Post-Harvest Operations and Processing of Fruits, Vegetables, Spices and Plantation Crop Products

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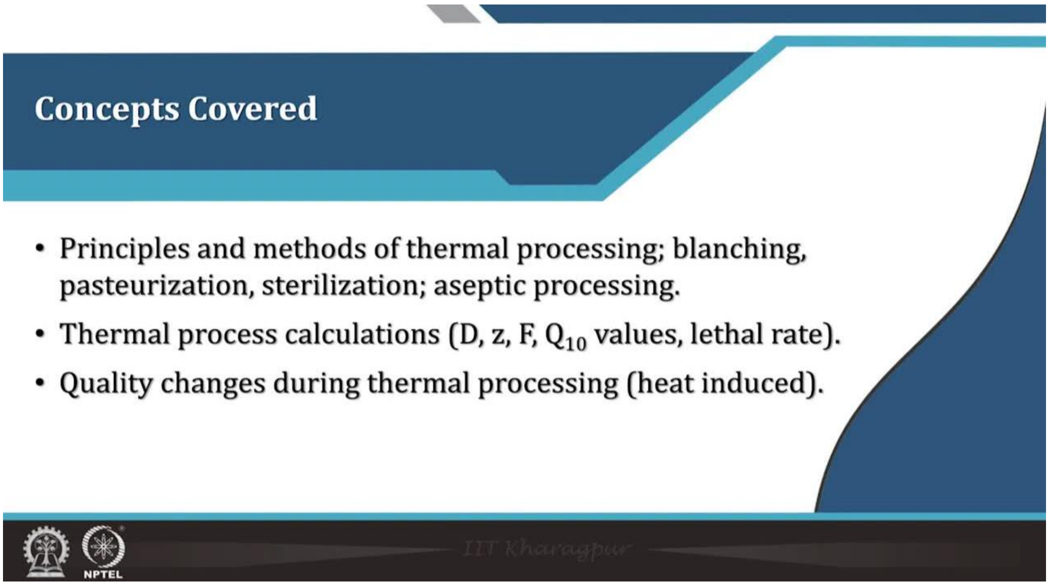
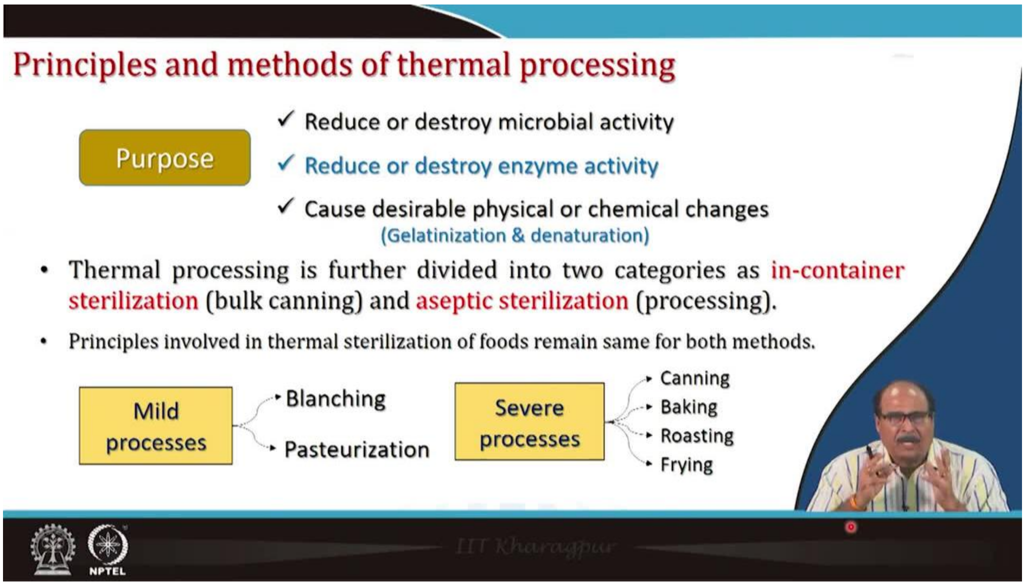
Lecture 13
Processing by Addition of Heat



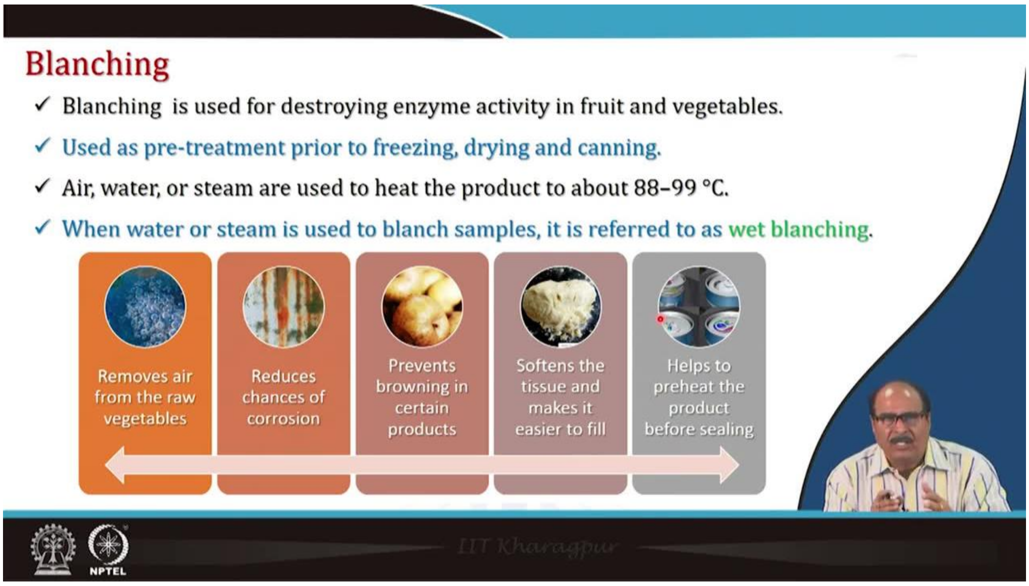
The concepts covered in the lecture include principles and methods of thermal processing, blanching, pasteurization, sterilization, aseptic processing, important aspects of the thermal process calculations like D value, z value, lethal rate and the quality changes during thermal processing.



Principles and methods of thermal processing

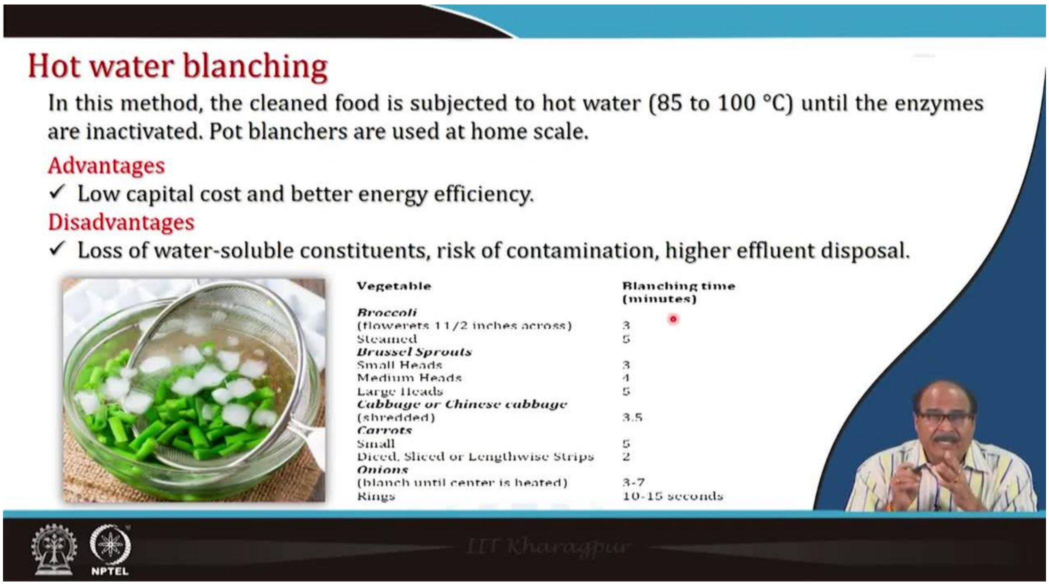
The purpose of the addition of heat or thermal processing is to reduce or destroy the microbial activity, reduces or destroys the undesirable enzyme activity, and it causes desirable physical and chemical changes such as gelatinization and denaturation in the product to give the desired characteristics.

The thermal processing is divided into 2 major categories i.e. in-container sterilization (also called as bulk canning) and the aseptic sterilization (aseptic processing and packaging). The principle involved in both the processes remains the same. These heat processes can also be categorized on the basis of their severity like milder processes (blanching and pasteurization), and severe processes including canning, baking, roasting and frying.



Blanching

Blanching is used for destroying enzyme activity in fruits and vegetables, it is used as a pretreatment to freezing drying and canning. Air, water or steam are used to heat the product to about 88 to 99 °C and when the water or steam is used to blanch the product, it is referred to as wet blanching. So, it is a very important operation to improve or to get the desired characteristics of the product after the drying or during the canning or freezing of vegetables.



Hot water blanching

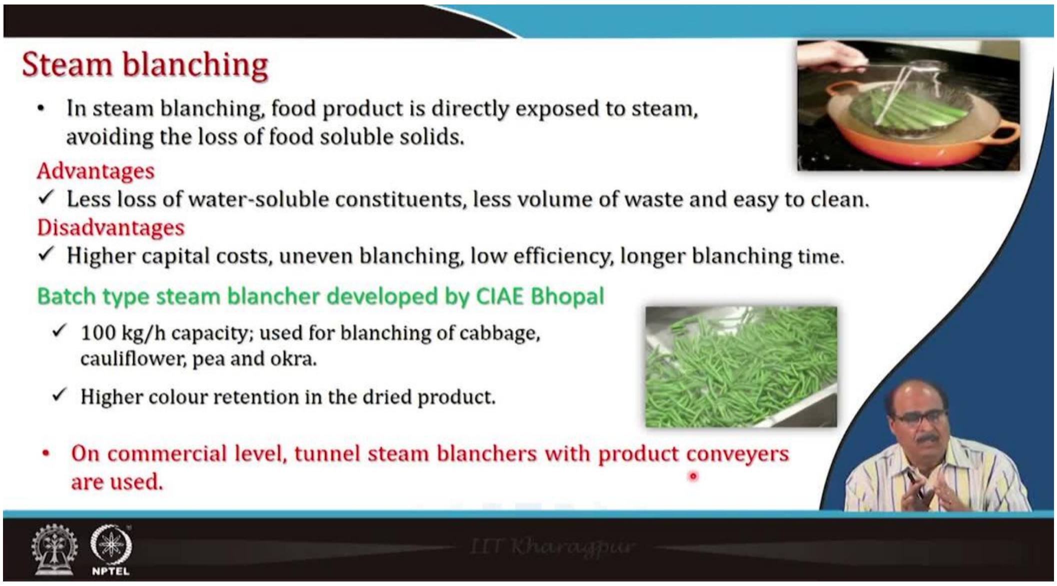
In this method, the cleaned food is subjected to hot water (85 to 100 °C) until the enzymes are inactivated. Port blanchers are used at home scale. Its capital cost is low and it has better energy efficiency. However, there are certain disadvantages such as loss of water soluble constituents, risk of contaminants, and higher effluent disposal.

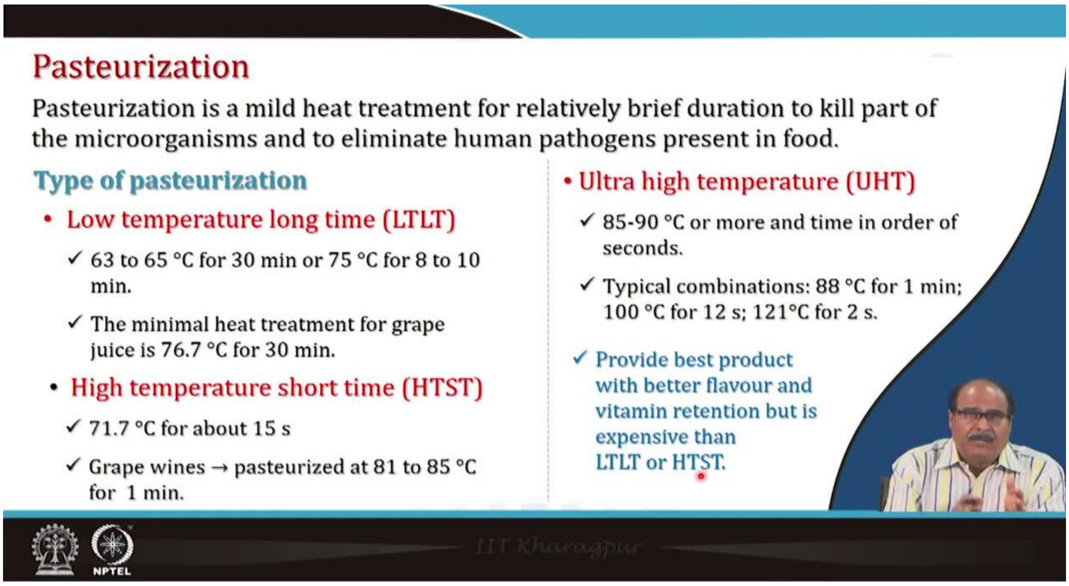
The table shows the blanching time (in minutes) for different vegetables. For example, broccoli can be blanched 3 to 5 minutes, the blanching time of carrots depends on the size and varied from 2 to 5 minutes etc.

Steam blanching

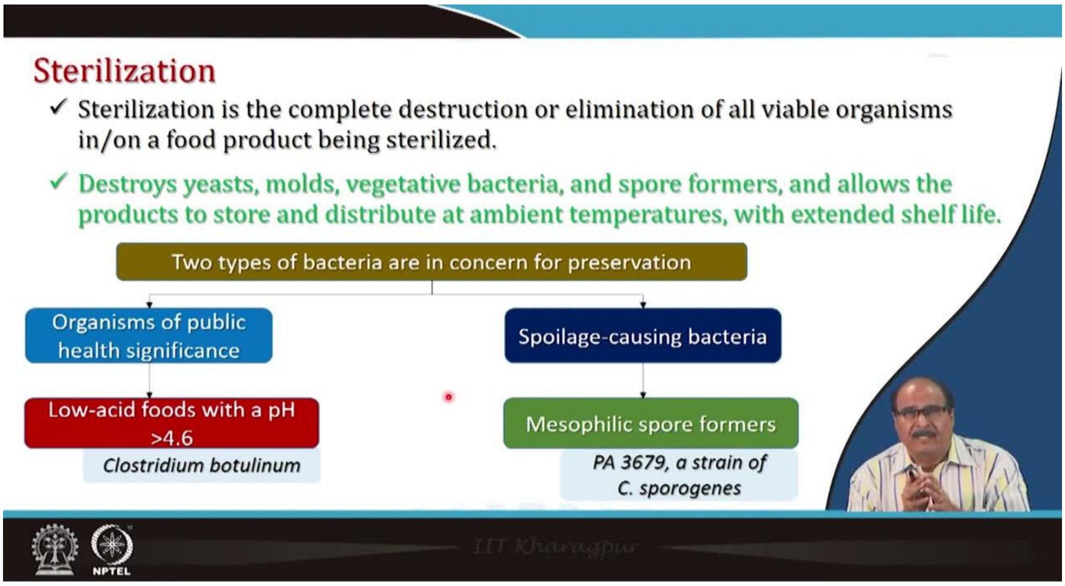
In steam blanching, food product is directly exposed to steam to avoid the loss of the food soluble solids. On commercial level tunnel steam blanches with product conveyors are used. CIAE Bhopal has claimed they are developing a steam blancher that is having 100 kg capacity per hour and it is used for blanching of the cabbage, cauliflower, pea and okra and they claim that there is better retention of the color in the dried product.

Pasteurization, it is a mild heat treatment for relatively brief duration to kill the part of the microorganism and to eliminate human pathogens present in the food. Pasteurization may be either low temperature long time popularly known as LTLT, or high temperature short time (HTST) method or ultra-high temperature (UHT) methods. The LTLT method is generally used at 63 to 65 °C for 30 minute or 75 °C for 8 to 10 minutes. This is a minimal heat treatment for grape juice, it is normally done at 76.7 °C for 30 minutes.



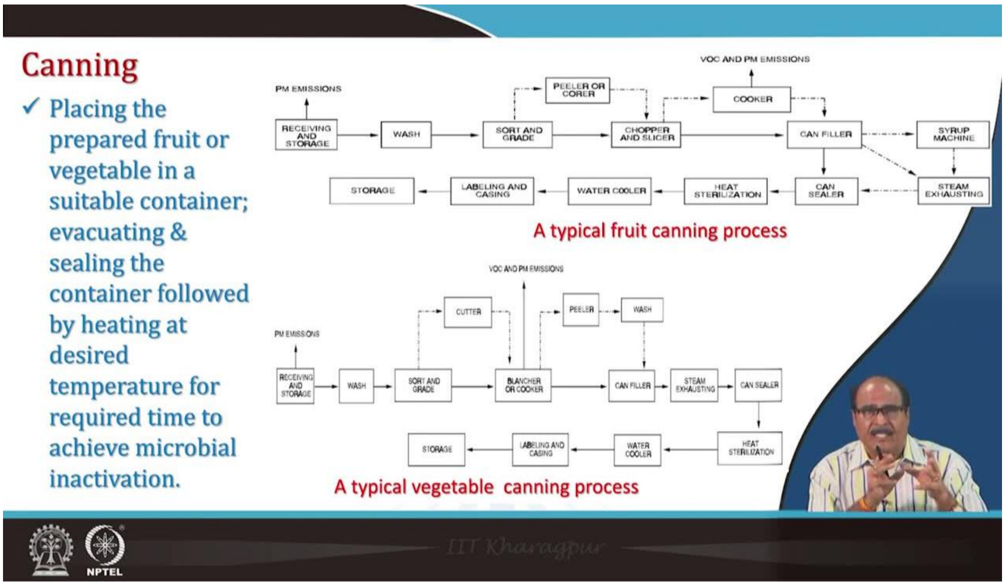


The HTST process is generally used at 71.7 °C for about 15 seconds, grape wines are pasteurized at 81 to 85 °C for about 1 minute. In the UHT process, it is operated at 85 to 90 °C or more temperature and time in order of seconds. Typical combinations are 88 °C for 1 minute, 100 °C for 12 seconds or 121 °C for 2 seconds are used in UHT process, which provides the best product with better flavor and vitamin retention but it is generally expensive than LTLT and HTST.



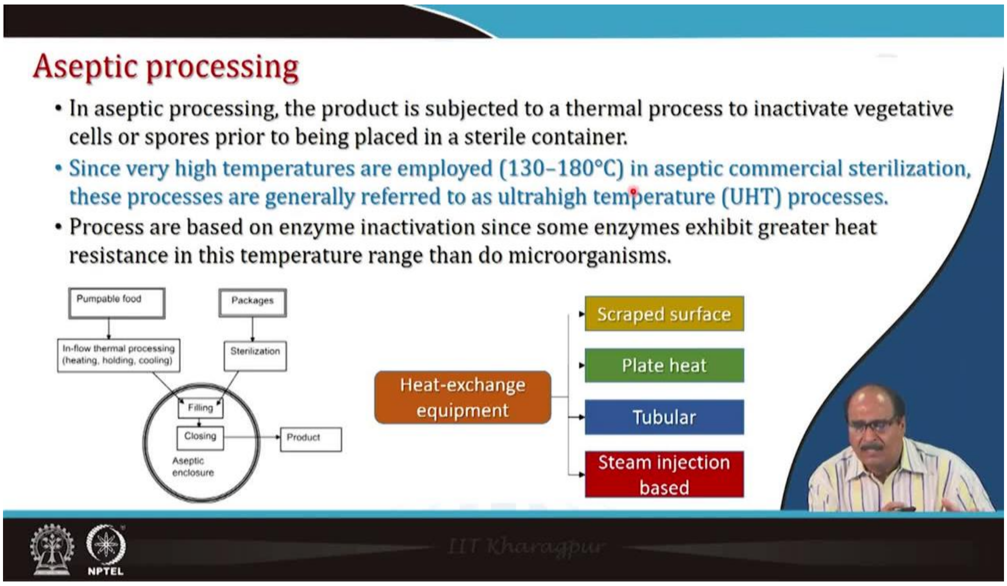
Sterilization

Sterilization involves the complete destruction or elimination of all viable organisms in all food product, it destroys yeasts, molds, vegetative bacteria and spore formers and allows the product to store and distribute at ambient temperature with extended shelf life.



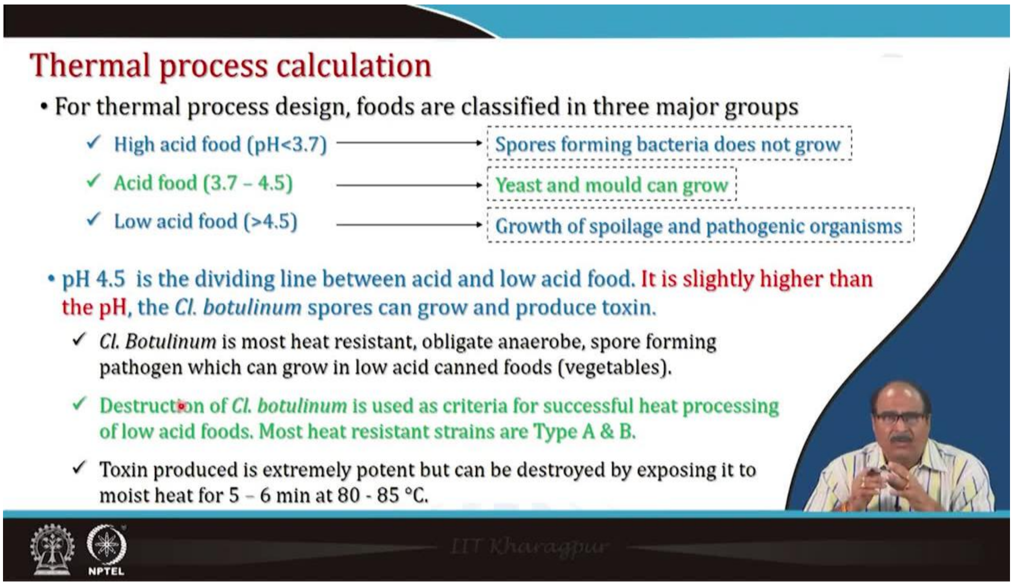
Canning

Canning involves placing the prepared fruit or vegetable in a suitable container, evacuating and sealing the container followed by heating at desired temperature for required time to achieve microbial inactivation. The typical fruit canning process involves various treatments such as peeling, washing, cleaning, peeling coating, cutting, slicing, filling the cans, syrup addition, exhausting the steam, sterilization, water cooling, and storing. Blanching is a suitable method and then finally, the fruits and vegetables are sealed into the suitable cans. In vegetable canning process, the steam or hot water blanching is done in order to facilitate the better heat transfer inside the vacuum. So, to facilitate the heat transfer in the case of vegetable, generally brine solution is added, whereas in the case of fruit generally sugar syrup of variant concentration depending upon the type of the fruits and its acidity is used.

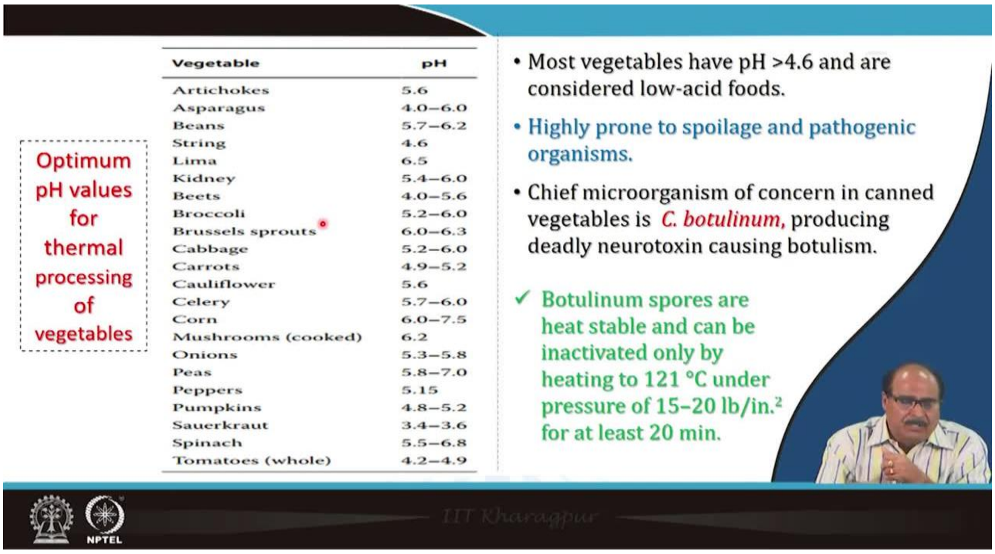


Aseptic processing

In aseptic processing, the product is subjected to a thermal process to inactivate vegetative cells or spores prior to being placed in the sterile container, where the packaging material is sterilized separately and the pump able food mostly liquid foods which are used are sterilized separately and then the product is aseptically packaged in the using form fill and seal (FFS) machine. For the sterilization of the juices different types of heat exchanger equipments like scraped surfaces exchangers, plate heat exchangers, tubular heat exchangers or steam injection based heat exchangers are used. Most of the packets which are seen in the market with various brands of vegetable juices, fruit juices, majority of them are produced using this aseptic processing and packaging technologies.



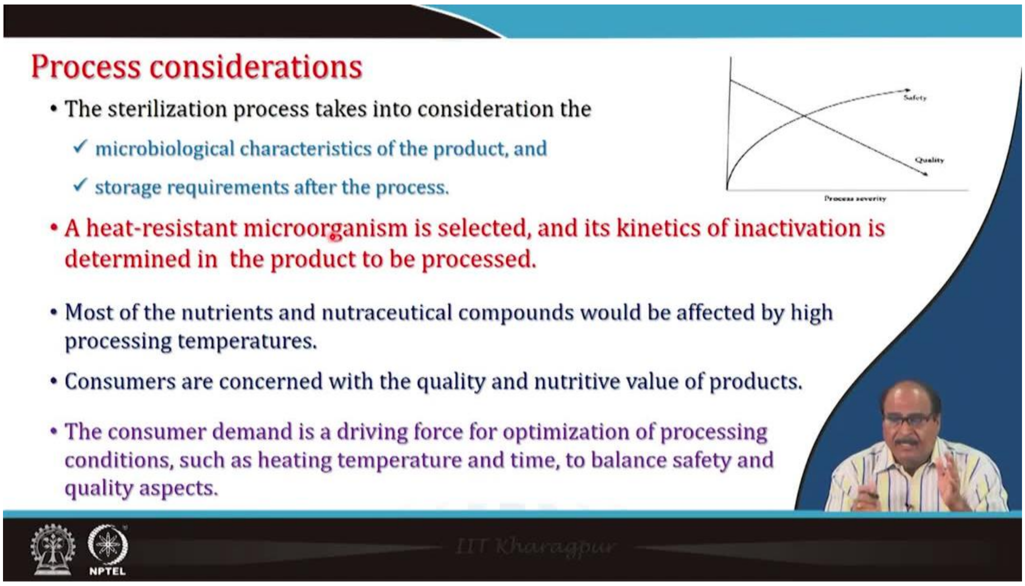
For thermal process design, the foods are normally classified into 3 groups on the basis of their pH like high acid food, acid food and low acid food since the pH of the food is an important factor affecting the growth and multiplication of microorganism. In high acid food having pH less than 3.7, spore forming bacteria does not grow. In acid foods which has pH between 3.7 to 4.5 yeast and molds can easily grow. There is growth of spoilage and pathogenic organisms in low acid foods. The pH 4.5 is the dividing line between acid and low acid food. It is slightly higher than the pH, the *Cl. botulinum* spores can grow and produce toxin. *Cl. Botulinum* is most heat resistant, obligate anaerobe, spore forming pathogen which can grow in low acid canned foods (vegetables). Destruction of *Cl. botulinum* is used as criteria for successful heat processing of low acid foods. Most heat resistant strains are Type A & B. Toxin produced is extremely potent but can be destroyed by exposing it to moist heat for 5 – 6 min at 80 - 85 °C.

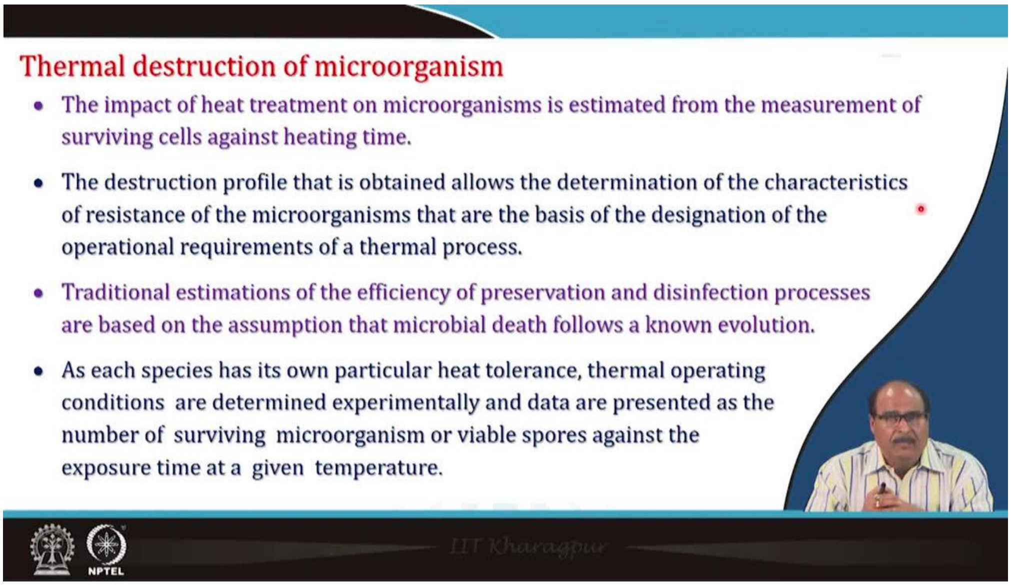


In this slide, the optimum pH values for the thermal processing of vegetables in order to categorize these into low and high acid foods and most probable spoilage organisms acting on the products. Most vegetables have pH > 4.6 and are considered low-acid foods and these are highly prone to spoilage and pathogenic microorganisms. *Clostridium botulinum* is the main criteria. Botulinum spores are heat stable and can be inactivated only by heating to 121 °C under pressure of 15–20 lb/in.^{2} for at least 20 min.

Process considerations

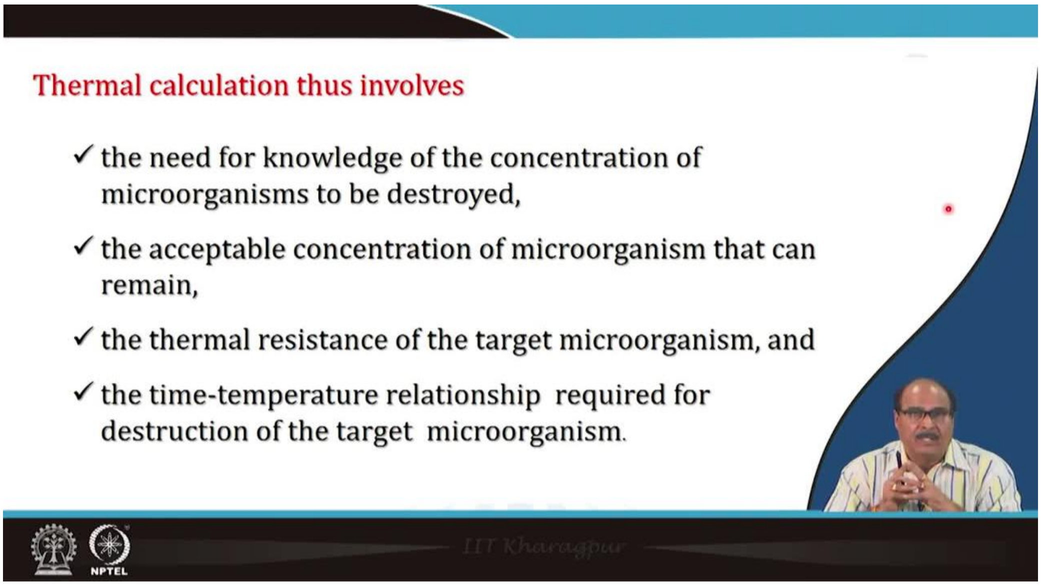
The process severity is directly proportional to the safety and quality of the product, more the severe process, then it will reduce the quality of the processed product. The sterilization process takes into consideration the microbiological characteristics of the product, and storage requirements after the process. A heat-resistant microorganism is selected, and its kinetics of inactivation is determined in the product to be processed. Most of the nutrients and nutraceutical compounds would be affected by high processing temperatures. Consumers are concerned with the quality and nutritive value of products. The consumer demand is a driving force for optimization of processing conditions, such as heating temperature and time, to balance safety and quality aspects.



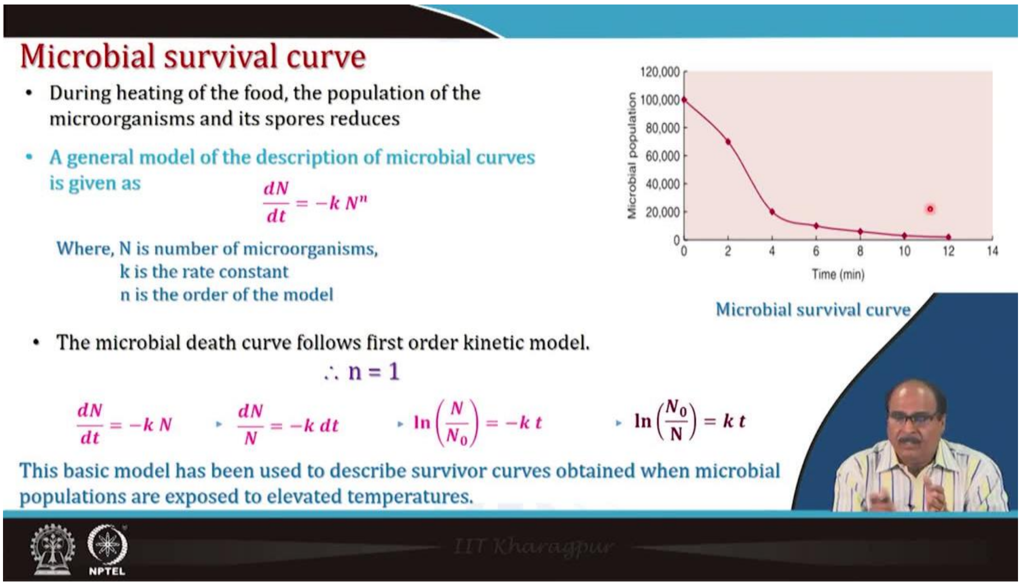


Thermal destruction of microorganisms

The impact of heat treatment on microorganisms is estimated from the measurement of surviving cells against heating time. The destruction profile that is obtained allows the determination of the characteristics of resistance of the microorganisms that are the basis of the designation of the operational requirements of a thermal process. Traditional estimations of the efficiency of preservation and disinfection processes are based on the assumption that microbial death follows a known evolution. As each species has its own particular heat tolerance, thermal operating conditions are determined experimentally and data are presented as the number of surviving microorganism or viable spores against the exposure time at a given temperature.



Thermal calculation involves the need for the knowledge of the concentration of the microorganisms to be destroyed, the acceptable concentration of microorganism that can remain, the thermal resistance of the target microorganisms, and the time-temperature relationship required for destruction of the target microorganism.



Microbial survival curve

During heating of the food, the population of the microorganisms and its spores reduces. A general model of the description of microbial curves is given as

$$\frac{dN}{dt} = -k\, N^n$$

Where, N is number of microorganisms, k is the rate constant, and n is the order of the model. The microbial death curve follows first order kinetic model (n=1). Hence,

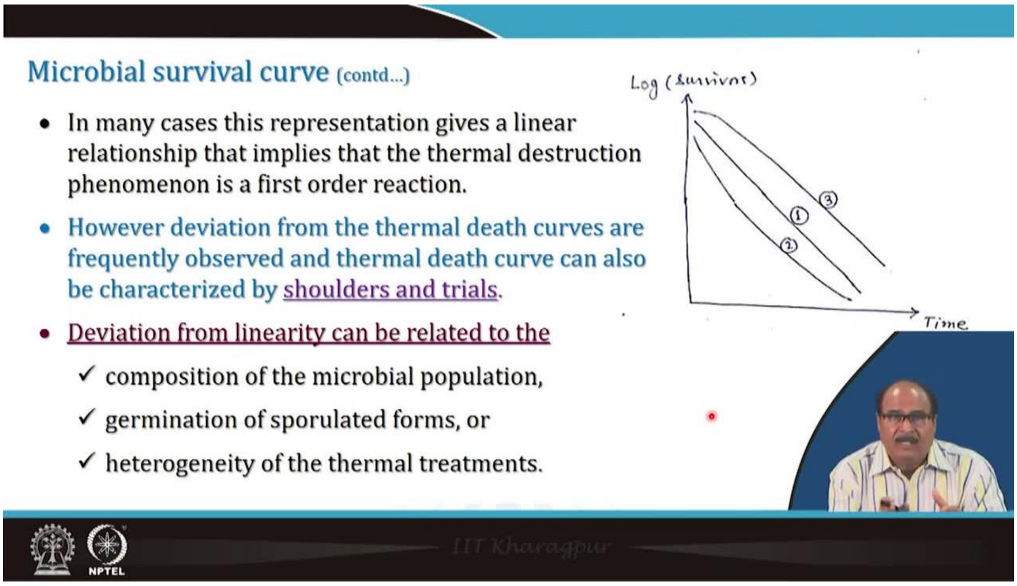
$$\frac{dN}{dt} = -k\, N$$

$$\frac{dN}{N} = -k\,dt$$

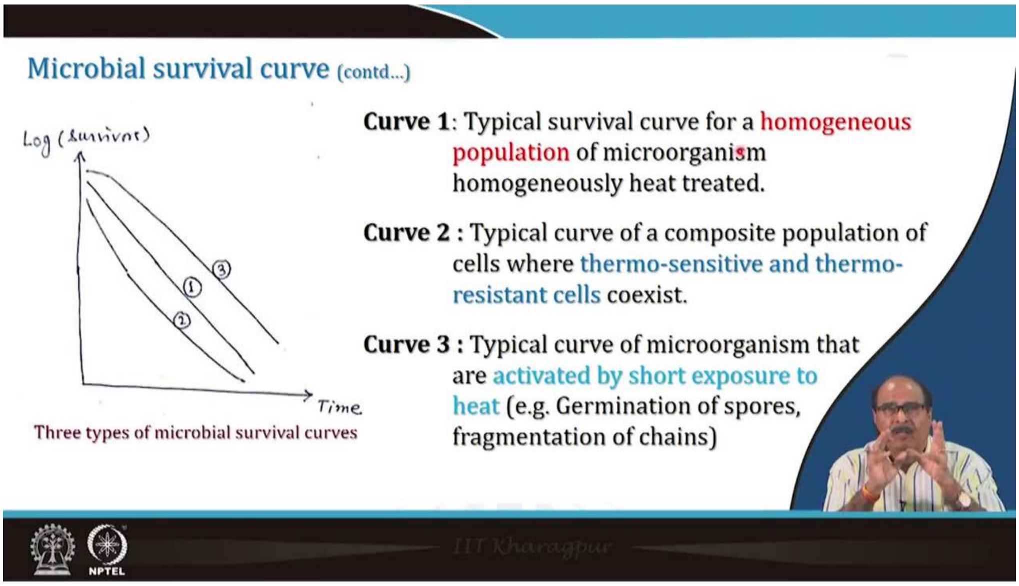
$$\ln\left(\frac{N}{N_0}\right) = -k\,t$$

$$\ln\left(\frac{N_0}{N}\right) = k\,t$$

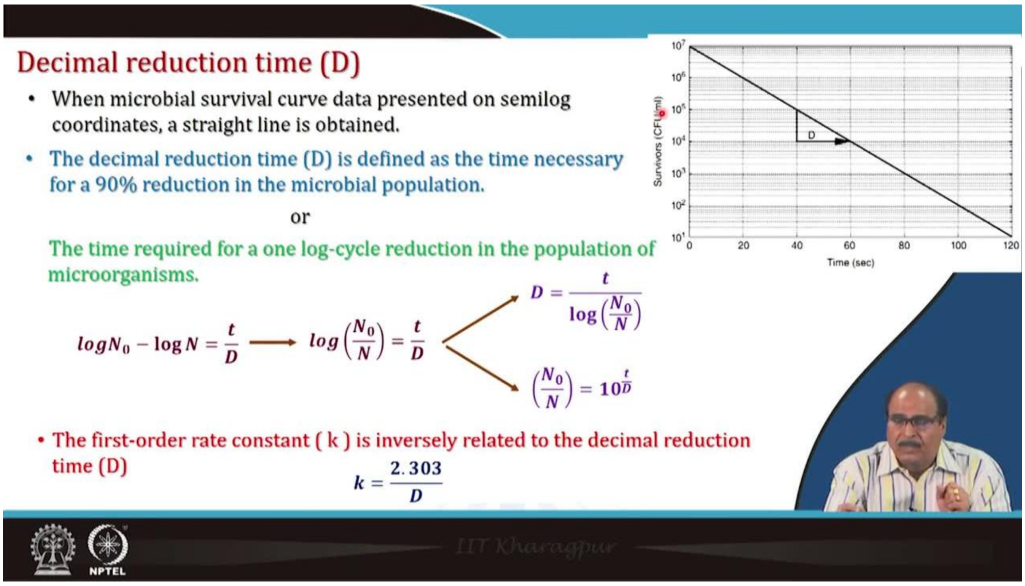
This basic model has been used to describe survivor curves obtained when microbial populations are exposed to elevated temperatures.



In many cases this representation gives a linear relationship that implies that the thermal destruction phenomenon is a first order reaction. However deviation from the thermal death curves are frequently observed and thermal death curve can also be characterized by shoulders and trials. Deviation from linearity can be related to the composition of the microbial population, germination of sporulated forms, or heterogeneity of the thermal treatments.



In this plot between log of survivors vs time, the curve 1 represents the typical survival curve for a homogeneous population of microorganism homogeneously heat treated. Curve 2 represents the typical curve of a composite population of cells where thermo-sensitive and thermo-resistant cells coexist. Curve 3 represents the typical curve of microorganism that are activated by short exposure to heat (e.g. Germination of spores, fragmentation of chains).



Decimal reduction time

When microbial survival curve data presented on semilog coordinates, a straight line is obtained. The decimal reduction time (D) is defined as the time necessary for a 90% reduction in the microbial population or the time required for a one log-cycle reduction in the population of microorganisms.

$$\log N_0 - \log N = \frac{t}{D}$$

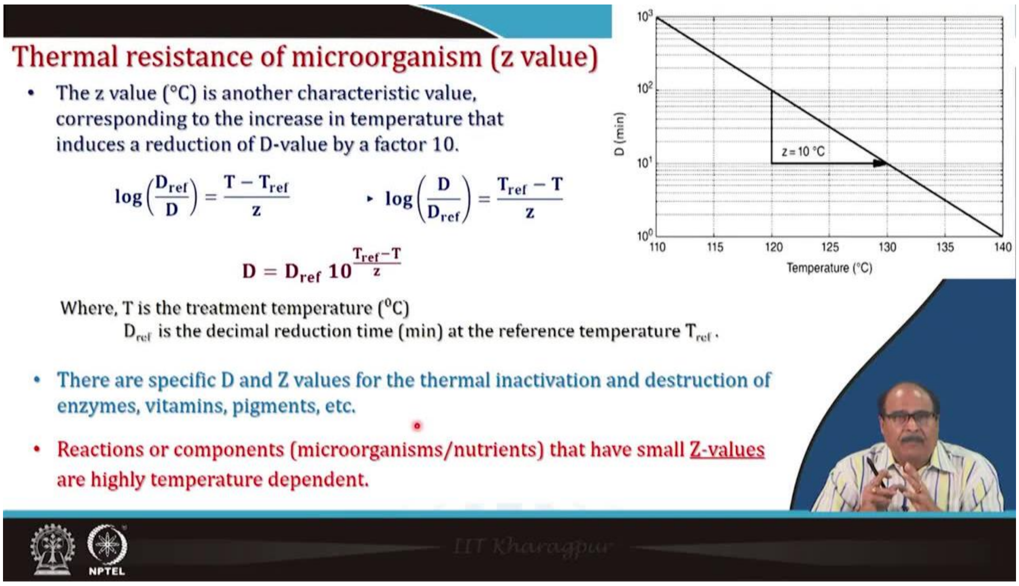
$$\log\left(\frac{N_0}{N}\right) = \frac{t}{D}$$

$$D = \frac{t}{\log\left(\frac{N_0}{N}\right)}$$

$$\left(\frac{N_0}{N}\right) = 10^{\frac{t}{D}}$$

The first-order rate constant (k) is inversely related to the decimal reduction time (D)

$$k = \frac{2.303}{D}$$



Thermal resistance of microorganism (z value)

The z value (°C) is another characteristic value, corresponding to the increase in temperature that induces a reduction of D-value by a factor 10.

$$\log\left(\frac{D_{ref}}{D}\right) = \frac{T - T_{ref}}{z}$$

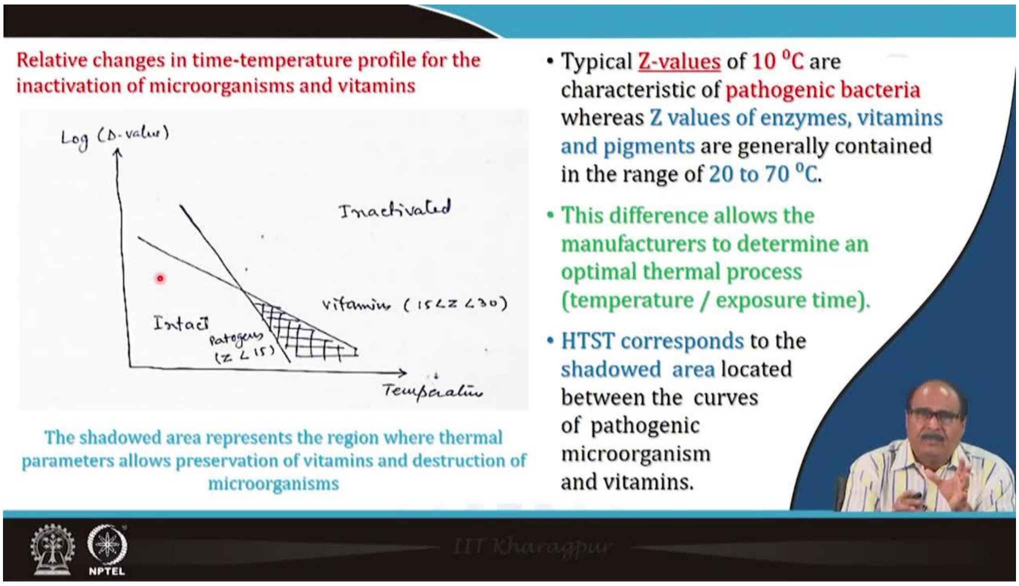
$$\log\left(\frac{D}{D_{ref}}\right) = \frac{T_{ref} - T}{z}$$

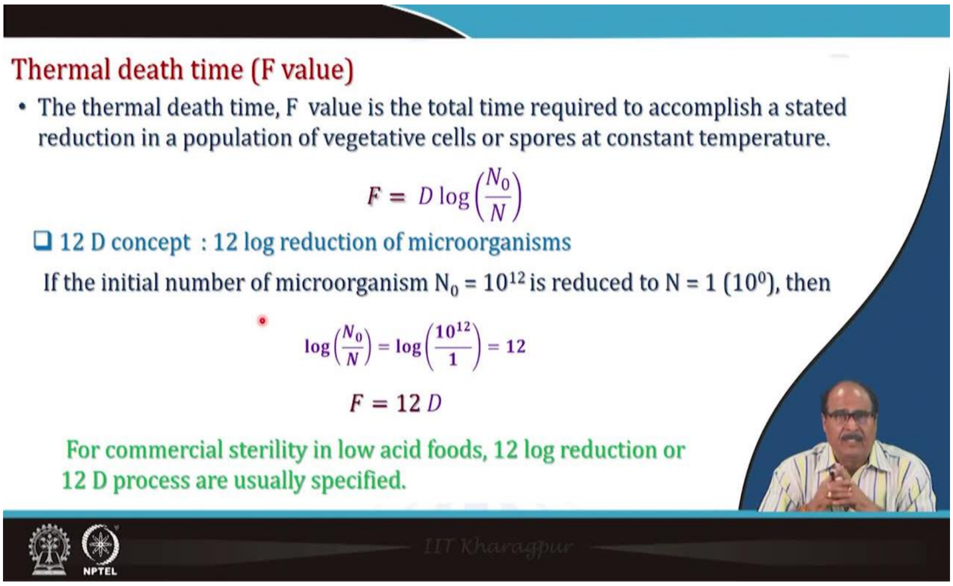
$$D = D_{ref}\, 10^{\frac{T_{ref}-T}{z}}$$

Where, T is the treatment temperature (°C), D_{ref} is the decimal reduction time (min) at the reference temperature T_{ref} .

There are specific D and z values for the thermal inactivation and destruction of enzymes, vitamins, pigments, etc. Reactions or components (microorganisms/nutrients) that have small z-values are highly temperature dependent.

Typical z-values of 10 °C are characteristic of pathogenic bacteria whereas z values of enzymes, vitamins and pigments are generally contained in the range of 20 to 70 °C. This difference allows the manufacturers to determine an optimal thermal process (temperature / exposure time). HTST corresponds to the shadowed area located between the curves of pathogenic microorganisms and vitamins. The figure shows the relative changes in time-temperature profile for the inactivation of microorganisms and vitamins. The shadowed area represents in the region where thermal parameters allows preservation of vitamins and destruction of microorganisms.





Thermal dead time (F value)

The thermal death time, F value is the total time required to accomplish a stated reduction in a population of vegetative cells or spores at constant temperature.

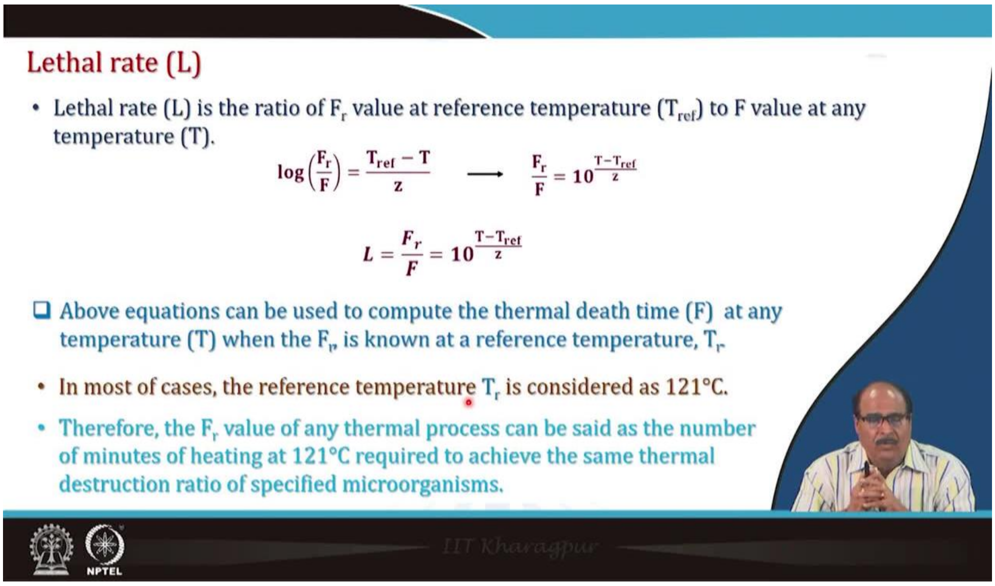
$$F = D \log\left(\frac{N_0}{N}\right)$$

12 D concept means12 log reduction of microorganisms. If the initial number of microorganism $N_0 = 10^{12}$ is reduced to $N = 1$ (10^0), then

$$\log\left(\frac{N_0}{N}\right) = \log\left(\frac{10^{12}}{1}\right) = 12$$

$$F = 12\,D$$

For commercial sterility in low acid foods, 12 log reduction or 12 D process are usually specified.



Lethal rate (L)

Lethal rate (L) is the ratio of Fr value at reference temperature (T_{ref}) to F value at any temperature (T).

$$\log\left(\frac{F_r}{F}\right) = \frac{T_{ref} - T}{z}$$

$$\frac{F_r}{F} = 10^{\frac{T-T_{ref}}{z}}$$

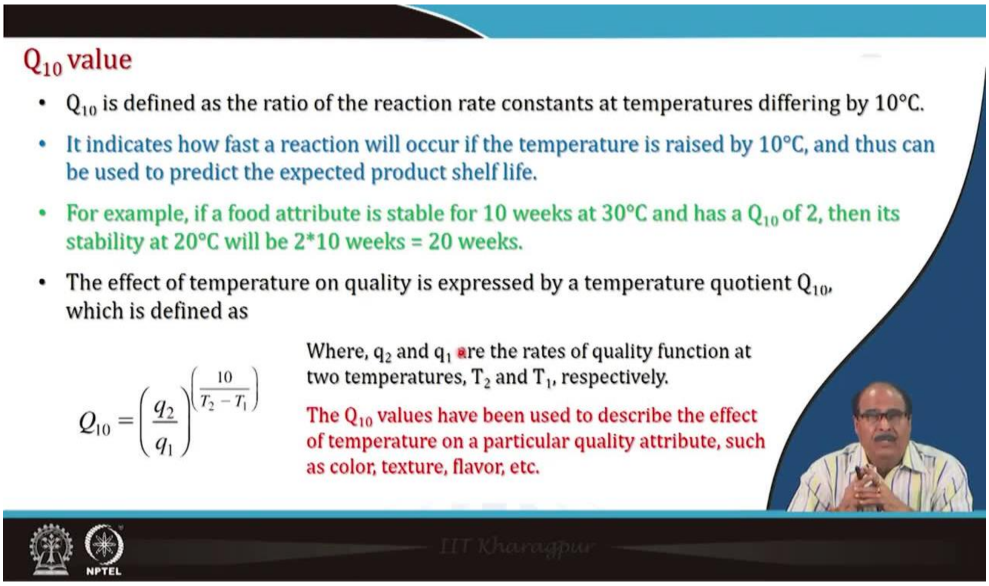
$$L = \frac{F_r}{F} = 10^{\frac{T-T_{ref}}{z}}$$

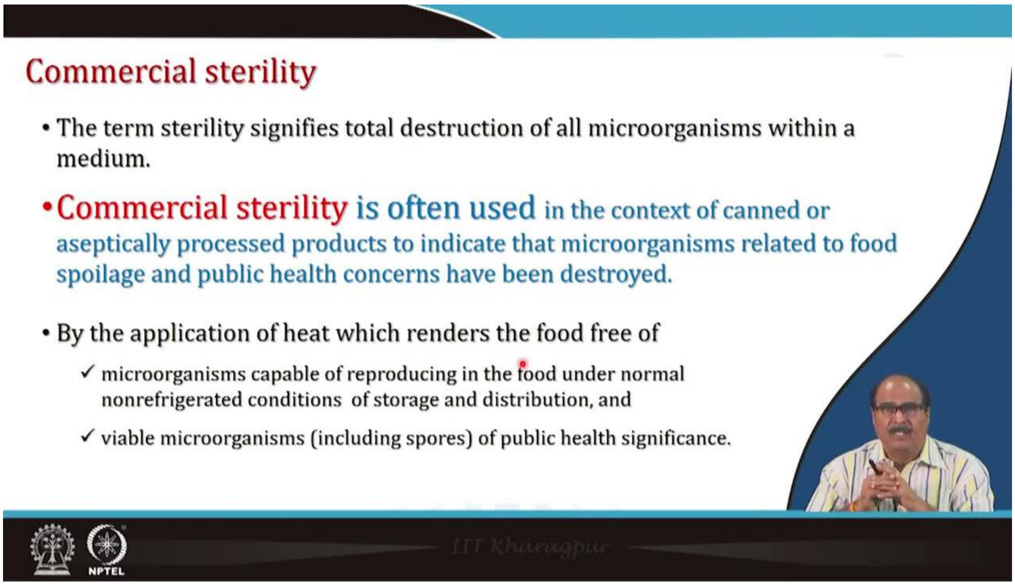
Above equations can be used to compute the thermal death time (F) at any temperature (T) when the F_r, is known at a reference temperature, T_r. In most of cases, the reference temperature T_r is considered as 121 °C. Therefore, the Fr value of any thermal process can be said as the number of minutes of heating at 121 °C required to achieve the same thermal destruction ratio of specified microorganisms.

Q_{10} value is defined as the ratio of the reaction rate constant at temperature differing by 10°C. It indicates how fast a reaction will occur if the temperature is raised by 10°C, and thus can be used to predict the expected product shelf life. For example, if a food attribute is stable for 10 weeks at 30°C and has a Q10 of 2, then its stability at 20°C will be 2*10 weeks = 20 weeks. The effect of temperature on quality is expressed by a temperature quotient Q10, which is defined as

$$Q_{10} = \left(\frac{q_2}{q_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)}$$

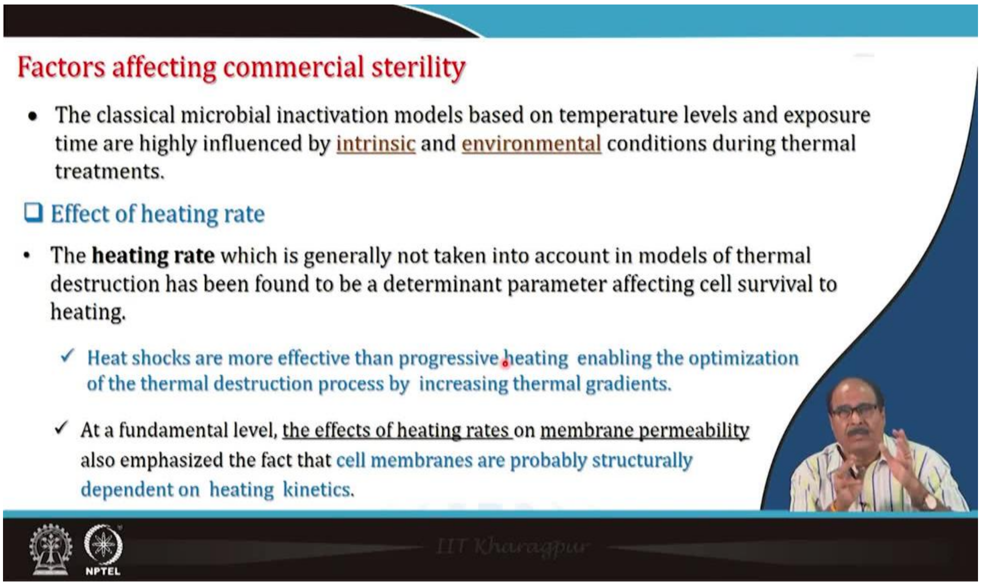
Where, q_2 and q_1 are the rates of quality function at two temperatures, T_2 and T_1, respectively. The Q_{10} values have been used to describe the effect of temperature on a particular quality attribute, such as color, texture, flavor, etc.





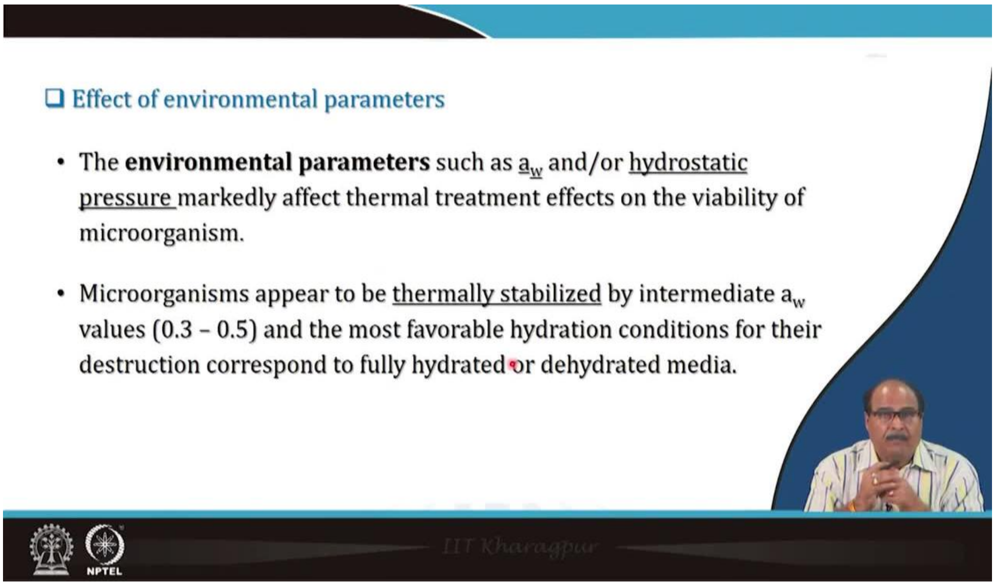
The term commercially sterility signifies total destruction of all microorganisms within a medium. Commercial sterility is often used in the context of canned or aseptically processed products to indicate that microorganisms related to food spoilage and public health concerns have been destroyed, but there are several cases where the product there do exist some thermophilic bacteria like *Clostridium thermosaccharolyticum*, *Bacillus stearothermophilus* and they have much higher resistance than *Clostridium botulinum*, they are ignored.

So, in the commercial processing they are ignored means that but they are taken care of their thermal, there are thermophilic microorganisms they require high temperature may be around 50 - 55 ^{o}C for their growth. So, the current food so, obviously, this is taken care of that these microorganisms survive, their survival is not a problem, but only when they grow and multiply will create problems. So, their growth and multiplication post processing is taken care by appropriate handling, appropriate storage of the products. By the application of heat which renders the food free of microorganism capable of reproducing of the food under normal refrigerated condition of this storage and distribution and viable microorganism including spores of public health significance and that means the commercial sterility.

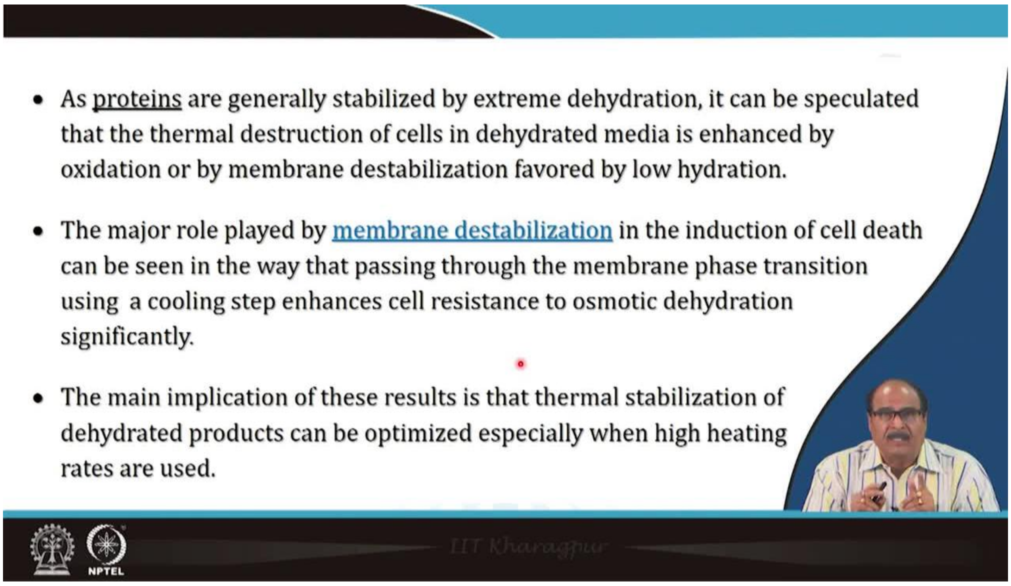


Factors affecting commercial sterility

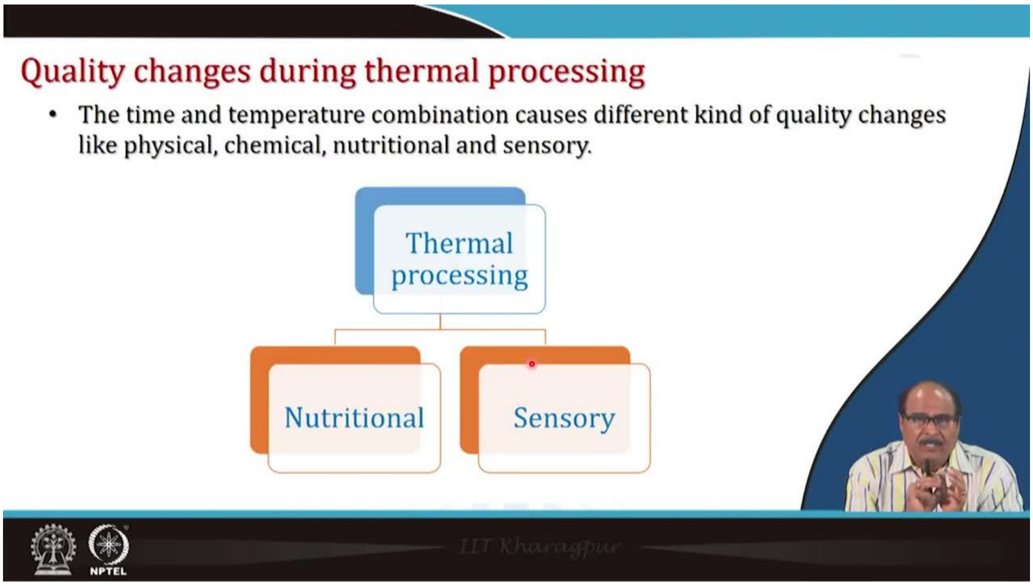
The classical microbial inactivation models based on temperature levels and exposure time are highly influenced by intrinsic and environmental conditions during thermal treatments. The heating rate which is generally not taken into account in models of thermal destruction has been found to be a determinant parameter affecting cell survival to heating. Heat shocks are more effective than progressive heating enabling the optimization of the thermal destruction process by increasing thermal gradients. At a fundamental level, the effects of heating rates on membrane permeability also emphasized the fact that cell membranes are probably structurally dependent on heating kinetics.



Effect of environmental parameter like water activity and other hydrostatic pressure markedly affect the thermal treatment effects on the viability of the microorganisms. Microorganisms appear to be thermally stabilized by intermediate water activity value in the range of 0.3 to 0.5 and the most favorable hydration conditions for their destruction correspond to either fully hydrated or fully dehydrated media.

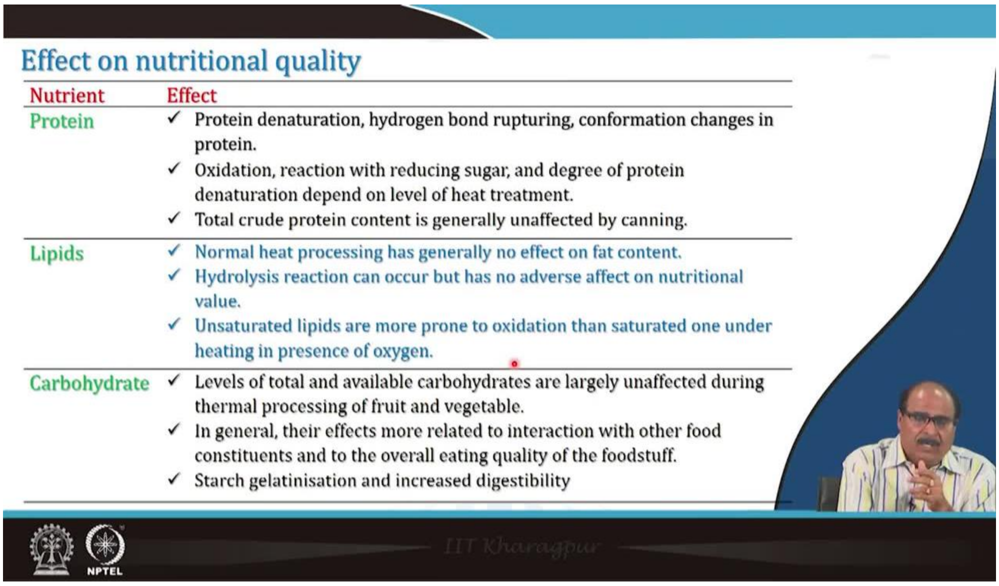


As proteins are generally stabilized by extreme dehydration, it can be speculated that the thermal destruction of cells in dehydrated media is enhanced by oxidation or by membrane destabilization favored by low hydration. The major role played by membrane destabilization in the induction of the cell death can be seen in the way that passing through the membrane phase transition using a cooling step enhances cell resistance to osmotic dehydration significantly. So, the main implication of these results is that thermal stabilization of dehydrated products can be optimized especially when heating rates are used.



Quality changes during the thermal processing

The time and temperature combination causes different kind of quality changes like physical, chemical, nutritional and sensory.



Effects on nutritional quality

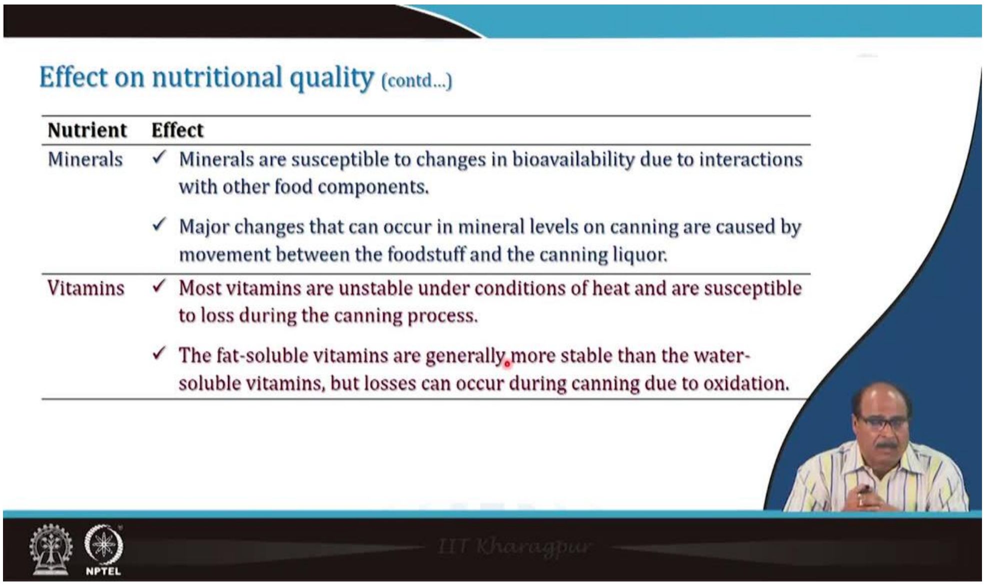
***Protein*:** Protein denaturation, hydrogen bond rupturing, conformation changes in the protein, there will be oxidation reaction with reducing sugar, degree of protein denaturation depends on the level of heat treatment and total crude protein content is generally not affected by canning.

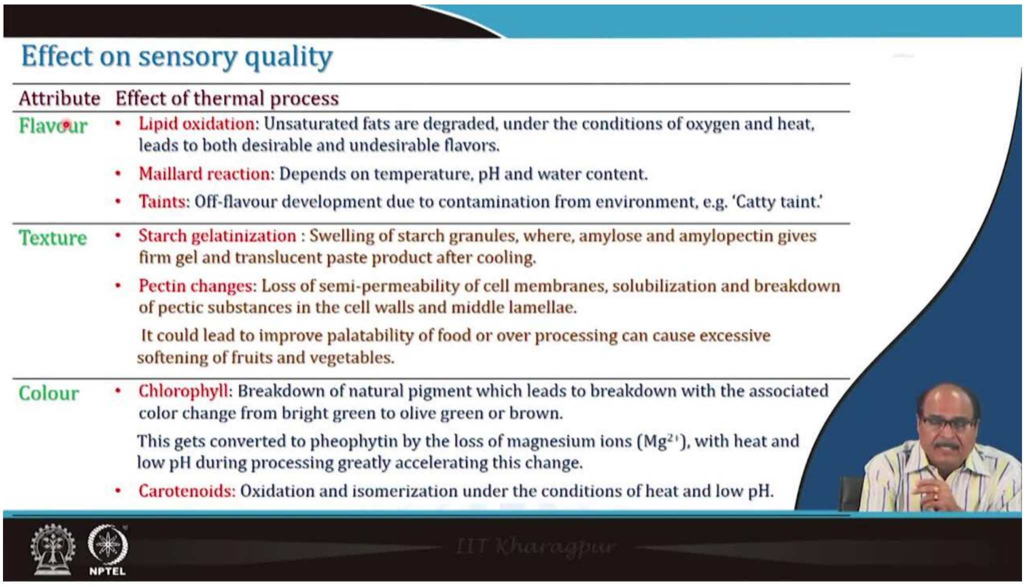
***Lipids*:** Normal heat processing has generally no effect on fat content. Hydrolysis reaction can occur but has no adverse effect on nutritional value. Unsaturated lipids are more prone to oxidation than saturated one under heating in presence of oxygen.

***Carbohydrate*:** Levels of total and available carbohydrates are largely unaffected during thermal processing of fruit and vegetable. In general, their effects more related to interaction with other food constituents and to the overall eating quality of the foodstuff. Starch gelatinisation and increased digestibility.

***Minerals*:** Minerals are susceptible to changes in bioavailability due to interactions with other food components. Major changes that can occur in mineral levels on canning are caused by movement between the foodstuff and the canning liquor.

***Vitamins*:** Most vitamins are unstable under conditions of heat and are susceptible to loss during the canning process. The fat-soluble vitamins are generally more stable than the water-soluble vitamins, but losses can occur during canning due to oxidation.



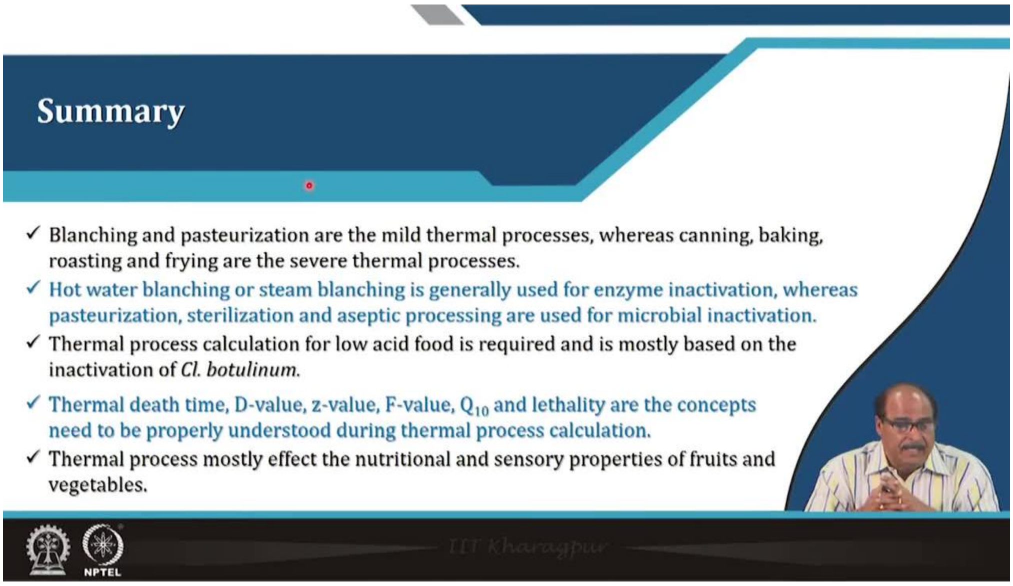


Effects on sensory quality

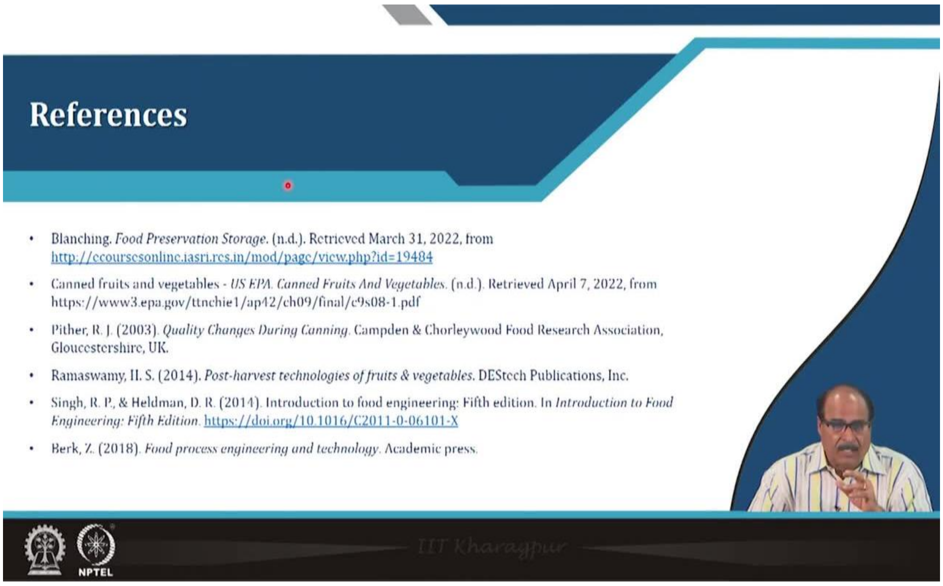
Flavour**:** Lipid oxidation (Unsaturated fats are degraded, under the conditions of oxygen and heat, leads to both desirable and undesirable flavors), Maillard reaction (Depends on temperature, pH and water content), Taints (Off-flavour development due to contamination from environment, e.g. 'Catty taint').

Texture**:** Starch gelatinization (Swelling of starch granules, where, amylose and amylopectin gives firm gel and translucent paste product after cooling), Pectin changes (Loss of semi-permeability of cell membranes, solubilization and breakdown of pectic substances in the cell walls and middle lamellae). It could lead to improve palatability of food or over processing can cause excessive softening of fruits and vegetables.

Colour**:** Chlorophyll (Breakdown of natural pigment which leads to breakdown with the associated color change from bright green to olive green or brown, this gets converted to pheophytin by the loss of magnesium ions (Mg^{2+}), with heat and low pH during processing greatly accelerating this change), Carotenoids (Oxidation and isomerization under the conditions of heat and low pH).



In summary, Blanching and pasteurization are the mild thermal processes, whereas canning, baking, roasting and frying are the severe thermal processes. Hot water blanching or steam blanching is generally used for enzyme inactivation, whereas pasteurization, sterilization and aseptic processing are used for microbial inactivation. Thermal process calculation for low acid food is required and is mostly based on the inactivation of *Cl. botulinum.* Thermal death time, D-value, z-value, F-value, Q_{10} and lethality are the concepts need to be properly understood during thermal process calculation. Thermal process mostly effect the nutritional and sensory properties of fruits and vegetables.



These are the references for further study.