Post Harvest Operations and Processing of Fruits, Vegetables Spices and Plantation Crop Products
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Lecture 51
Packaging Technology

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Hello everyone, we are in the module 11 of the course. In this five lectures of 11th week, we will discuss various aspects of packaging and storage of horticultural and plantation crop product. What is packaging technology.

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In this, we will study the properties of packaging materials like mechanical, thermal, optical and barrier properties. And we will discuss about the self-life of packaged foods including how to predict shelf-life in packaging, packaged foods.

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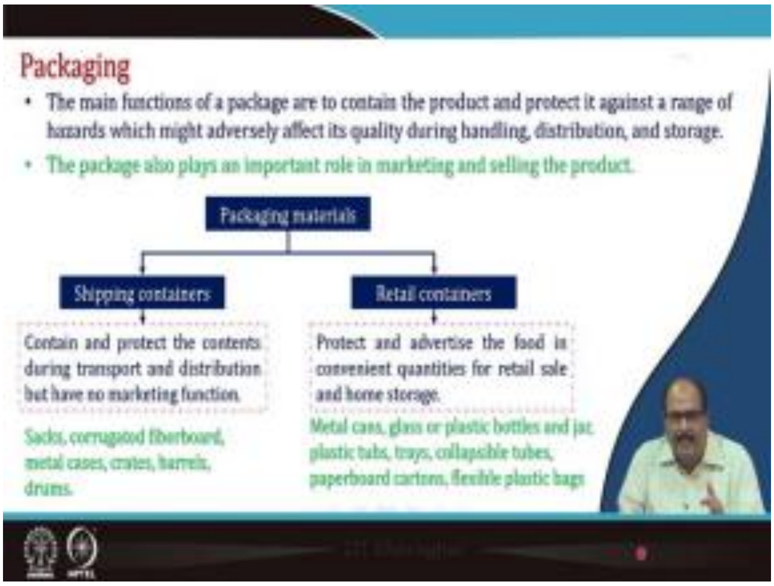

We discussed the main function of a package are to contain the product and protect it against a range of hazards, which might adversely affect quality during handling, distribution, and storage. The package plays an important role in marketing and selling of the produce or the product. The various forms of packaging materials are used to prepare various shipping containers or retail containers.

The shipping containers contain and protect the contents during transport and distribution. But they have no function in the marketing of the products like for example, sacks, corrugated fiber, metal cases, crates, barrels, drums, etc. On the other hand, retail containers protect the food as well as advertise the food in convenient quantities for retail sale and home storage. Examples of the retained containers include metal cans, glass or plastic bottles, jar, plastic tube, trays, etc.

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The various types of packaging materials like wood, textile, metal, glass, even flexible films, plastic containers, paper, and board, etc are used for making different types of either shipping containers or even the household retail containers. The various details of these containers as well as packaging materials used for these containers and also the packaging methods and equipment, we have elaborated in lecture 19 and 20. So, I request all of few to please refer to the lecture 19 and 20 for these details.

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In this lecture today particularly, we will discuss about the properties of the packaging materials. When you are keeping any food in a packet whether it is a fruit vegetable or any such commodity, then basically this packaging material performs certain functions like it offers protection, containment, convenience, as well as it helps in transporting, communicating like the labeling of the packet. It gives information about the food which is packed inside.

So, basically in the packaging, we create some sort of wall that is a packaging wall between the food and the environment. And therefore, this packaging material and packaging wall performs various functions. Depending upon the interactions among the package, package material, food and the surrounding environment or environment inside the packet like for example, oxygen.

Depending upon the permeability of the packaging material, the packaging wall may allow the oxygen to go out. And if oxygen goes out inside the packet, it may catalyze oxidation reaction color flavor as well as this oxygen is used for respiration. When the food respires, fruits and vegetables respire, they release carbon dioxide. There may be carbonation loss and the carbon dioxide changes the environment inside and then it may be reduce the shelf-life.

The packaging material should have good oxygen permeability, carbon dioxide permeability, water vapor permeability. When the food is dehydrated food and put in the package, we want that it should not regain moisture or it should not lose moisture etc.

Similarly, light transmission food is kept inside a package. So, to protect them from the light, the packaging walls will provide different protection. A component migration might be happened from the packaging material into the food products. So, there are various interactions between the food, package and the environment.
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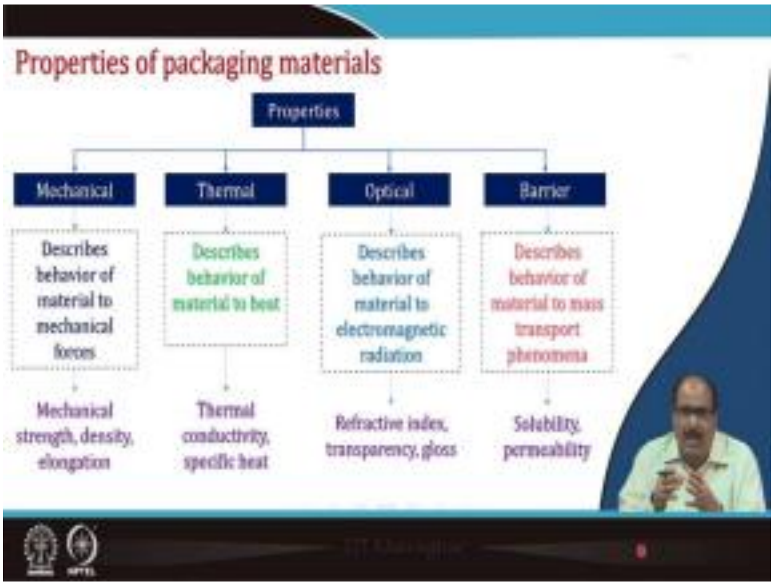

So, as per the requirement, we try to control the interactions. Sometimes, the beneficial interaction you want to encourage and the undesirable interactions want to discourage and want to stop and accordingly the packaging type and properties of packaging material play very important role in this direction.

Packaging material should have a proper property like, mechanical property which describes the behavior of material to mechanical forces like mechanical strength, density, elongation, etc. Thermal properties describe behavior of material to heat like thermal conductivity, specific heat, etc. Optical properties describe behavior of material to electromagnetic radiation such as refractive index, transparency and glass. Barrier property describes behavior materials of glass like solubility, permeability, etc.

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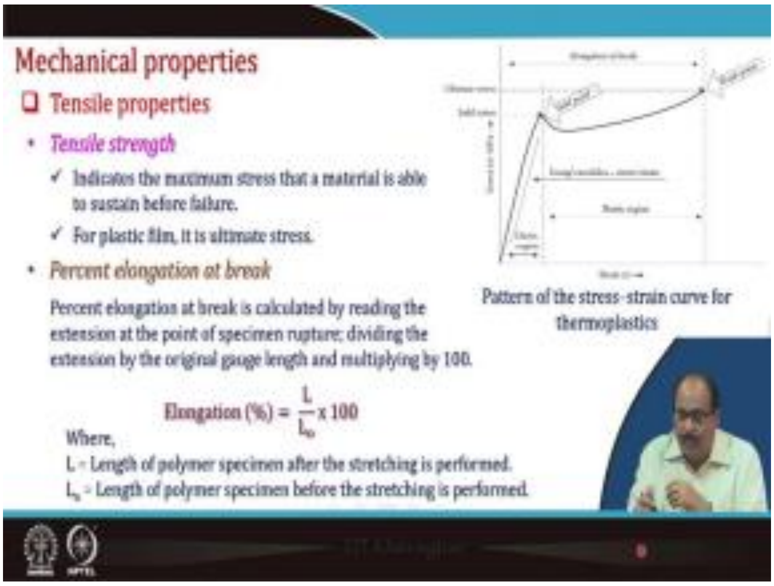

These properties play very important role and one has to choose a packaging material of desirable property, depending upon what results is required, what type of the food material or fruits or vegetable is being packaged. So, in the mechanical property, first important property is tensile strength,

Pattern of stress strain curve for thermoplastic is shown here in this figure. This tensile strength indicates the maximum stress that a material is able to sustain before failure, for plastic films it is the ultimate stress.

Percent elongation at a break is calculated by reading the extension at the point of specimen

$$Elongation\ (\%) = \frac{L}{L_o} \times 100$$

Where elongation percent is equal to L/L_0 multiplied by 100. And you can see here in this figure different points are shown.

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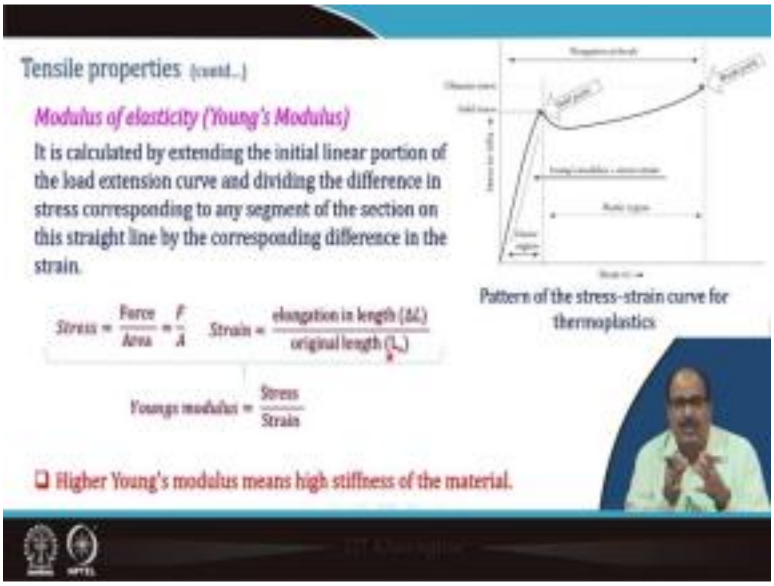

Then, modulus of elasticity or Young's modulus, it is calculated by extending the initial linear proportion of the load extension curve by dividing the difference in the stress corresponding to any segment of the section. Stress is force divided by area and strain is the elongation in length divided by original length. Young modulus is the stress by strain.

$$Stress = \frac{Force}{Area} = \frac{F}{A}$$

$$Strain = \frac{elongation\ in\ length\ (\Delta L)}{original\ length\ (L_o)} = \frac{F}{A}$$

$$Youngs\ modulus = \frac{Stress}{Strain}$$

So, high Young’s modulus means high stiffness of the material.

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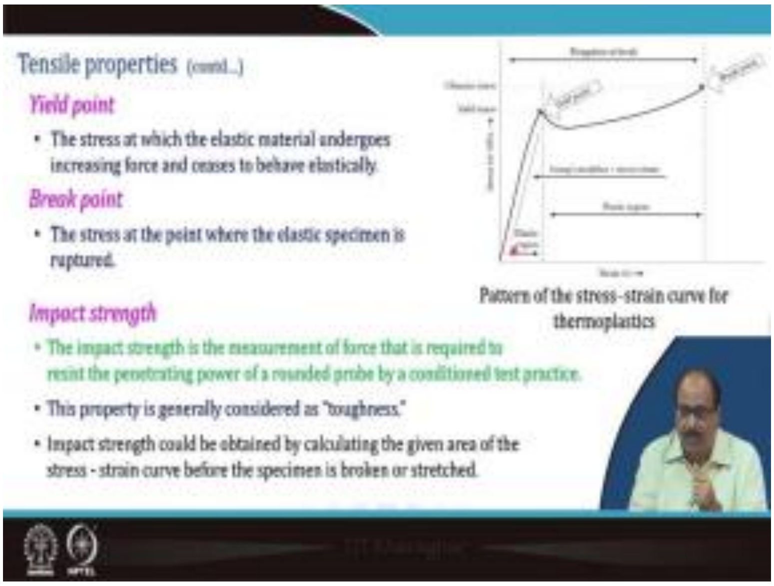

Then yield point, the stress at which the elastic material undergoes increasing force and ceases to behave elastically. Break point is the point when the stress at the point where the elastic specimen is ruptured. And impact strength is the measurement of force that is required to resist the penetration power of a rounded probe by a conditioned test practice. This property is generally considered as "toughness". Impact strength could be obtained by calculating the given area of the stress-strain curve before the specimen is broken or stretched you can see that it is the break point here. There is the yield point here in this graph, that is, so the elastic region.

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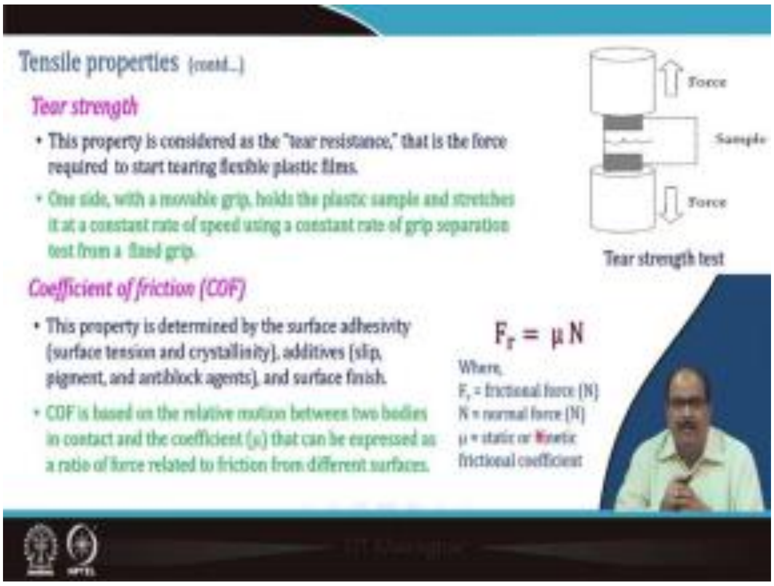

Tear strength, this property is considered as the "tear resistance" that is the force required to start tearing flexible plastic films. One side, with a movable grip, holds the plastic sample and stretches it at a constant rate of speed using a constant rate of grip separation test from a fixed grip. Coefficient of friction, this property is determined by the surface adhesivity that is surface tension and crystallinity are additives which are may be slip pigment and anti-block agents and surface finish. The coefficient of friction is based on the relative motion between two bodies in contact and the coefficient (μ) that can be expressed

$F_r = \mu N$

where N is the normal force, F_r is the frictional force, μ is the static or kinetic frictional coefficient.

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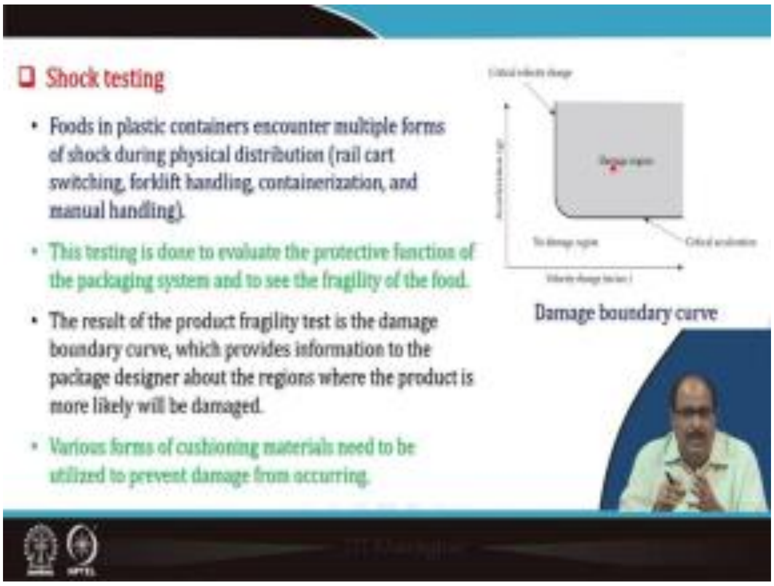

Shock testing, foods in plastic containers encounter multiple forms of shock during the physical distribution (rail cart switching, forklift handling, containerization, and manual handling). Barriers are depending upon the type of the packet size and packet type of the foods. So, this testing is done to evaluate the protective functions of the packaging system and to see the fragility of the food. The result of the product fragility test is the damage boundary curve, which provides information to the package designer about the regions where the product is more likely will be damaged. You can see here, in this region there will be no damage region, this is the critical acceleration if you give a critical velocity. Various forms of cushioning material need to be utilized to prevent damage from occurring.

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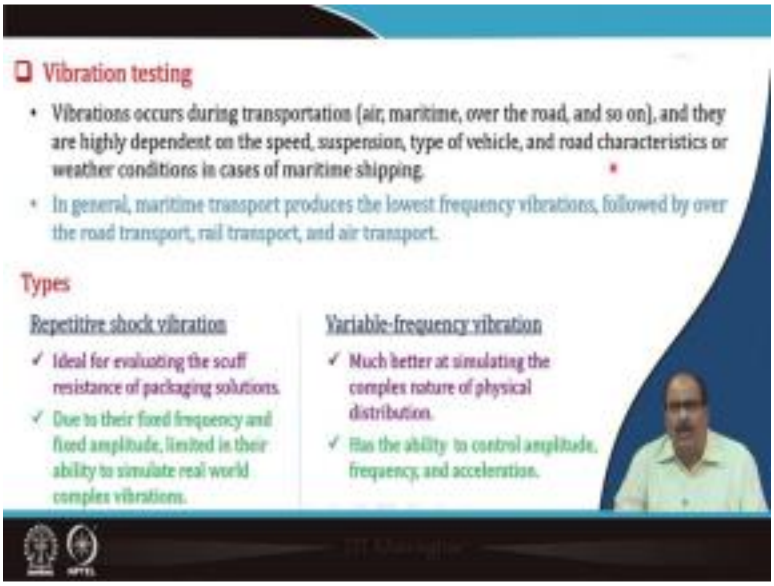

Vibration testing, vibration occurs during transportation whether it is air transportation, maritime transposition, or on the road transportation, etc. These vibrations are highly dependent on the speed suspensions, type of vehicle, and road characteristics or weather conditions in case of maritime shipping etc. In general, maritime transport produces, the lower frequency vibrations, followed by over the road transport, rail transport, and air transport.

So, the types of vibrations may be repeated to shock vibration, it is the ideal for evaluating the shock resistance of packaging solutions. Due to their fixed frequency and fixed amplitude, limited in their ability to simulate the real word competitive vibrations. The variable frequency vibration testing is much better at simulating the complete nature of the physical distribution, it has the ability to control amplitude, frequency and acceleration.

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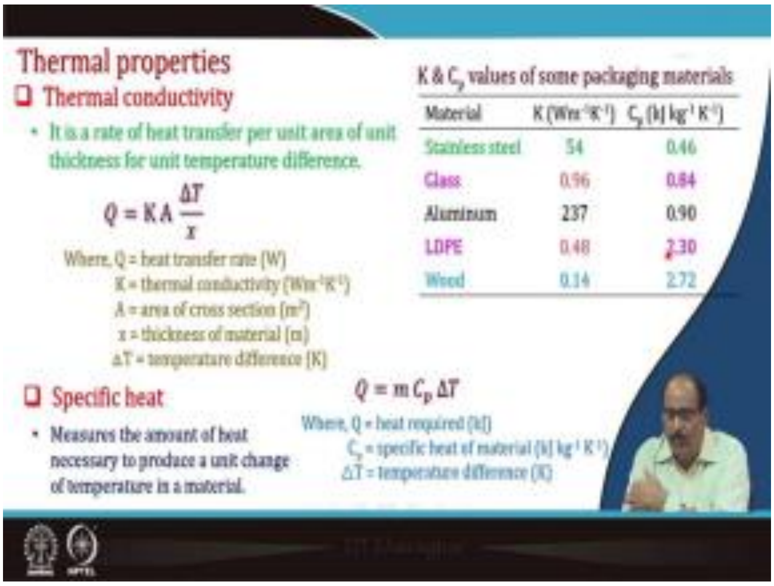

Then, let us discuss the thermal properties of the packaging materials and in this, thermal conductivity and specific heat are two important properties. Thermal conductivity is a rate of heat transfer per unit area of unit thickness per unit temperature difference.

$$Q = KA\frac{\Delta T}{x}$$

Q is equal to K A delta T by x where K is the thermal conductivity, A is the area of cross section, x is thickness of the material and delta T is the temperature difference, Q is the heat transfer rate. Q is equal to m C_p delta T, C_p is the specific heat of the material, Q is the heat required, and delta T is the temperature difference.

$$Q = mC_p\Delta T$$

So, a specific heat measures the amount of heat necessary to produce a unit change of temperature in a material.

So, in this table, the specific heat and thermal conductivity of different packaging materials are given like stainless steel. You can see, it has the highest higher thermal conductivity K value. So, it has a lower specific heat. So, wood which has a higher specific heat like 2.72, it has a lower thermal conductivity. Aluminum you see it has the maximum thermal conductivity and it has a lowest specific heat.

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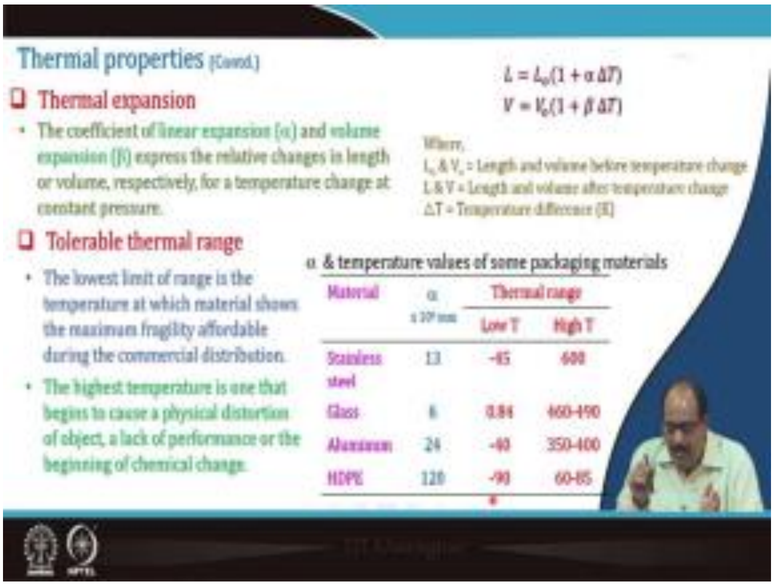

Then, thermal expansion, there is coefficient of linear expansion, alpha, and volume expansion, beta, express the relative change in length or volume, respectively, for a temperature change at a constant pressure.

$$L = L_o(1 + \alpha\Delta T)$$

$$V = V_o(1 + \beta \Delta T)$$

where L and V are the length and value after temperature change and L_0 and V_0 are the length and value before temperature change and delta T is the temperature change.

Tolerable thermal range, the lowest limit of range is the temperature at which material shows the maximum fragility affordable during the commercial distribution. The highest temperature is one that begins to cause a physical distortion of the object, a lack of performance or the beginning of the chemical change. The temperature is another important property which is required, which should be considered while selecting a packaging material. For example, you see the stainless steel its alpha that is the linear expansion is 13 multiply 10 to the power 6 mm whereas the temperature range, the lowest range is minus 45 to about 600 degrees.

This HDPE, it has alpha 120 and the lowest temperature is minus 90 and highest temperature is 60 to 80 degree and these temperatures are generally in degree Celsius.

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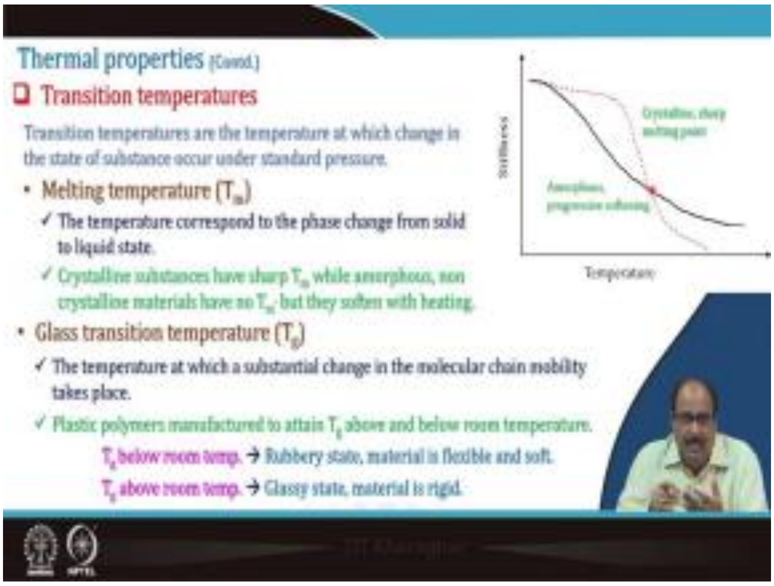

Transition temperatures are the temperature at which change in the state of the substance occur under standard procedure. The graph of stiffness versus temperature graph. And this side it shows that amorphous progressive softening or crystalline sharp melting point. So, in transition temperature, there are two: melting temperature (T_m) and the glass transition temperature (T_g).

So, the melting temperature is the temperature correspond to the phase change from solid to liquid state. Crystalline substances, have a sharp melting point, while the amorphous or non-crystalline materials have no melting point, but they soften with the heating.

Glass transition temperature is the temperature at which is substantial change in the molecular chain mobility takes place. Plastic polymers manufacture to attend T_g above and below room temperatures. T_g below room temperature, rubbery state, material is flexible and soft.

T_g above room temperature, glassy state and it will be a rigid material.

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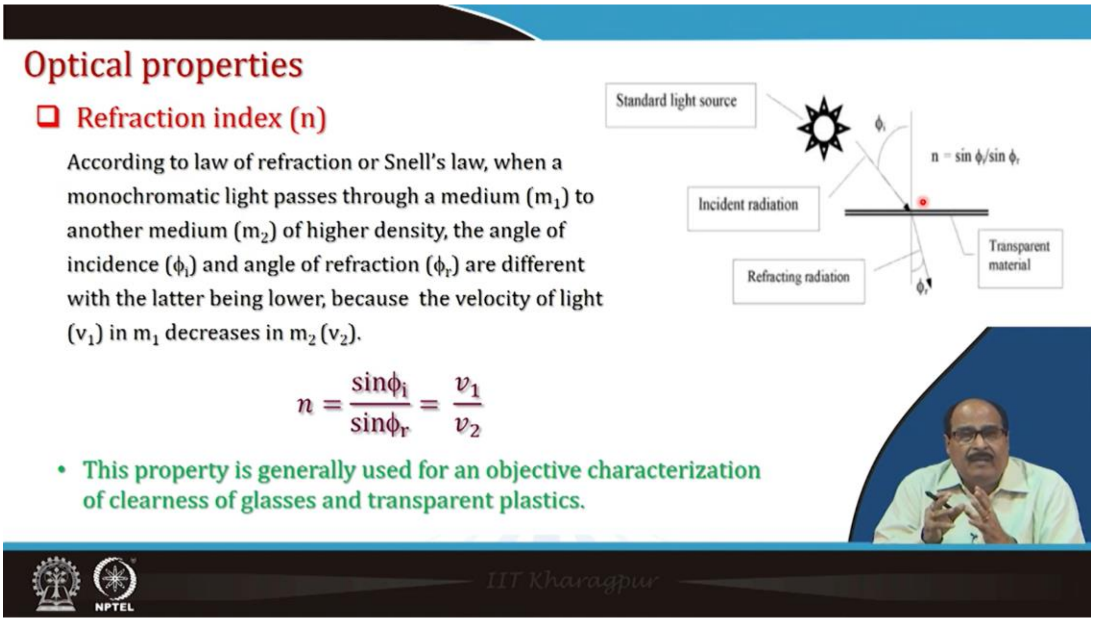

Then, we will discuss optical properties, the refraction index is an important optical property and it is according to the law of refractions or Snell's law. A monochromatic light passes through a medium m_1 to another medium m_2 of higher density. The angle of incidence (Φ_i) and the angle of refraction (Φ_r) are different with the latter, that is the angle of refraction being lower because the velocity of light (v_1) in m_1 decreases in m_2 (v_2).

So, the n that is the refractive index is equal to sin Φ_i by sin Φ_r and is equal to v_1 by v_2.

$$n = \frac{\sin \emptyset_i}{\sin \emptyset_r} = \frac{v_1}{v_2}$$

So, this property is generally used for an objective characterization of clearness of the glass and transparent plastics.

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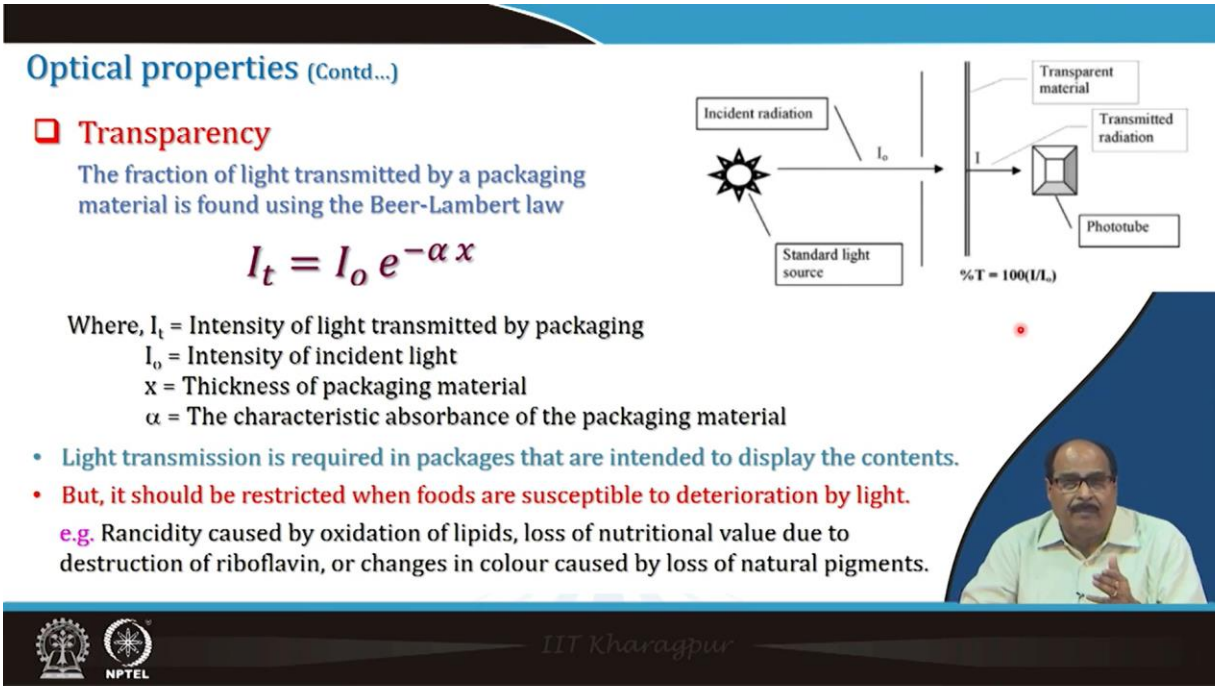

Transparency, the fraction of light transmitted by a packaging material is found using the Beer-Lambert law that is I_t. Here you see that there is a transparent material and the incident radiation is going I_0 intensity from the standard the light source, when it falls that light is light transmitted I.

$$I_t = I_o exp^{(-\alpha x)}$$

where, I_t is the intensity of light transmitted by packaging and x is the thickness of the packaging material and alpha is the characteristic absorbance of the packaging material.

So, light transmission is required in packages that are intended to display the containers. Many a times we want that inside the material whatever is packed in which form, it should be visible to the consumer. So, in such cases, it should be restricted when the food are susceptible to deterioration by light.

For example, rancidity caused by oxidation of lipid, loss of nutritional value due to destruction of riboflavin, or changes in the color caused by loss of natural pigments etc. So, these are light catalyzed reaction. So, accordingly the material which are susceptible to these reactions they should be packed in opaque or non-transparent containers or packaging material.

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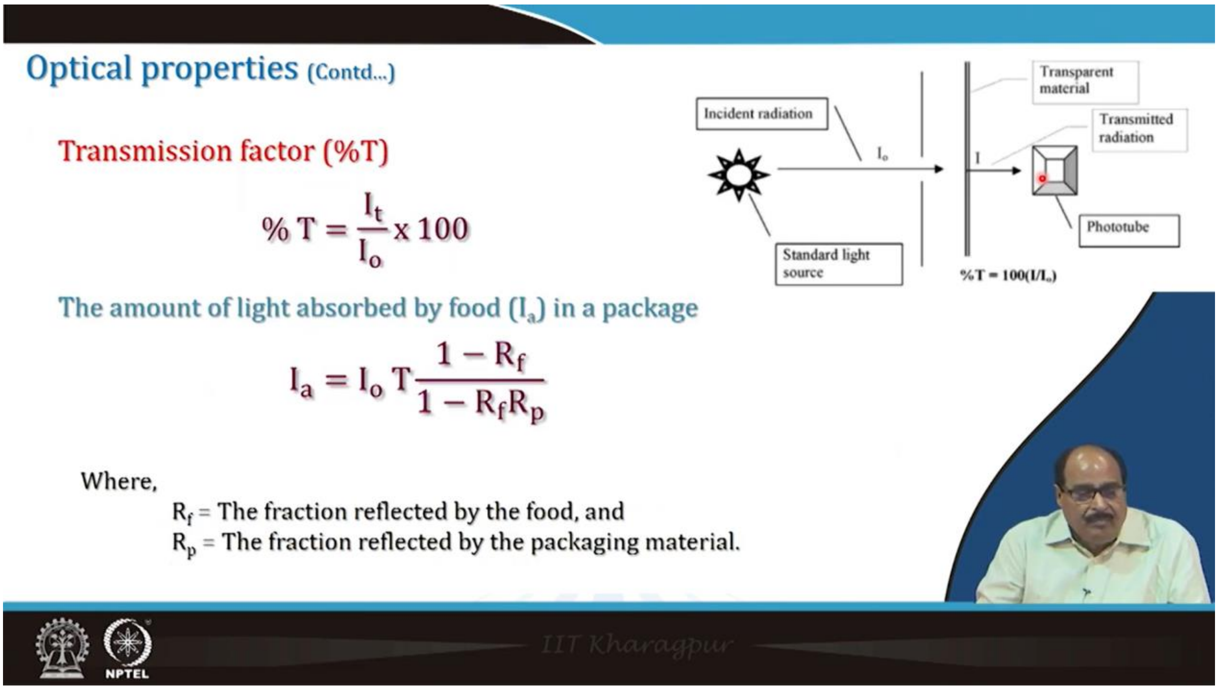

So, transmission factor that is the percent T is calculated as,

$$\%T = \frac{I_t}{I_o} \times 100$$

that is the amount of light absorbed by the food

$$I_a = I_o T \frac{1 - R_f}{1 - R_f R_p}$$

where R_f is the fraction reflected by the food and R_p is the fraction reflected by the packaging material you can see here is the figure I_0 is falling and then I is going.

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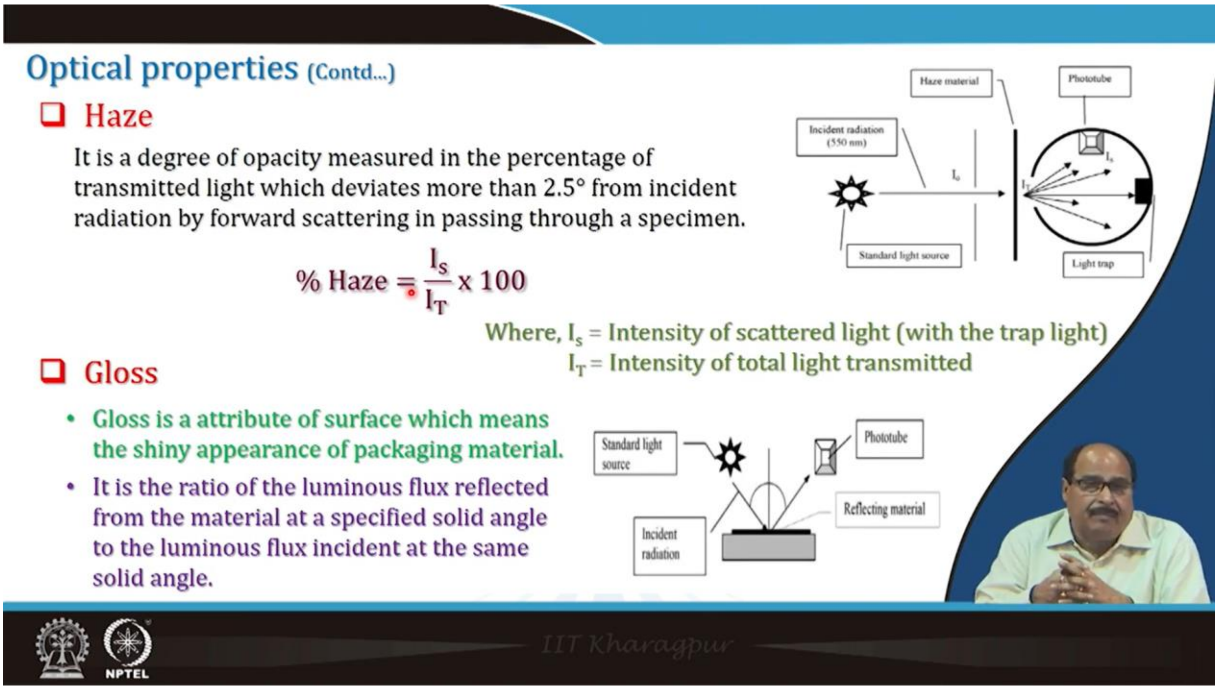

Then haze is another important property, optical property, it is a degree of opacity measured in the percentage of transmitted light, which deviates more than 2.5 degree from incident radiation by forward scattering in passing through a specimen.

$$\%Haze = \frac{I_S}{I_T} \times 100$$

where I_s is the intensity of the scattered light with the trap light, whereas the I_t is the intensity of the total light transmitted.

Gloss is the attribute of surface which means the shiny appearance of packaging material, it is the ratio of the luminous flux reflected from the material at a specified solid angle to the luminous flux incident at the same solid.

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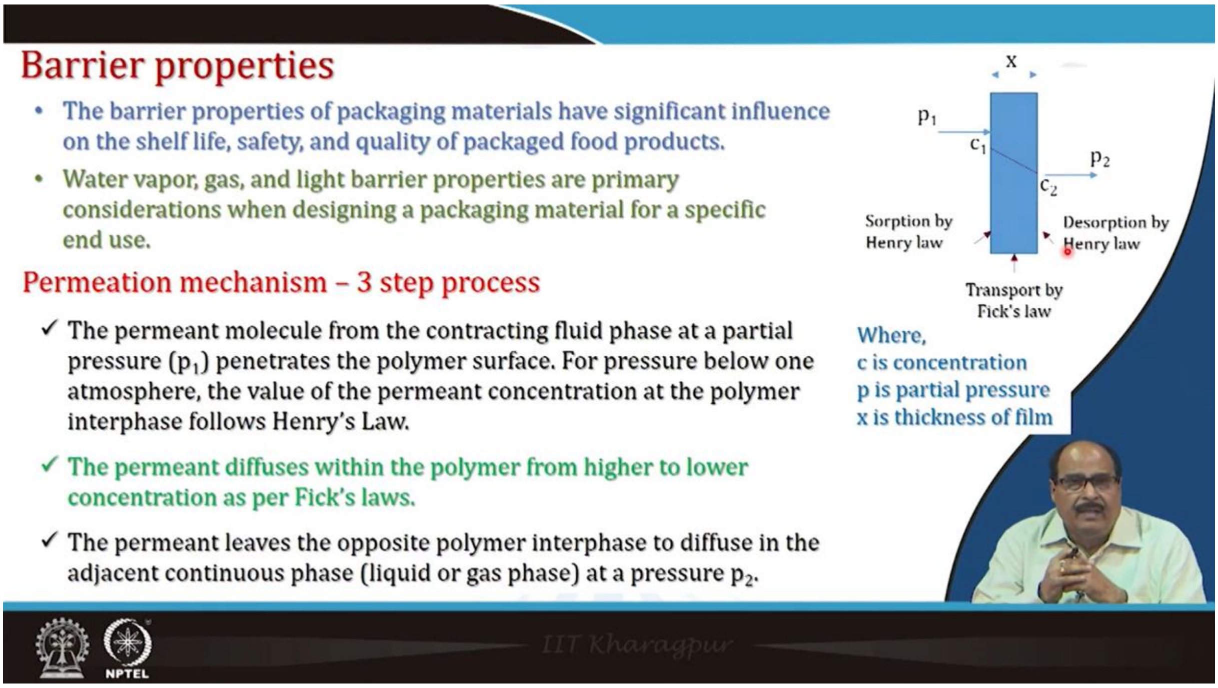

The barrier properties of the packaging materials have significant influence on the shelf-life, safety and quality of the packaged food properties. Water vapor, gas, and light barrier properties, these are the primary consideration when designing a packaging material for a specific end use. So, this barrier properties particularly in fruits and vegetable packaging they are much important.

So, the permeation mechanism which is a three-step process, that is the permeate molecule from the contracting liquid phase at a partial pressure P_1, penetrates through the polymer surface. For pressure below one atmosphere, the value of the permeate concentration at the polymer interface follows Henry's Law. The permanent diffuses within the polymer from higher to lower concentration as per the Fick's Law. And the permeant leaves the opposite polymer interface to diffuse in the adjacent continuous phase either liquid phase or gas phase at a pressure P_2 that is outside. Here is the C_1 and here is the C_2. C the concentration, P is the partial pressure and X is the thickness of the film.

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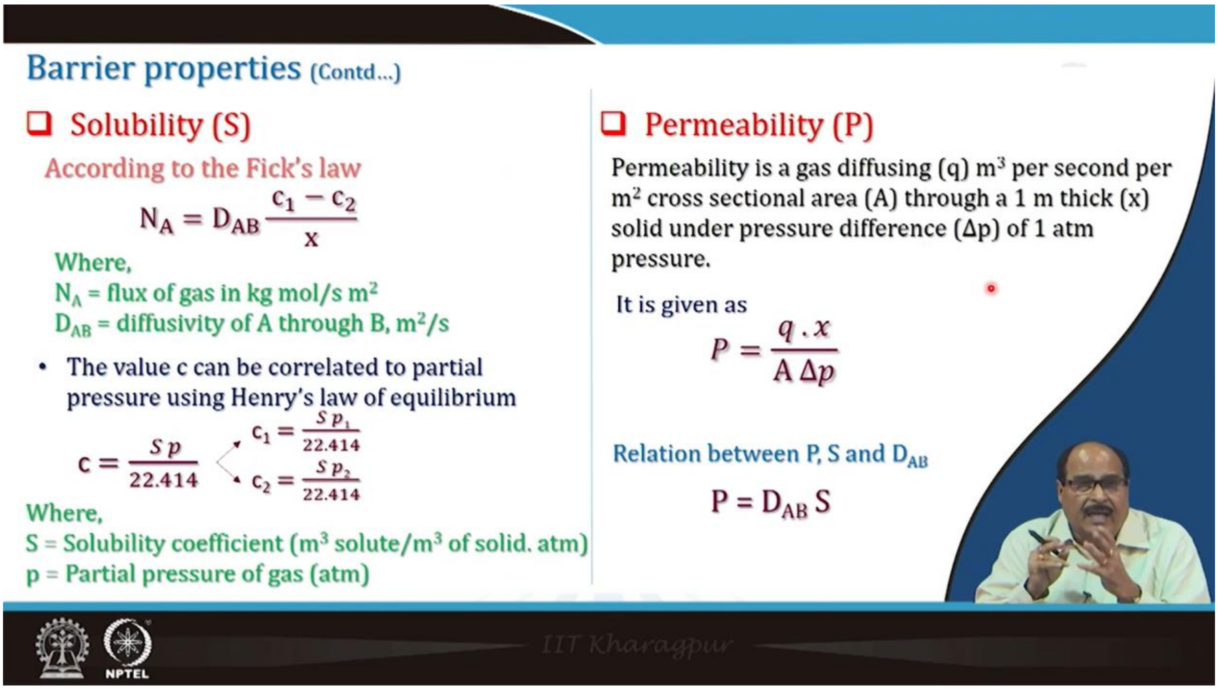

Then solubility according to the Fick's Law,

$$N_A = D_{AB}\frac{C_1 - C_2}{x}$$

where N_A is the flux of the gas and D_{AB} is the diffusivity of A through B. The value of c can be correlated to partial pressure using Henry's Law of equilibration that is

$$c = \frac{S_p}{22.414}$$

$$c_1 = \frac{S_{p1}}{22.414}$$

$$c_2 = \frac{S_{p2}}{22.414}$$

. S is the solubility coefficient and P is the partial pressure of the gas.

Permeability P is a gas diffusing that is a per cubic meter per second per square meter, cross sectional area A through 1 meter thick (x) solid under pressure difference of delta P of 1 atmosphere pressure. And it is given

$$P = \frac{qx}{A\Delta p}$$

So, the relationship between the P that is permeability and D_{AB} that is the divisibility of A through B and the solubility coefficient S is

$$P = D_{AB}S$$

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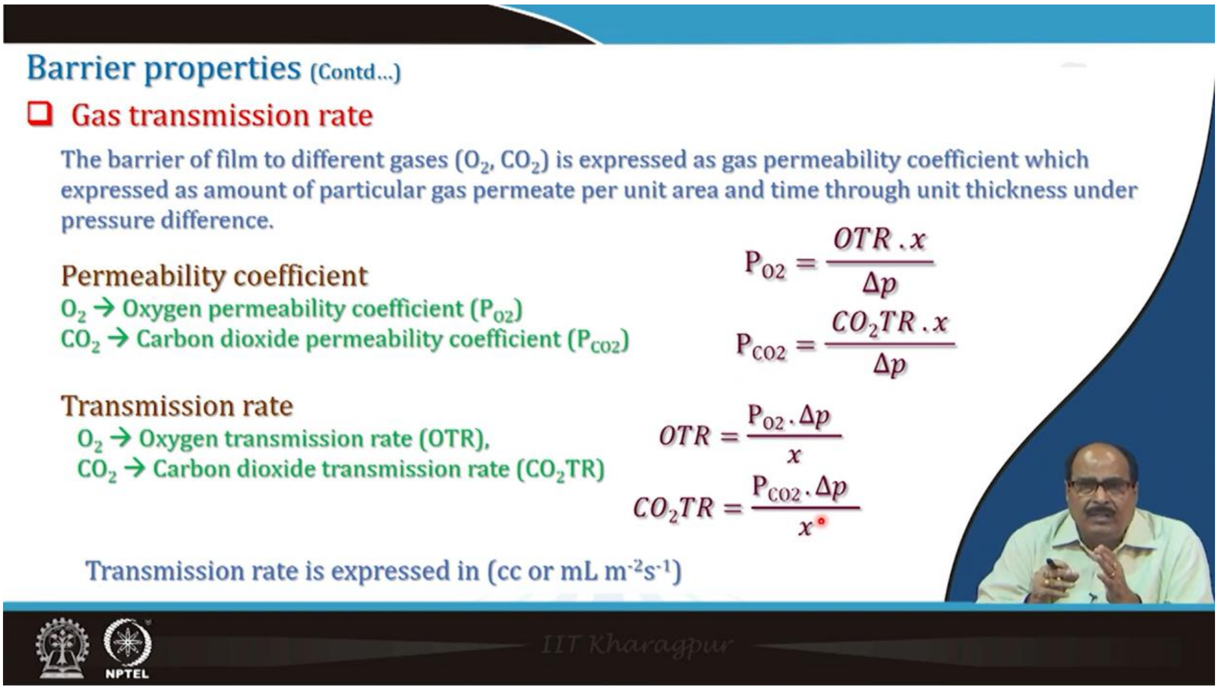

Gas transmission rate, the barrier of the film to different gases O_2 and CO_2 is expressed as per permeability coefficient which expresses as amount of particular gas permeate per unit area and the time through the unit thickness under the pressure difference. So, the permeability coefficient, P_{O2} for oxygen and P_{CO2} for carbon dioxide, similarly transmission rate is written as OTR for oxygen transmission and CO_2TR for the carbon dioxide.

$$P_{O2} = \frac{OTR\ x}{\Delta p}$$

$$P_{CO2} = \frac{CO_2TR\ x}{\Delta p}$$

Similarly, OTR and CO_2TR can be calculated, if you know the P_{O2} and partial pressure difference and the thickness of the material.

$$OTR = \frac{P_{O2}\Delta p}{x}$$

$$CO_2TR = \frac{P_{CO2}\Delta p}{x}$$

And these data the gas transmission rate data, they play very important role in selecting the type of the packaging material as well as the deciding the amount of the absorbent or emitters etc, which are required to be kept inside the package in the smart packaging system or active packaging system.

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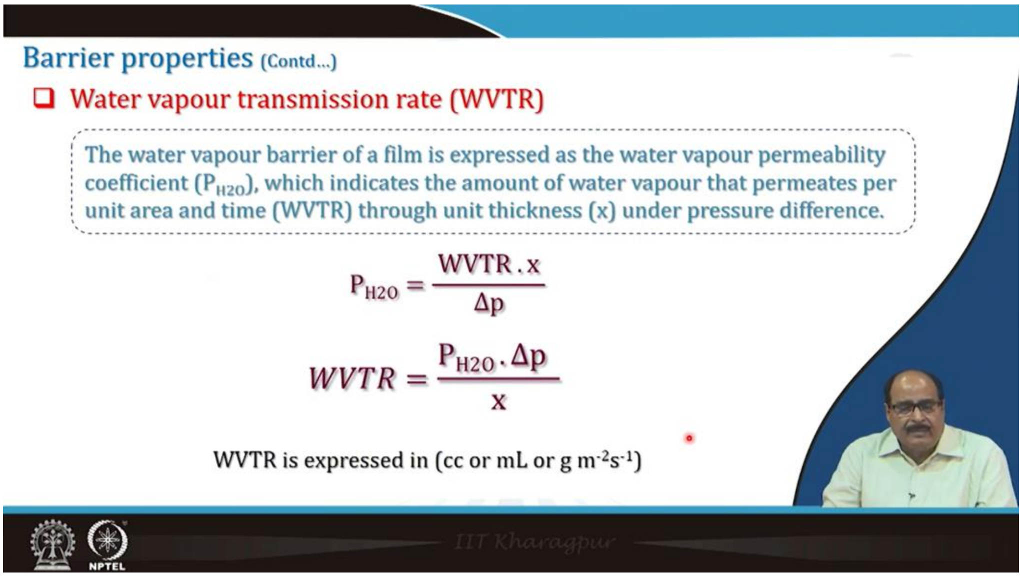

And water vapor transmission rate that is WVTR, the water vapor barriers of a film is expressed as the water vapor permeability coefficient, which indicates the amount of water vapor that permeates per unit area and time through unit thickness under pressure difference,

$$P_{H2O} = \frac{WVTR\ x}{\Delta p}$$

$$WVTR = \frac{P_{H2O}\ \Delta p}{x}$$

So, WVTR is generally expressed in either cc or ml or gram per square meter per second.

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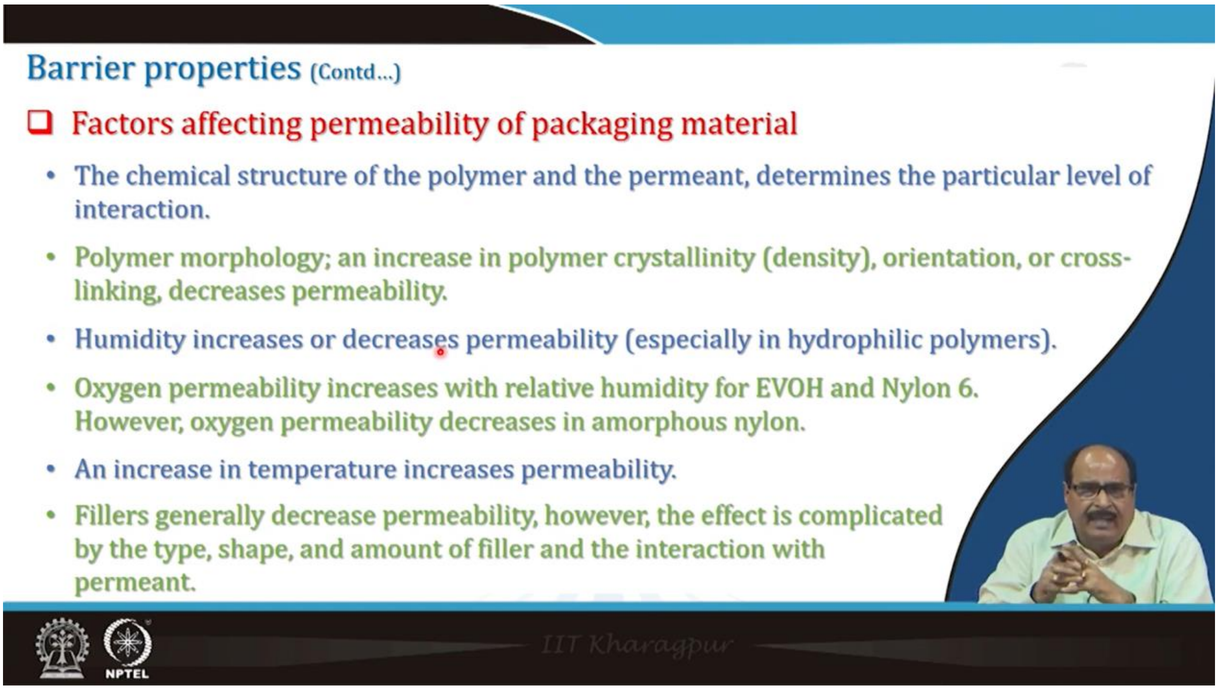

So, there are various factors which influence the permeability of a packaging material like the chemical structure of the polymer and the permeant, determines the particular level of interaction. Polymer morphology that is increase in the polymer crystallinity, there is density, orientation or cross linking decrease the decrease permeability. Humidity increases or decreases the permeability especially in hydrophilic polymers. Oxygen permeability increases with the increase in relative humidity for ethylene EVOH are Nylon 6.

However, oxygen permeability decreases in amorphous Nylon. An increase in the temperature increases the permeability. Fillers generally decreases the permeability however, the effect is complicated by the type, shape, amount of filler, and the interaction with the permeant.

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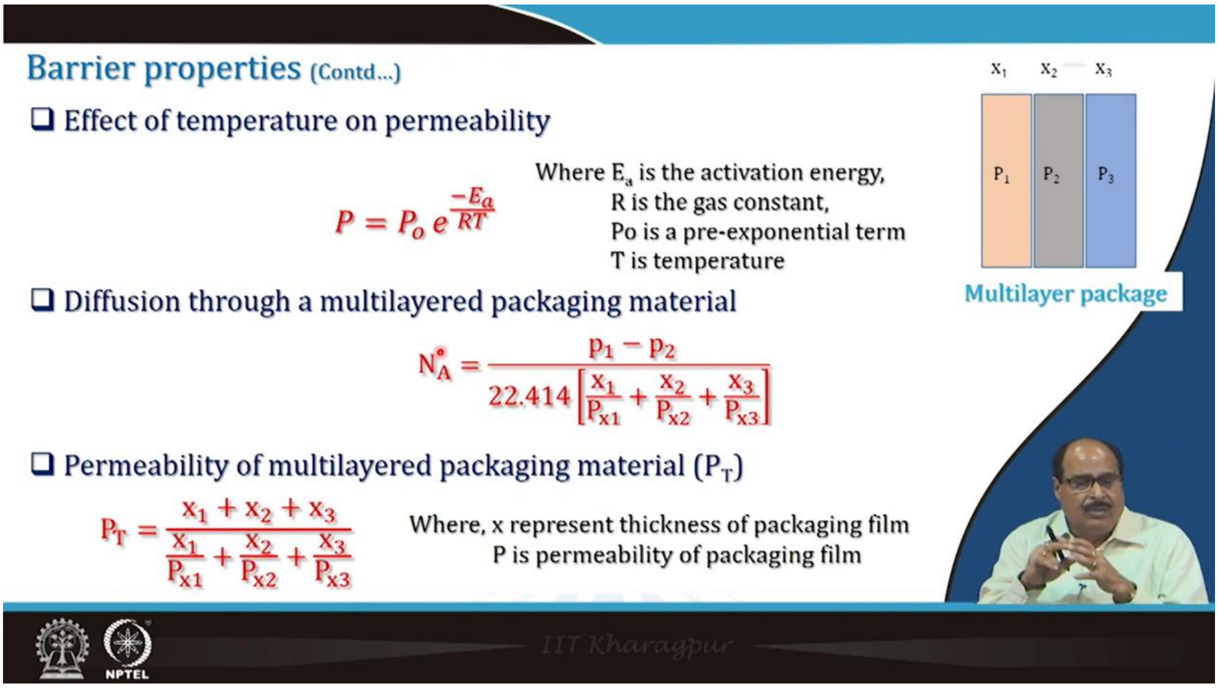

So, these here the effect of temperature on permeability and is expressed by

$$P = P_o exp^{\frac{-E_a}{RT}}$$

Diffusion through a multi-layer packaging material is described by

$$N_A = \frac{p_1 - p_2}{22.414\left[\frac{x_1}{P_{x1}} + \frac{x_2}{P_{x2}} + \frac{x_3}{P_{x3}}\right]}$$

Permeability of a multi layered packaging material that

$$P_T = \frac{x_1 + x_2 + x_3}{\frac{x_1}{P_{x1}} + \frac{x_2}{P_{x2}} + \frac{x_3}{P_{x3}}}$$

where X represent the thickness and T is the permeability of the packaging material.

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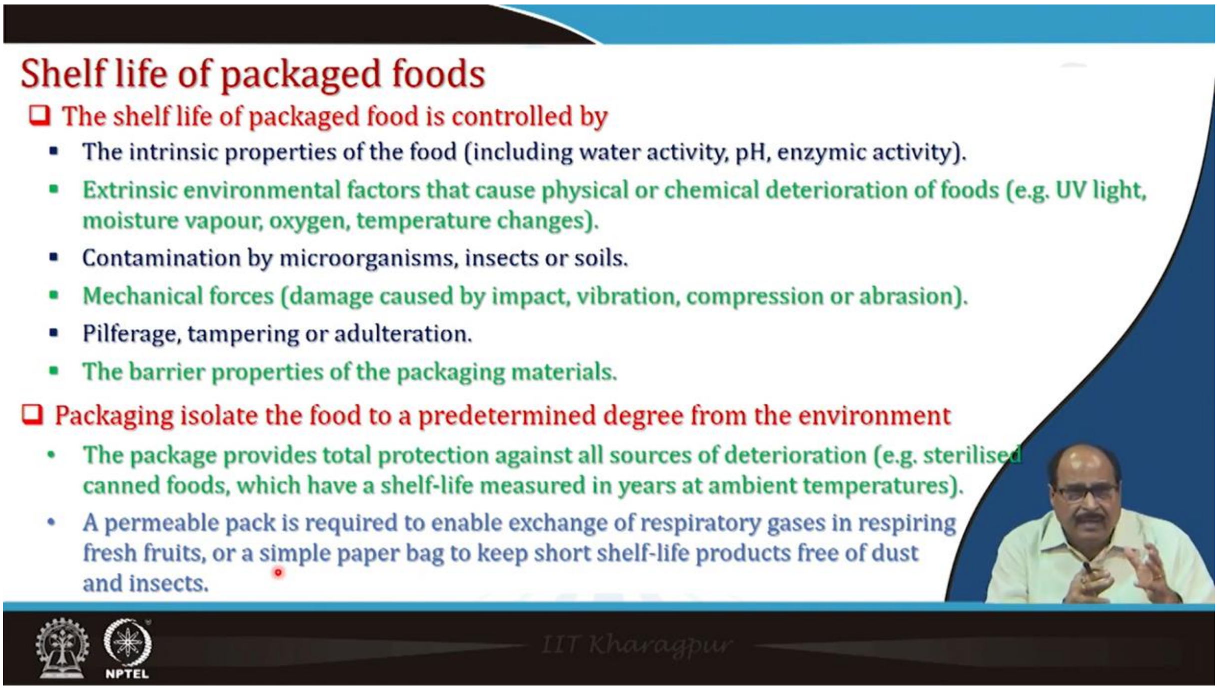

The shelf-life of packaged food is controlled by the intrinsic property of the food. Extrinsic environment factor is contamination by microorganism insect or soil. Mechanical forces like damage caused by the impact vibration, compression. Pilferage, tempering or adulteration are the various barrier properties of the packaging field. Packaging isolates the food to a predetermined degree from the environment as I discussed earlier also. So, the package provides total protection against all sources of deterioration, for example, sterilized canned food, which have a shelf-life of even several years at ambient conditions. A permeable pack is required to enable exchange of respiratory gases in respiring fresh fruits or a simple paper bag to keep short shelf-life products free from dust and insects.

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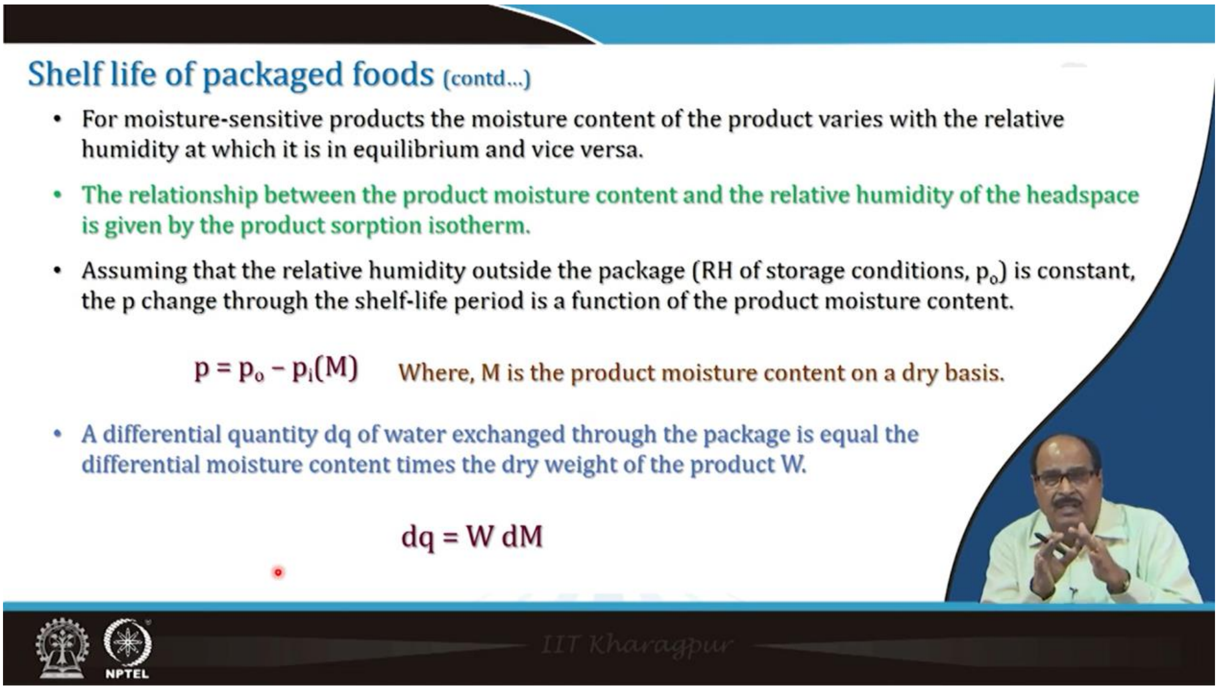

For moisture sensitive products, the moisture content of the product varies with the relative humidity at which it is in equilibrium and vice versa. The relationship between the product of moisture content and the relativity of the headspace is given by the products sorption isotherms. Assuming that the relative humidity outside the package (RH of storage conditions, p_o) is constant, where the p change through the shelf-life period is a function of the product moisture content.

$$p = p_o - p_i(M)$$

where M is the product moisture content on a dry basis and it is assumed that the RH of the storage environment is constant.

A differential quantity that is the d_q of water exchanged through the package is equal to the differential moisture content times the dry weight of the product W.

$$dq = WdM$$

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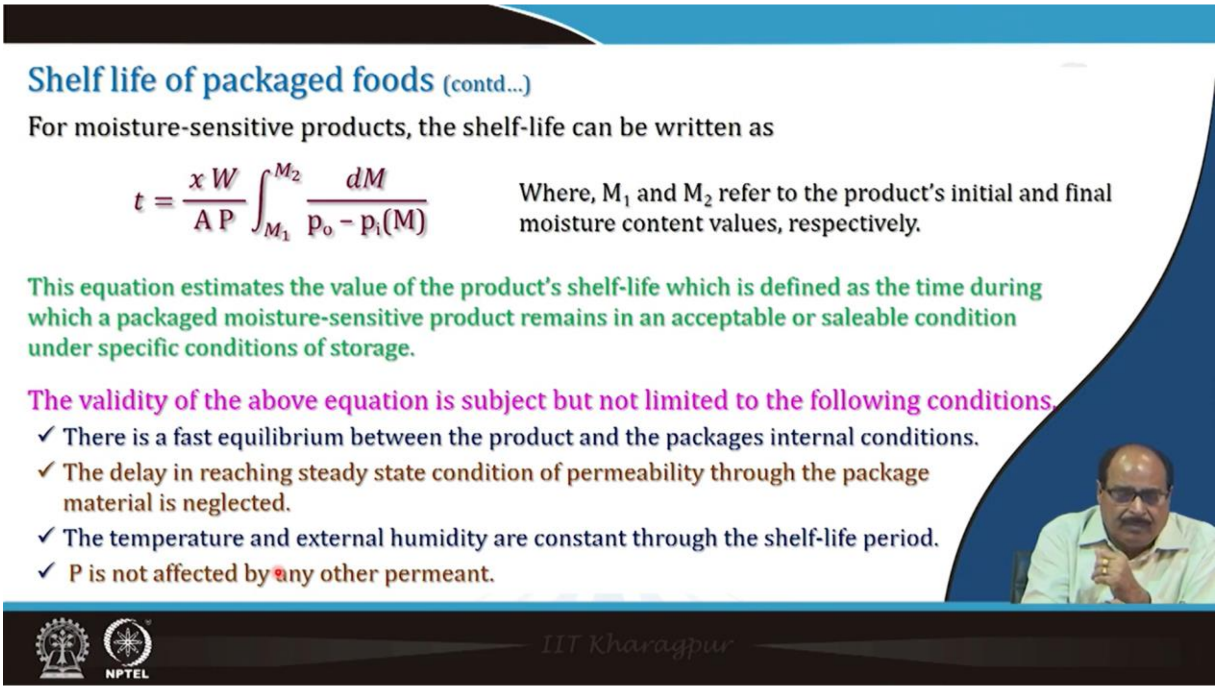

For moisture-sensitive foods, the shelf-life can be written as

$$t = \frac{xW}{AP}\int_{M_1}^{M_2}\frac{dM}{p_o - p_i(M)}$$

refer to the products initial and final moisture content respectively. This equation estimates the value of the product's shelf-life, which is defined as the time during which a packaged moisture-sensitive product remains in an acceptable or saleable condition under a specific condition of storage.

The validity of the above equation is subject but not limiting to the following condition such as there is a fast equilibrium between the product and the package of internal conditions. The delay in reaching steady state condition of permeability through the package material is neglected. The temperature and external humidity are constant through the shelf-life period. P is not affected by any permeant.

So, similarly like other models, this model is based upon the moisture content. Similarly, other similar models can be formed, they can be design or worked out or on the base of other suitable characteristics, the shelf-life can be predicted.

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The driving forces for innovation in food packaging are the consumer lifestyle, consumer demand for products of convenience, taste good, sale, wholesome, and nutritious, which create need and opportunity for innovation in the food packaging. Then, value, higher benefits may also be achieved by enhancing functions of the packaging, which satisfies the unmet needs of the consumers. The good packaging may also help the manufacturer or producer to earn more profit.

Innovative food packaging can effectively protect against microbial contamination and product tempering. Stringent regulation drives research and development related to food packaging safety issues such as, migration of unwanted compounds from package to the food and recycling of packaging materials.

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So, finally I will conclude this lecture, I will summarize that packaging is a very important concept particularly for fruits, vegetables, spices. The fruits and vegetables that are highly respiring material and even they respire inside the packaging. In the next lectures, 2-3 lectures, we will discuss in detail about the respiratory behavior. How various active packaging, smart packaging can be done to use the shelf-life extension.

So, but for all these points the selection of the appropriate packaging material, appropriate the packaging that the material characteristics property that is how is the mechanical strength, when this packet is being transported, it is loaded, unloaded, how it will be at the packet should not tear during the transportation is important. How, it will absorb the shock? How, it will permit a transmit, the flow of gases from inside to outside, outside to inside and then light, all these influence the shelf-life as well as not the product inside the packet and value. So, this would be properly (collected) designed. Taking into consideration of the food characteristics, the intended shelf-life and the packaging material properties.

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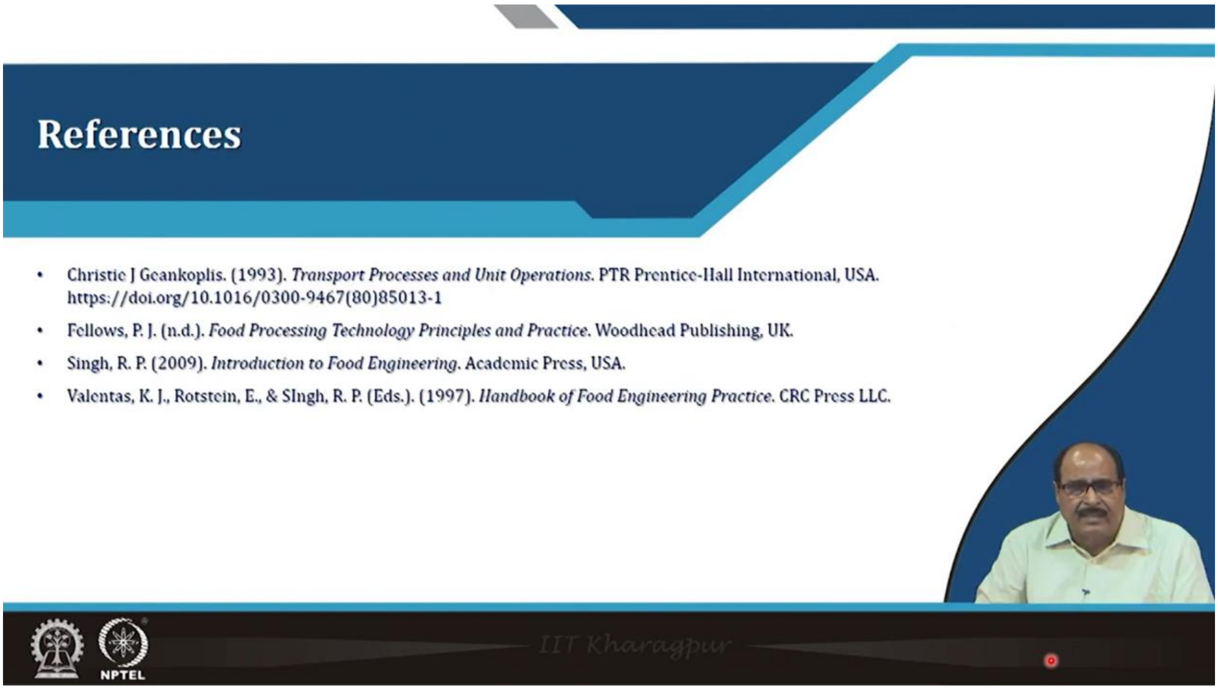

So, this I come to the end of this lecture. These are the references which has been used in this lecture. Finally, thank you very much for your hearing.