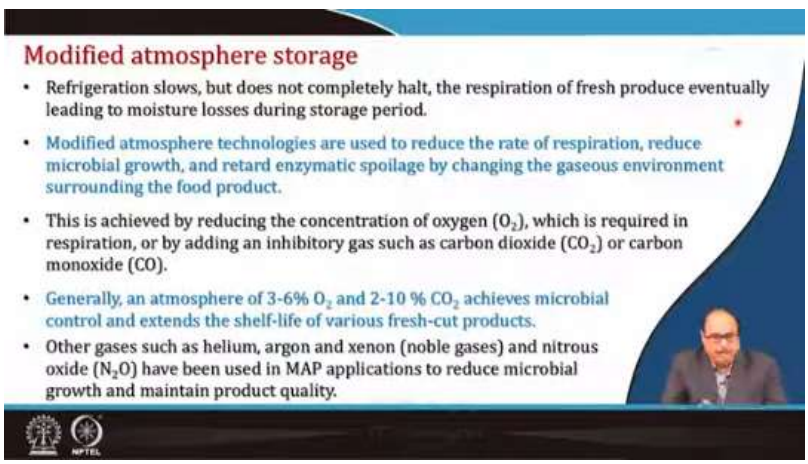


So, refrigerated storage involves raw materials, particularly perishable materials. They are sorted, graded, cleaned, blanched, and packed, and finally, they are put into the storage environment and okay. So, this is particularly useful for preserving perishable foods. This low temperature is very important. 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.

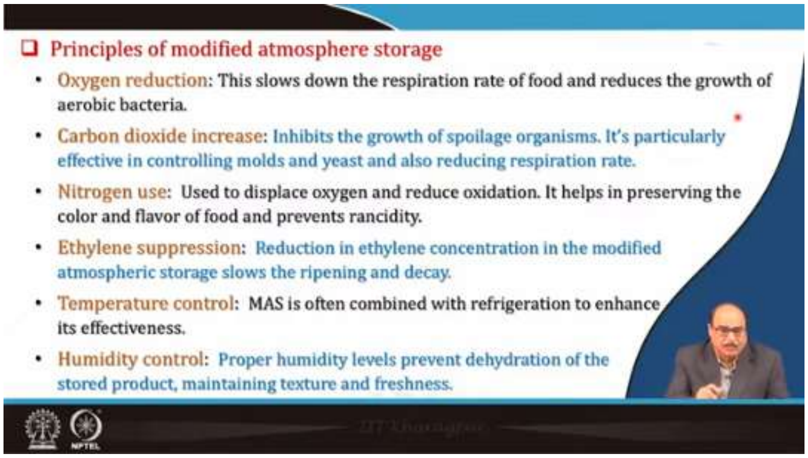
So, the first principle of refrigerated storage we have already discussed is temperature control: you bring down the storage facility temperature to an unfavourable level where microorganisms cannot grow, and enzymes cannot act. Their undesirable activities and undesirable chemical reactions are stopped. 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.



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.

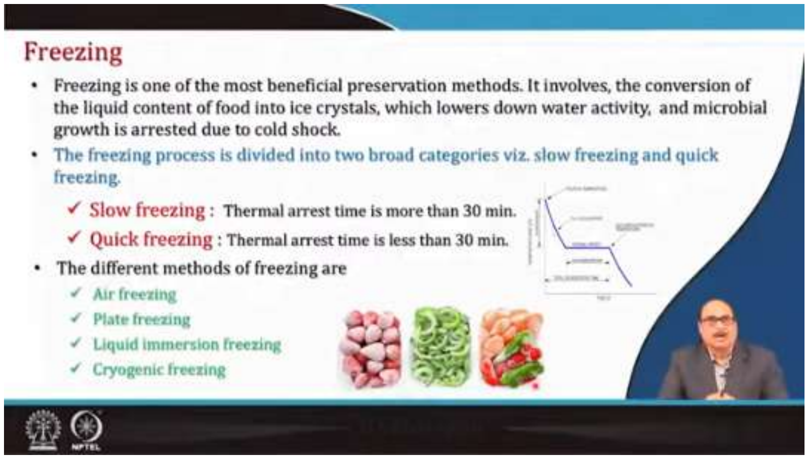


Now, we see the modified atmosphere storage. So, modified atmosphere storage is the same principle in the same storage facility as refrigerated storage. We just lower the temperature. However, in the modified atmosphere storage, along with the temperature, we also lower the gaseous composition in the 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 O_2 and CO_2 conditions might vary. So, other gases such as helium, argon, and xenon, that is, the noble gases, etcetera, nitrous oxide, and N_2O have been used in modified atmosphere packaging applications to reduce microbial growth and maintain product quality.

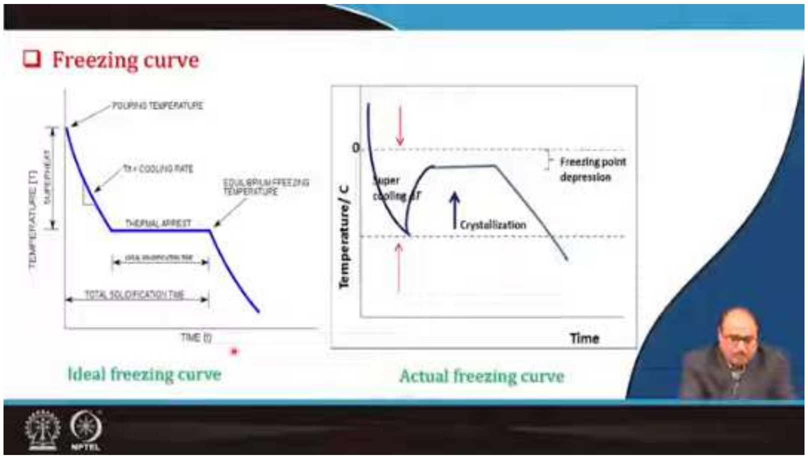


So, here again, if you talk about the principle that is oxygen reduction when you lower the oxygen, it not only slows down the respiration process, but it also helps reduce the oxygen or oxidation or other chemical reactions as well as the growth of the aerobic bacteria and all those things. Then carbon 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, O_2, CO_2, and ethylene control are done to get the desired effect.

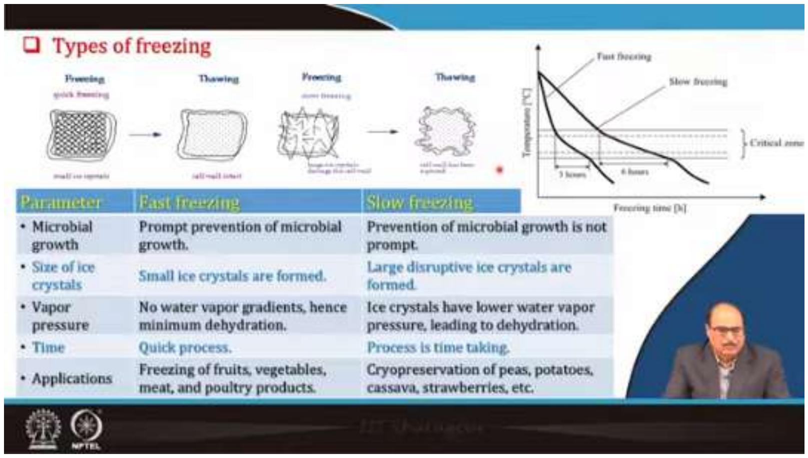
So, these various methods, that is, of the modified atmosphere storage and modified atmosphere packaging, include one, which is active packaging, which involves modifying the atmosphere within the packaging using gas flux techniques. The package is evacuated of air and replaced with a gas mixture, often 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: O_2, CO_2, and N_2. 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.



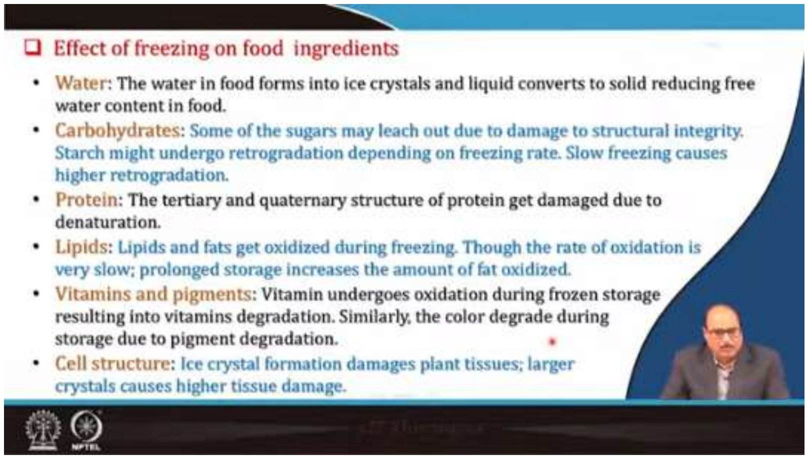
Now, we talk about freezing. So, freezing is again one of the most beneficial preservation methods. It involves converting the liquid content of the food into ice crystals in the food in earlier classes; we discussed that it has some free water and some wound water. So, in the freezing process, temperature 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.



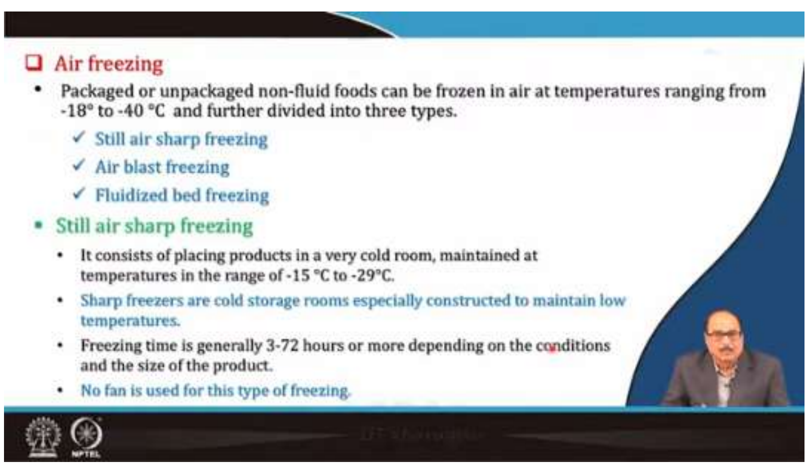
So, in the last slide, you saw that figure that this is here a little bigger than what is happening that is the ideal freezing curve, that is, if you put the material inside, there is a lowering that may be a room temperature 20 or 25°C. So, you give that to cool it down at a specific rate, such as the 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.



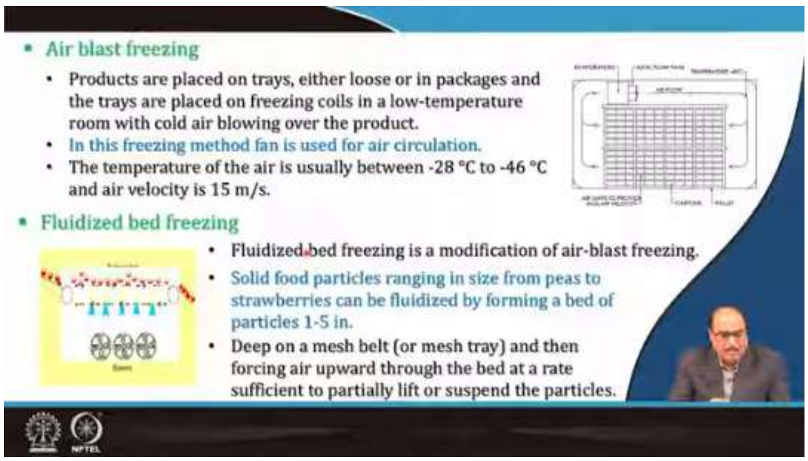
So, this is freezing, and that is the type of freezing. Interesting that is freezing is that you can say quick freezing or slow freezing. Here, the water is quick, the number of ice crystals may be larger, and the size of the ice crystals may become smaller. There is not much structural dislocation and 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.



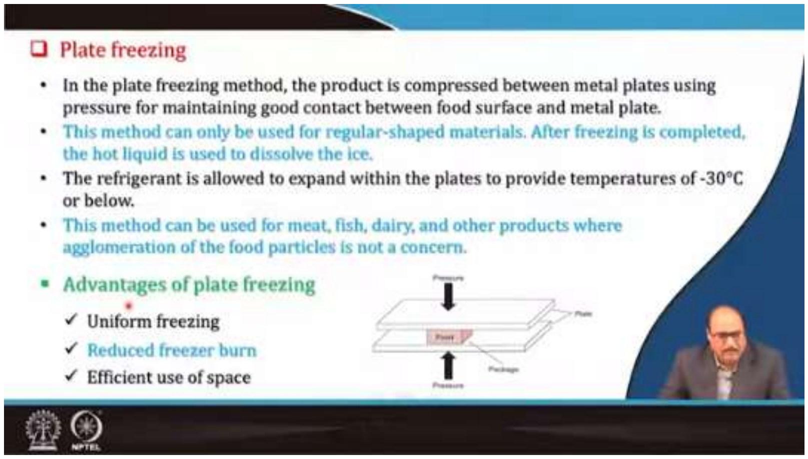
So, the effect of freezing on food ingredients like water in the food forms into ice crystals, and the liquid converts into solids, reducing free water content. Even in carbohydrates, some of the sugars may leach out due to damage to structural integrity, particularly in the case of slow freezing. Starch 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.



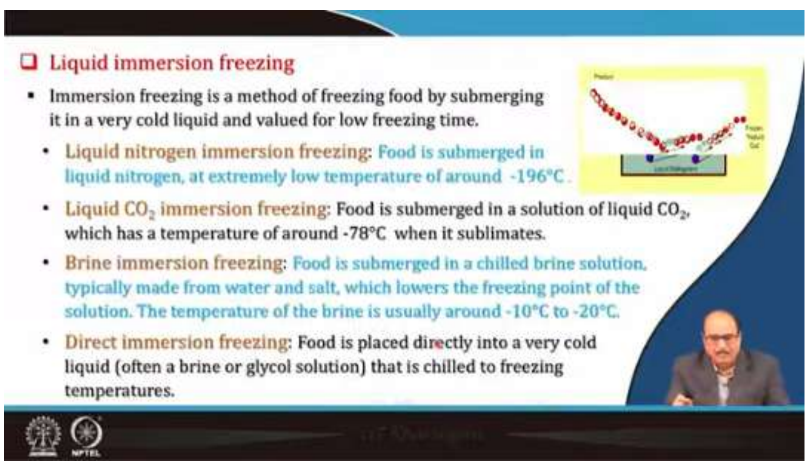
So, methods of the freezing air freezing. Here, packaged or unpackaged non-fluid foods can be frozen in the air at a temperature ranging from -18 to -40 °C and further divided into three types: still air sharp freezing, air blast freezing, or fluidized breath freezing. Still, air-sharp freezing here 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.



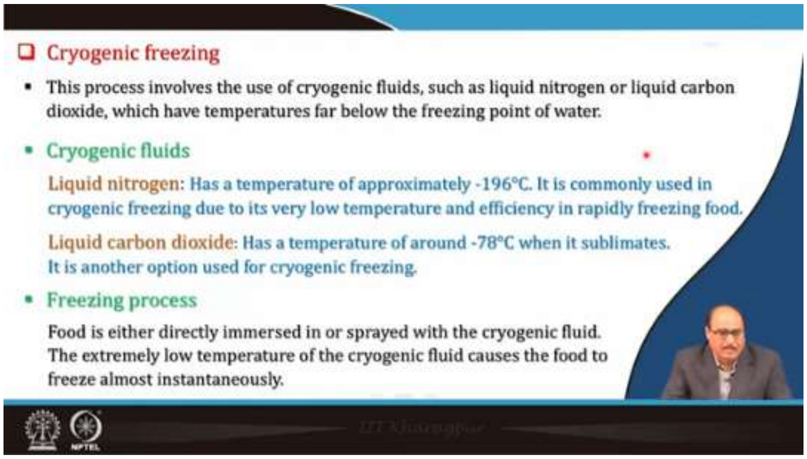
Air blast freezing, you can say the products are placed on trays either loose or in packaged form, and the trays are placed on freezing coils in a low-temperature room with which the air blows, and the air is blown on the top of the product's surface. So, a fan is used for air circulation in this freezing 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.



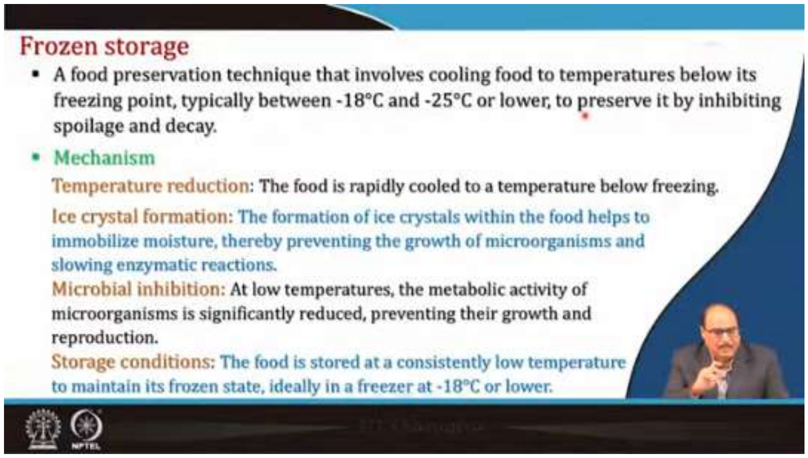
Then it becomes plate freezing. You can see here the plate; the full material is pressed between two plates, and this method can only be used for regularly shaped materials. After freezing, the hot liquid dissolves the ice for thawing purposes, etcetera. The refrigerant can expand within the plates to 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.



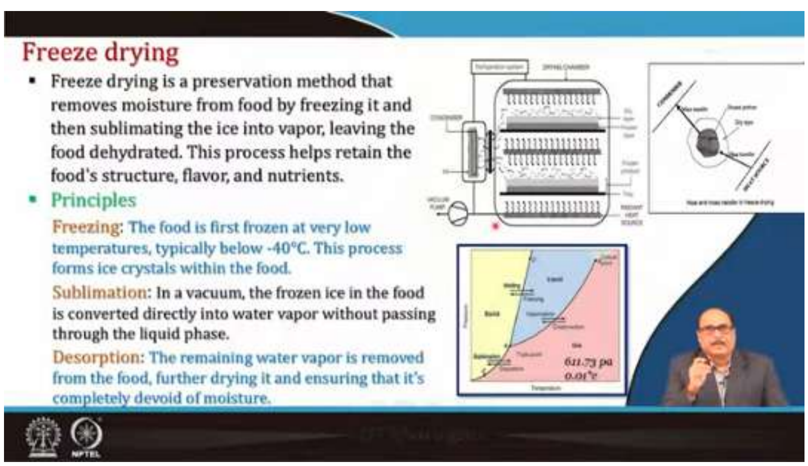
Then the other method is liquid immersion freezing. Immersion freezing is the method of freezing food by submerging it in a very cold liquid and is valued for its low freezing times. So, you can see it is a liquid refrigerant; the product flows and is immersed in the material for the desired period. So, the food is submerged in liquid nitrogen, which is maintained at an extremely low temperature, maybe -196 °C or liquid carbon dioxide immersion freezing, where the liquid carbon dioxide is maintained at around -78°C. Even brine solution can be used simply as a brine or salt solution; its temperature may be -10°C to -20 °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.



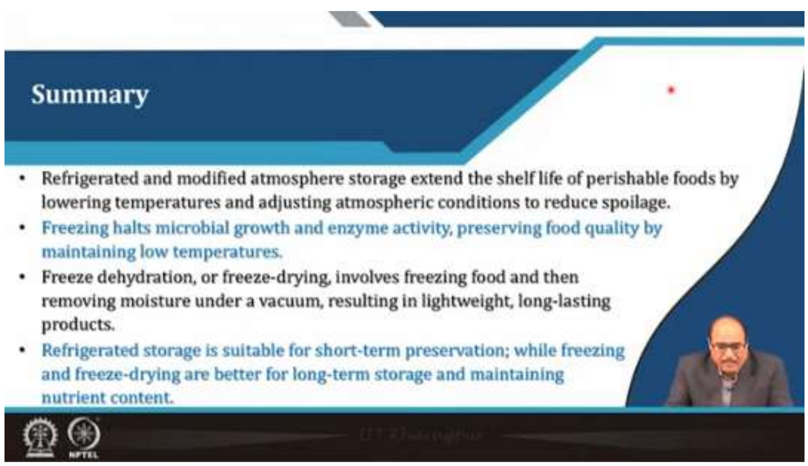
Cryogenic freezing is, again, a process that involves cryogenic fluids such as liquid nitrogen or liquid carbon dioxide, which have temperatures far below the freezing point of water. So, as mentioned in the earlier slide, liquid nitrogen typically has a temperature of -196 °C. So, it is used in cryogenic freezing due to its very low temperature and high efficiency, resulting in very fast freezing. Liquid carbon dioxide has a temperature of around -78 °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.



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.



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 subliming. 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 sublimes 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, deserter 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.



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.