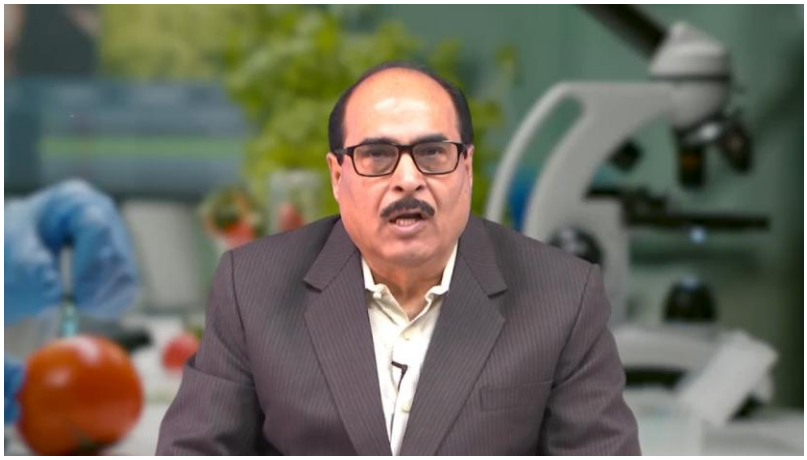
**FOOD SCIENCE AND TECHNOLOGY**

**Lecture46**

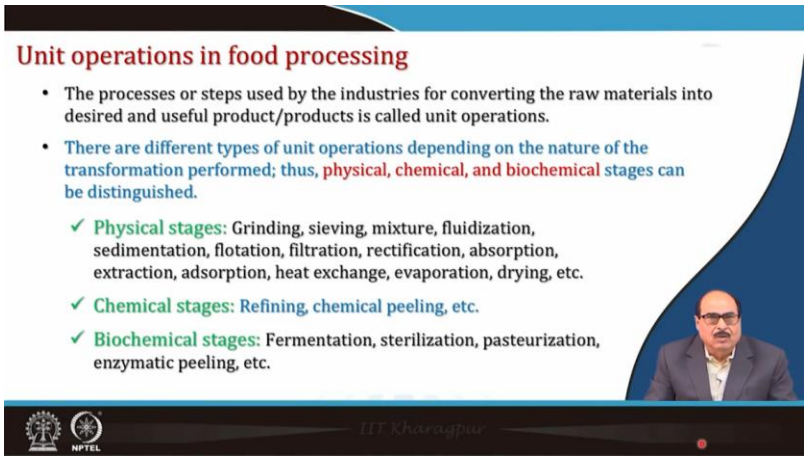
## Lecture 46: Food Process Principles and Operations



Hello friends, namaste.

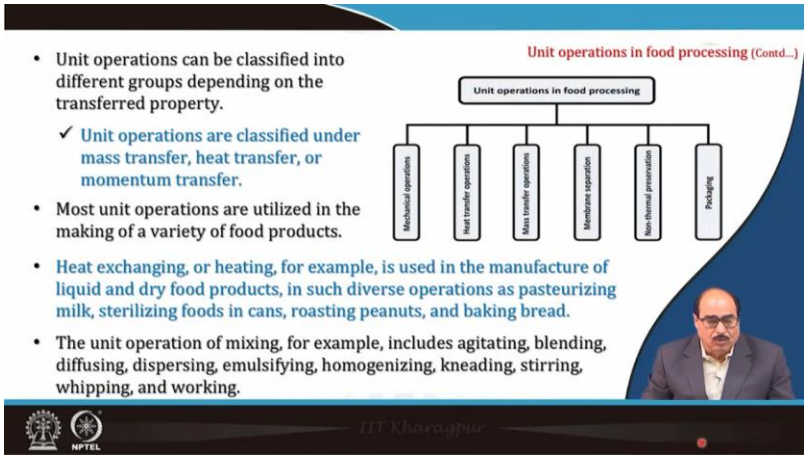

We are now in the tenth module of this course, and the next five classes of this module will be devoted to food formulation and processing.


In today's lecture, we will talk about food process principles and operations. We will discuss what the various unit operations in food processing, material handling, and cleaning, batch versus continuous processes, and towards the end, we will also talk briefly about post-processing operations.




So, let us see what unit operations in food processing are. You know, the processes used by industries for converting raw materials into desired and useful products are called unit operations or a process. There are different types of unit operations depending upon the nature of the transformation performed, that is, what the material is and what type of transformation we are doing, and therefore, the physical, chemical, and biochemical stages can be distinguished in the processing. Physical unit operations, or you can say unit operations, physical stages in the unit operations may be grinding, sieving, mixing, fluidization, flotation, filtration, drying, heat exchange, evaporation, etc., so many processes. Similarly, chemical stages may be refining, chemical peeling, etc. Biochemical

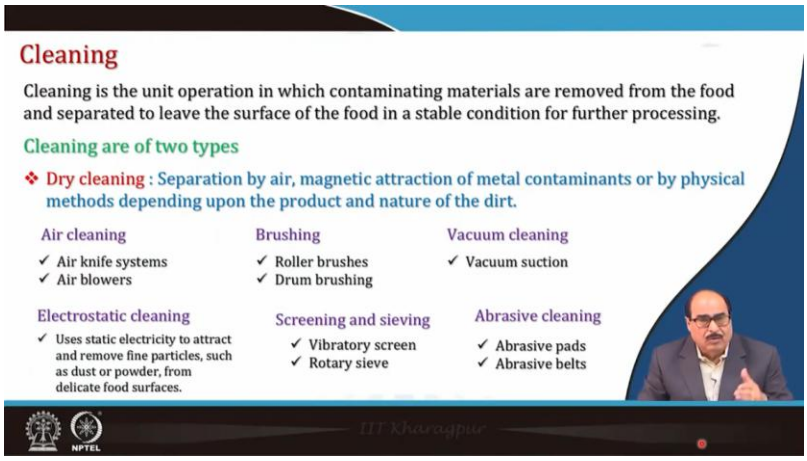
stages may include fermentation, sterilization, pasteurization, enzymatic peeling, and so on.




So, the unit operations can be classified into different groups depending upon the transferred property. That is, unit operations are classified under mass transfer, heat transfer, momentum transfer, or some other processes like even membrane processes or other units. And most of these unit operations are utilized in making a variety of food products.

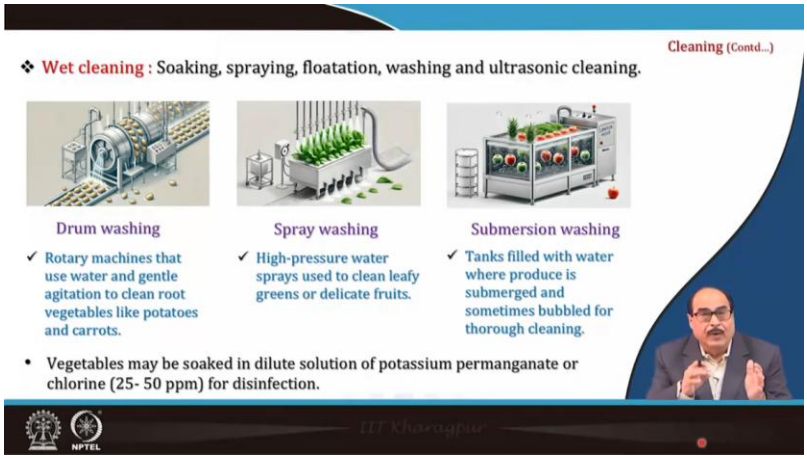
Heat exchange or heating, for example, is used in the manufacturing of liquid and dry food products in such diverse operations as pasteurizing milk, sterilizing food in cans, roasting peanuts, baking bread, and so on. There are several examples. Similarly, the unit operation of mixing may include agitating, blending, diffusing, dispersing, emulsifying, homogenizing, kneading, stirring, whipping, and working, among many other operations.

So, let us talk about material handling. At the time of harvest or slaughter, most foods are likely to contain contaminants, depending on the agronomical conditions or other conditions prevailing in the farm, process, or value chain. The material may have various contaminants or components that might be inedible or have variable physical characteristics, such as shape, size, color, and so on. Efficient material handling is the organized movement of materials in the correct quantities, to and from the correct place, accomplished with minimal time, labor, wastage, and expenditure. More importantly, with maximum safety, the material should remain safe during handling, and it should be conveyed, handled, transferred, or transported in good quality and safe conditions to the manufacturing unit. Equipment used for material handling may include conveyors, such as belt conveyors and screw conveyors, as well as lifters and elevators like forklifts, bucket elevators, etc. Other examples include palletizers, containers for material storage, and automated guided vehicles for transportation inside the warehouse.



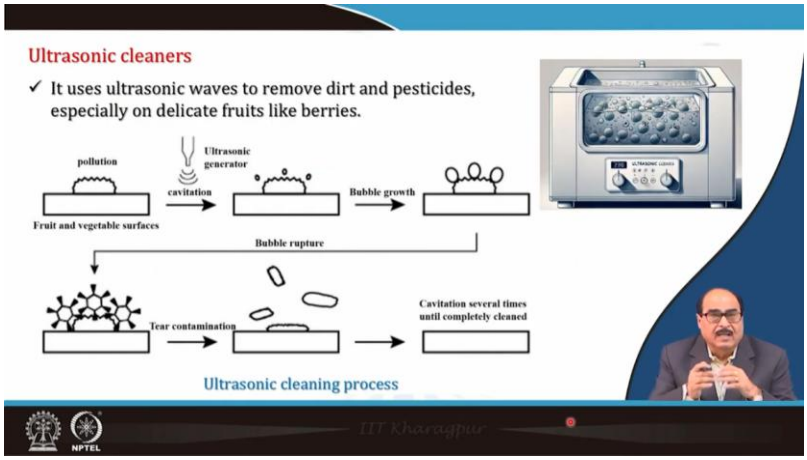

Now, let us briefly discuss several important unit operations one by one, starting with cleaning. Cleaning is the unit operation in which contaminants are removed from the food and separated to leave the surface of the food in a stable condition for further processing. Cleaning may be of two types. One may be a dry cleaning like separation by air, magnetic attraction of metal contaminants or by physical methods depending upon the product and nature of the dirt. It may include, dry cleaning may include air cleaning, brushing, vacuum cleaning or even electrostatic cleaning, which uses static electricity to attract and remove fine particles such as dust or powders from delicate food surfaces.

Even screening and sieving or abrasive cleaning cleaning like abrasive pads, abrasive belts etcetera is used for the cleaning. So, these all come under the category of dry cleaning.

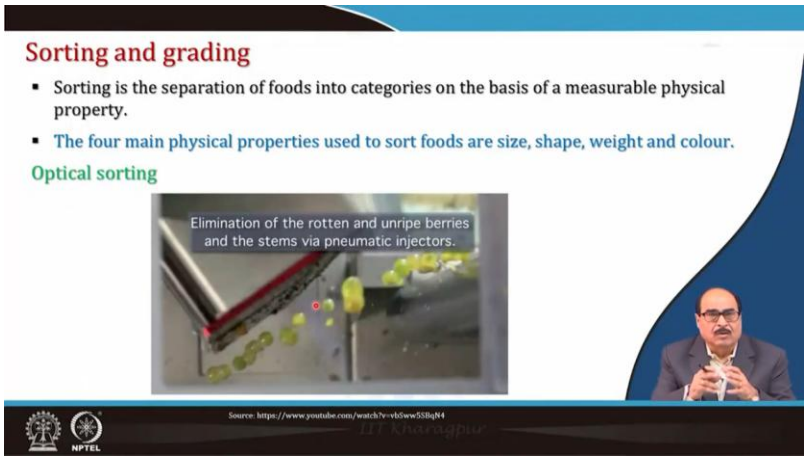



Wet cleaning may be soaking, spraying, floatation, washing or even ultrasonic cleaning. Like in the drum washing, you can say as you can see here in the figure that rotary machines that use water and gentle agitation to clean root vegetables like potato and carrots etcetera. In the case of spray washing, here, there is high pressure water sprays are used to clean leafy vegetables, greens or delicate fruits. In the immersion washing, submersion washing where the tanks filled with water are taken where the produce is submerged.

You can see here in this figure the produce is submerged and sometimes even bubbled for thorough cleaning. And for the vegetables cleaning, normally a dilute solution of potassium permanganate or chlorine in the range of 20 to 50 ppm is used for disinfection. For example, the vegetables because of their proximity to the soil, their contamination level might be little higher. So, they also need to be disinfected while cleaning, generally using these sanitizing solutions.

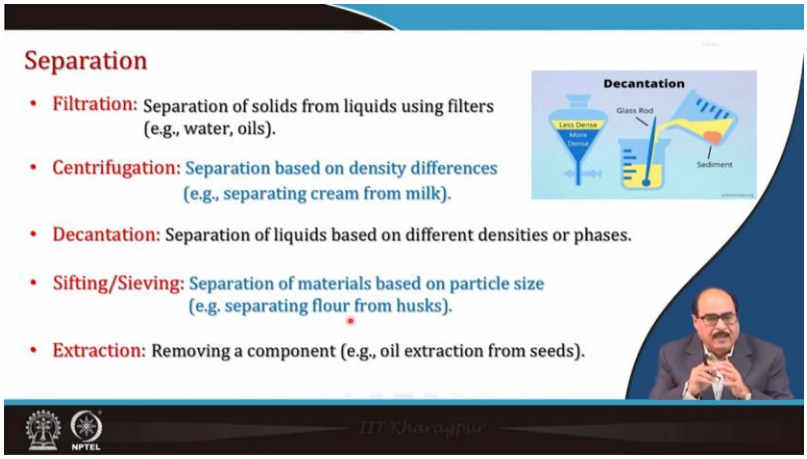



Then you can see the ultrasonic cleaners that use ultrasonic waves to remove dirt and pesticides, especially on delicate fruits like berries, etcetera. You can see here in the figure there is an ultrasonic cleaner. So, when these ultrasonic waves are applied to the fruits or vegetable surface, they may contain pollution, that is, foreign objects, particles, etcetera. Then, when these ultrasonic waves are generated, they cause cavitation in the material adhering to the surface of the fruits, and then there is bubble growth, and finally, the bubble ruptures. See here, and after that, the contamination level, that is, the contaminating molecules, material, etcetera, gets ruptured or torn, and then finally, it continues until the cavitation occurs several times, and the contaminating material is completely removed from the surface. So, this is, in brief, how ultrasonic cleaners work.

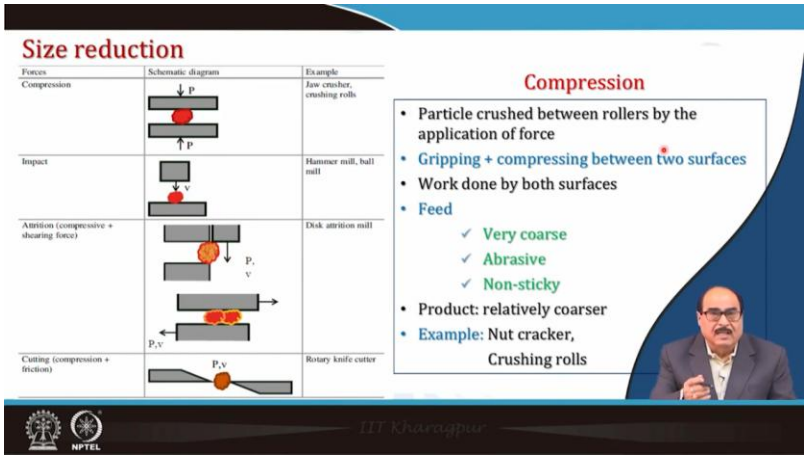



Now, the sorting and grading: sorting is the separation of foods into categories based on measurable physical properties. The four main physical properties used to sort the materials from one to another may be on the basis of size, sorting on the basis of shape,

on the basis of weight, as well as sorting on the basis of color, etcetera, color sorters, etcetera. You can see here in this figure, you see here, the material is coming, and it is getting optically sorted. So, even on the basis of color, they are getting sorted out.

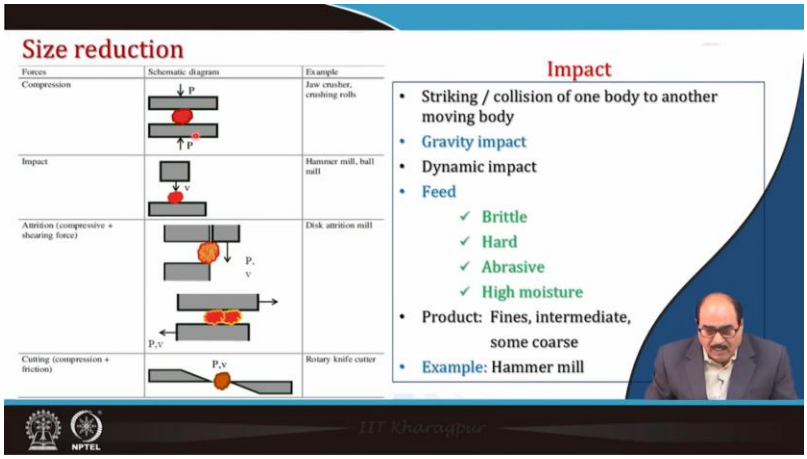



Then, this separation may be like filtration, where the separation of solids from the liquid is done using a filter, such as water or oils. The centrifugation process separates based on the differences in density. Decantation, as you can see here in this figure, is the separation of liquids based on different densities or phases. Similarly, shifting or sieving is the separation of materials based on their particle size, such as separating flour from the husk, etc. Extraction is the removal of one component from another, such as oil extraction from seeds.

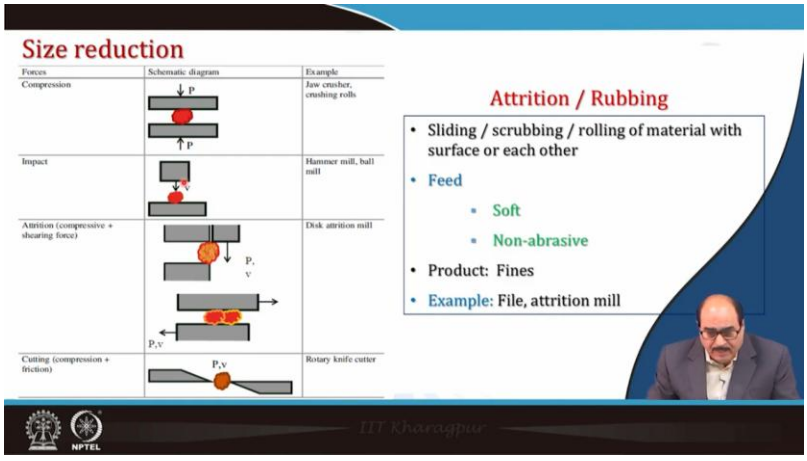



Then, size reduction is a very important unit operation in food processing. In size reduction, there may be compression, impact, attrition, compressive and shearing forces, and cutting. You can see in this compression. Here, the particle is crushed between rollers

by the application of force. Basically, the material is gripped and compressed between two surfaces, and work is done by both surfaces. The feed may be very coarse, abrasive, and non-sticky, and the product obtained after crushing, in this case, may be relatively coarser. For example, nut crackers and crushing rolls, etc., work on this principle.

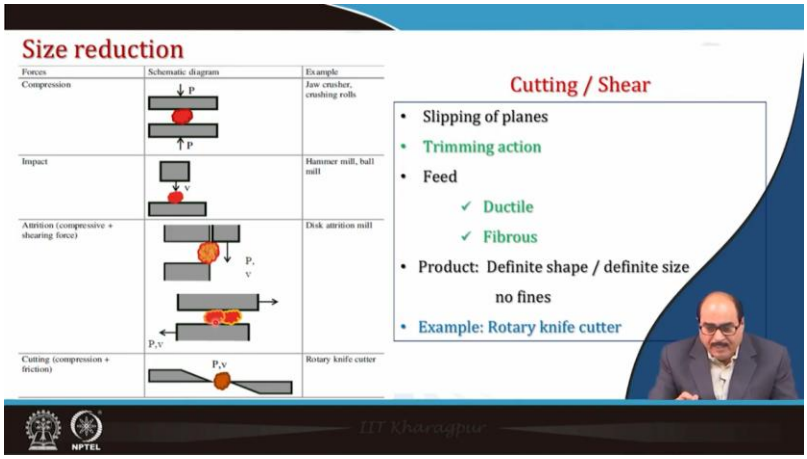



Then, the impact can be seen here, where the material is striking. There is a collision of one body with another moving body. It may be gravity impact or dynamic impact, and the feed may be brittle, hard, abrasive, or high-moisture feed material. The product obtained by this method of size reduction may be fine, intermediate, or some coarse products, etc., and then, examples which work on this principle are hammer mills.

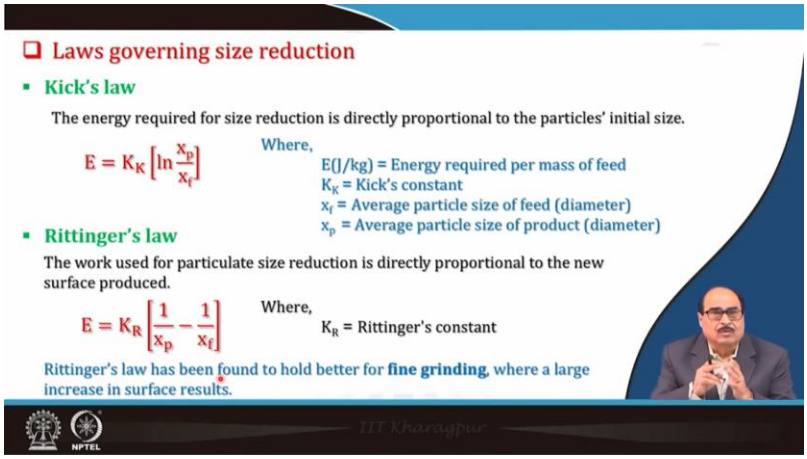



Then, attrition and rubbing, see here, that is, here, sliding action is taking place: sliding, scrubbing, or rolling of the material with the surface of each other. That is, it is coming here, that is, it is sliding here, rolling here, and then. So, the feed generally here is soft

material, non-abrasive material, and the product which we get in this includes fines, and the examples of this type of size reduction units may be file or attrition mills.




Then, cutting and shear, you can see here, that is, here, that is, the material slips, that is, in the plane, that is, slipping of the planes, and there is an action on the material. So, the feed may be ductile or fibrous, and the product which you get is a definite shape, a definite shape of the product we get after this and no fines, etcetera, are there. A definite size you get, and examples of this size of size reduction units include rotary drive cutters and other such units.




So, the large governing size reduction, there is the Kick's law that here. In the case of the Kick's law, is that the energy required for size reduction is directly proportional to the particle's initial size, like

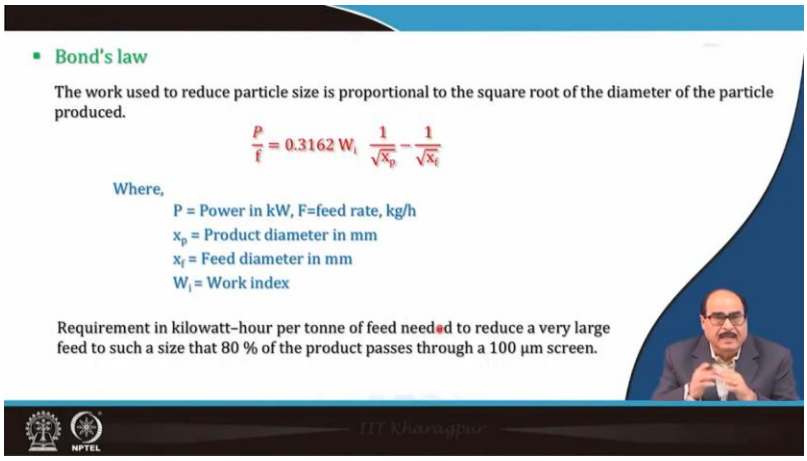
$$E = K_K \left[\ln \frac{x_p}{x_f}\right]$$

where E is the energy required per mass of the feed in joule per kg, $K_K$ is the Kick's constant, $X_f$ is the average particle size of the feed, like the diameter, and $X_p$ is the average particle size of the product or diameter of the product average.

Then another law which governs the size reduction is Rittinger's law. And here, the work used for particulate size reduction is directly proportional to the new surface produced, that is,

$$E = K_R \left[\frac{1}{x_p} - \frac{1}{x_f}\right]$$

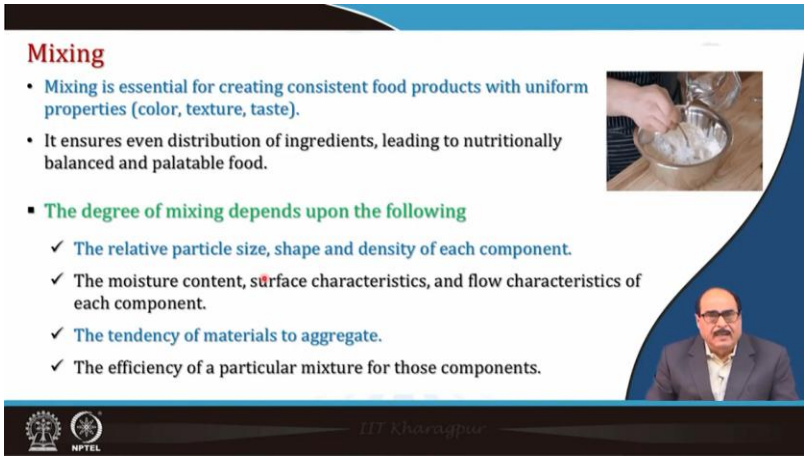
where $K_R$ is the Rittinger's constant, and Rittinger's law has been found to hold better for fine grinding, where a large increase in surface area results.




Then, the third and important law is Bond's law of size reduction. And in this case, the work used to reduce particle size is proportional to the square root of the diameter of the particle produced, like

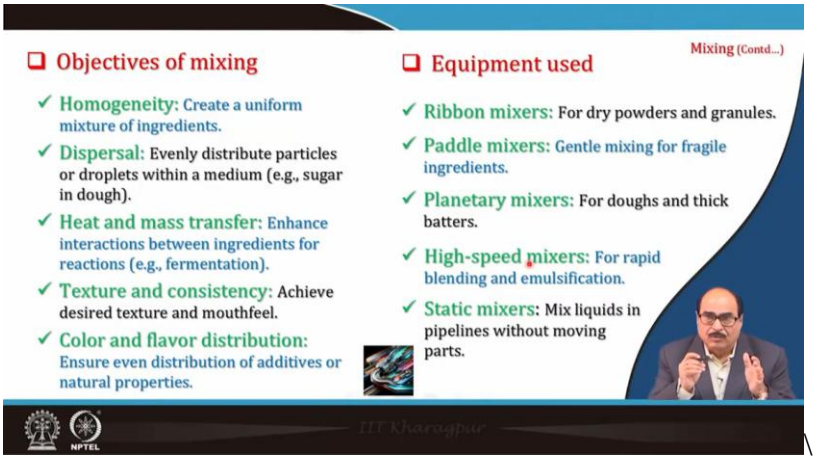
$$\frac{P}{f} = 0.3162\, W_i \left[\frac{1}{\sqrt{x_p}} - \frac{1}{\sqrt{x_f}}\right]$$

where P is the power in kilowatt, f is the feed rate, $X_p$ is the product diameter in mm, $X_f$ is the feed diameter in mm, and $W_i$ is the work index. And here, the requirement in kilowatt-hour per ton of the feed needed to reduce a very large feed to such a size that 80 percent of the product passes through a 100-micrometer screen.




Then, let us talk about mixing. You can see here in the figure, that mixing is essential for creating consistent food products with uniform properties, that is, the properties may be color, texture, taste, or other properties, but the materials are mixed uniformly. So, you get uniform properties. It ensures even distribution or uniform distribution of ingredients, leading to a nutritionally balanced and palatable product.

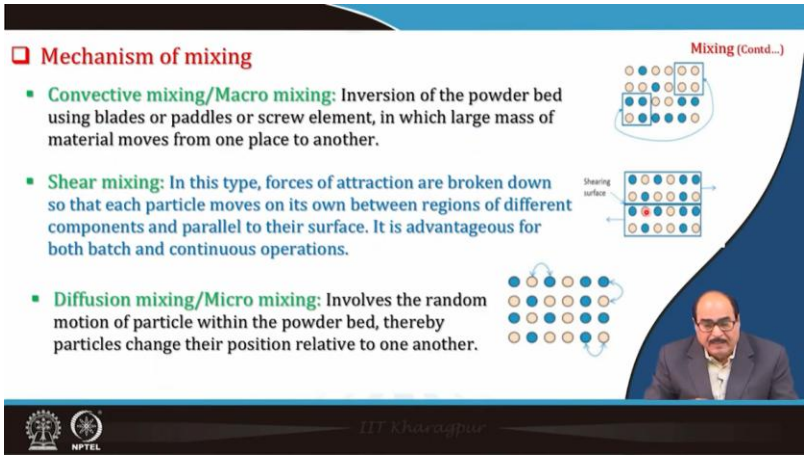
The degree of mixing depends upon the relative particle size, shape, and density of each component that is being mixed. The moisture content, surface characteristics, and flow characteristics of each component, the tendency of the material to aggregate, and finally, the efficiency of a particular mixture for those components. So, these are the various factors on which the degree of mixing will depend.




So, let us talk about the objective of mixing because, of course, in different processes for different products, the objectives may vary slightly, but one major objective, you can say, is to create a homogeneous or uniform mixture of almost all ingredients. So, that the

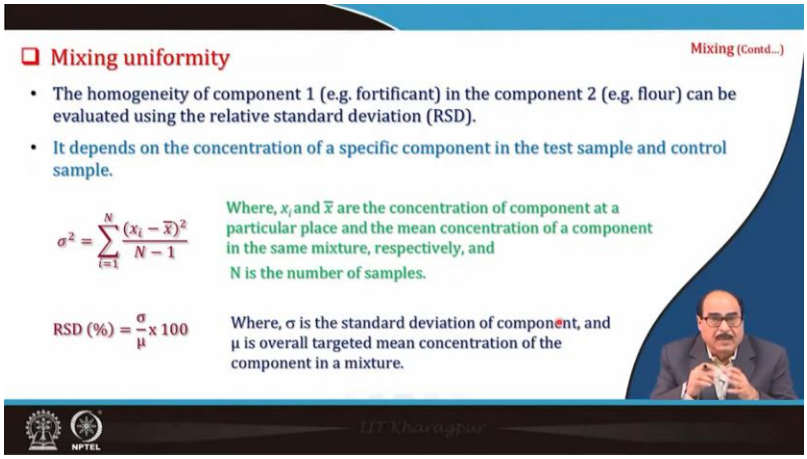
other processes and operations become smooth. The objective of mixing is to evenly distribute particles or droplets within a medium. Like, for example, when you are using sugar in a dough or batter. So, it should be properly mixed so that uniformity is achieved. Then, also, proper mixing is to enhance the interaction between ingredients and reactions, etcetera. So as to facilitate more and more heat and mass transfer, for example, in processes like baking, fermentation, etcetera. Also, one of the objectives of mixing is to achieve the desired texture and mouthfeel, that is, proper consistency and proper texture of the material. And finally, to ensure even distribution of additives or natural properties to get a properly uniformly mixed color, flavor, and all those of the materials.

Normally, the equipment used for mixing may be ribbon mixers for mixing dry powders and granules, paddle mixers which results in gentle mixing of fragile ingredients, planetary mixers used for dough and thick batters, high speed mixers may be used for rapid blending and emulsification, static mixers are used for mixing liquids in pipelines without moving parts.




The mechanism of mixing you can see that there is a convective mixing or macro mixing, where inversion of the powder bed using blades or paddles or screw elements, in which large mass of the material moves from one place to other place as you can see here in the figure. In the shear mixing, the forces of attraction are broken down. So, that each particle moves on its own between regions of different components and parallel to the surface as you can see here in this figure, and it is advantageous for both batches and continuous operations. Diffusion mixing or micro mixings involves the random motion of

particles within the powder bed, and thereby particles change their position relative to one another you can see they it changes their position.



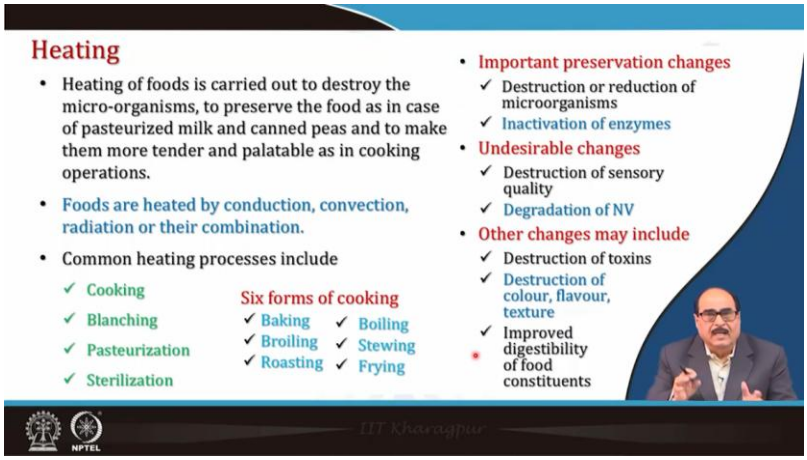

Mixing uniformity that is the homogeneity of the component, like for example, homogeneity of the component like in the flour we are using sometime fortificants etcetera. So, the homogeneity of the component 1 in the component 2 can be evaluated using the relative standard deviation. RSD is used to calculate to know whether how the homogeneous mixture has been produced or not, and it depends on the concentration of a specific component in the test sample and the control sample or you can say component 1 and component 2.

$$\sigma^2 = \sum_{i=1}^{N} \frac{(x_i - \bar{x})^2}{N-1}$$

where $x_i$ and $\bar{x}$ are the concentration of a component at a particular place and the mean concentration of a component in the same mixture, respectively, and N is the number of samples. So, relative standard deviation percent can be calculated as

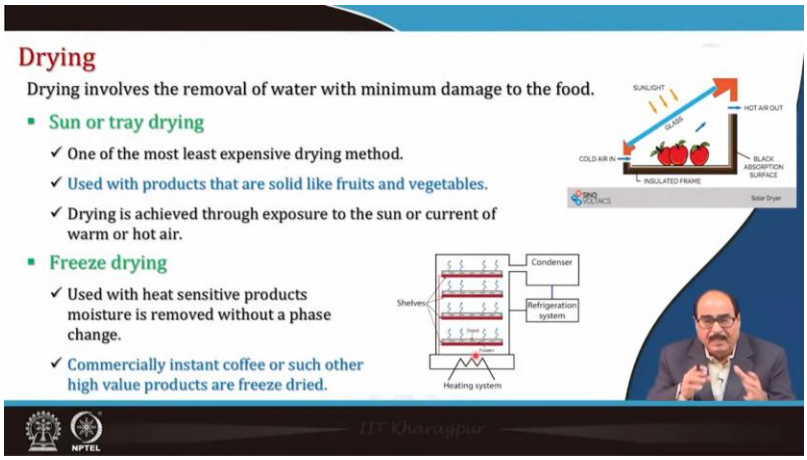
$$\text{RSD } (\%) = \frac{\sigma}{\mu} x\ 100$$

where μ is the overall targeted mean concentration of the component in a mixture. So, by using these equations, particularly relative standard deviations, one can determine mixing uniformity.



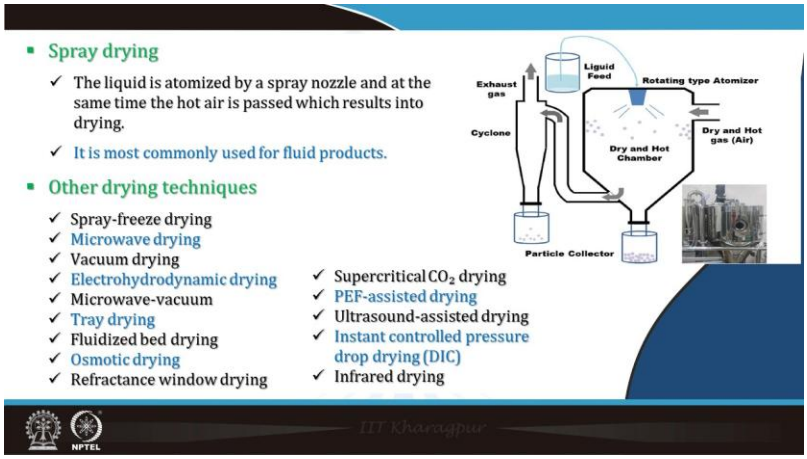

Now, let us talk about heating, that is, heating of food is carried out to destroy microorganisms to preserve the food, as in the case of pasteurized milk and canned peas, and to make them more tender and palatable, as in cooking operations. In earlier classes, we have also discussed something about heating processes. So, foods are heated by conduction, convection, radiation, or a combination of these processes. Some of the most common heating processes include cooking, blanching, pasteurization, and sterilization.

Six forms of cooking may include baking, broiling, roasting, boiling, steaming, frying, etc. The important preservation changes that take place in the material during heating or cooking include destruction or reduction of microorganisms, inactivation of enzymes, and undesirable changes. However, if excessive heating occurs, it may result in the destruction of sensory quality, degradation of nutritional value, and other changes, such as destruction of toxins, color, flavor, or texture, or improved digestibility of food constituents, and so on.



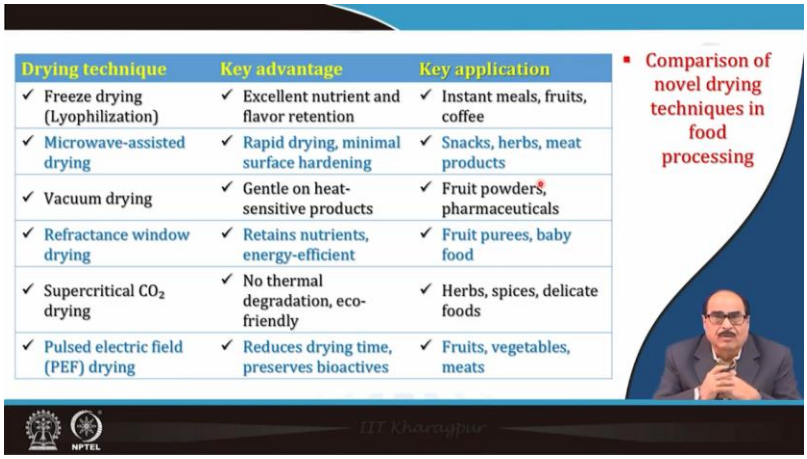
Then, drying again the drying involves the removal of water with minimum damage to the food quality and it may be either sun drying or tray drying that is sun drying is the one of the most least expensive drying method and it has been used traditionally for the drying of the food materials. And here it is used with the products that are solid like fruits and vegetables etcetera, and drying is achieved through exposure of the material to directly sun or current of warm or hot air that is even convective drying air drying. So, sun drying or tray drying can be used.

Then other may be a freeze drying where which is used with the heat sensitive product. like moisture is removed without a phase change ok. That is the material is conveyed and normally that is the first the material earlier we discussed about this also in little detail that is material is frozen and then it is sublimed. So, commercially the instant coffee or such other high value products are generally freeze dried.




Then spray drying is another technique for drying of the liquid food materials, where liquid is atomized using a suitable spray nozzle jets etcetera. And they, at the same time the hot air that is the material in the fine of mist and powder is coming in through spray jet. and then hot air and then it in the drying chamber it come in the contact with and the material as it passes out, its material gets dried moisture evaporates and with the cyclone separator the air and dried materials are dried powders are separated. So, it is most commonly used for fluid product like milk in the milk drying is milk dry milk powder etcetera are commonly used by obtained.

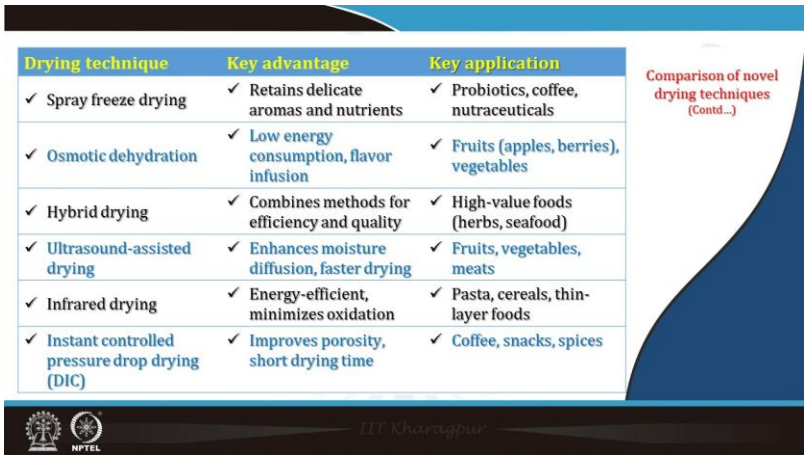
So, there are other drying technique also like spray freeze drying, electrohydrodynamic drying, fluidized bed drying, PEF assisted drying, instant controlled pressure drop drying, infrared drying and so on.



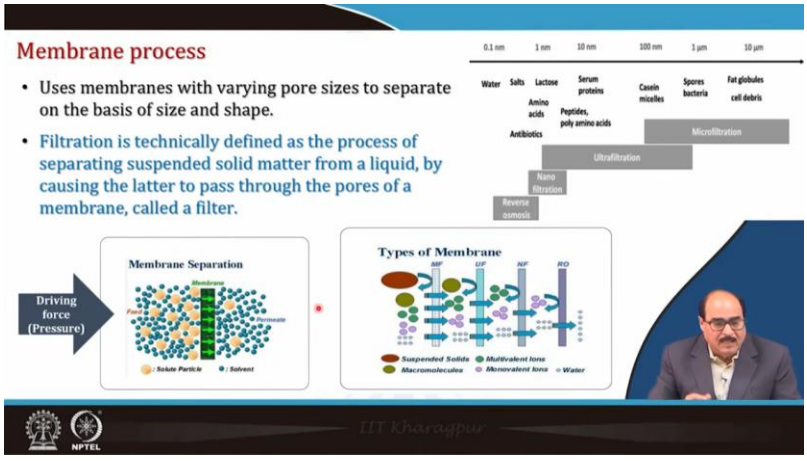

| Drying technique | Key advantage | Key application |
|---|---|---|
| ✓ Freeze drying (Lyophilization) | ✓ Excellent nutrient and flavor retention | ✓ Instant meals, fruits, coffee |
| ✓ Microwave-assisted drying | ✓ Rapid drying, minimal surface hardening | ✓ Snacks, herbs, meat products |
| ✓ Vacuum drying | ✓ Gentle on heat-sensitive products | ✓ Fruit powders, pharmaceuticals |
| ✓ Refractance window drying | ✓ Retains nutrients, energy-efficient | ✓ Fruit purees, baby food |
| ✓ Supercritical $CO_2$ drying | ✓ No thermal degradation, eco-friendly | ✓ Herbs, spices, delicate foods |
| ✓ Pulsed electric field (PEF) drying | ✓ Reduces drying time, preserves bioactives | ✓ Fruits, vegetables, meats |

So, let us now briefly I will tell you what are the major drying techniques, the key advantages of these methods, and what are the application area like freeze drying which also called a lyophilization. It is excellent nutrient retention and flavor retention there in this process and as I told you normally the instant meals, fruits, coffee or other high value products are used. Then microwave assisted drying, it is a wrapping drying process results in minimum surface hardening and it is used for snacks, herbs, meat products, and then vacuum drying, here it is gentle and heat sensitive products and fruit powders, pharmaceutical materials etcetera. are dried using this.

Then refractive window drying it retains nutrients and it is energy efficient the fruit purees, baby foods, etcetera are used by this. Then supercritical carbon dioxide there is no thermal damage, herbs, spices, and delicate materials are dried using this. Pulse electric field drying like PEF assisted drying, it reduces the drying time, preserves bioactives, and mostly the fruits, vegetables, meats etcetera are preferred to be dried using this material.

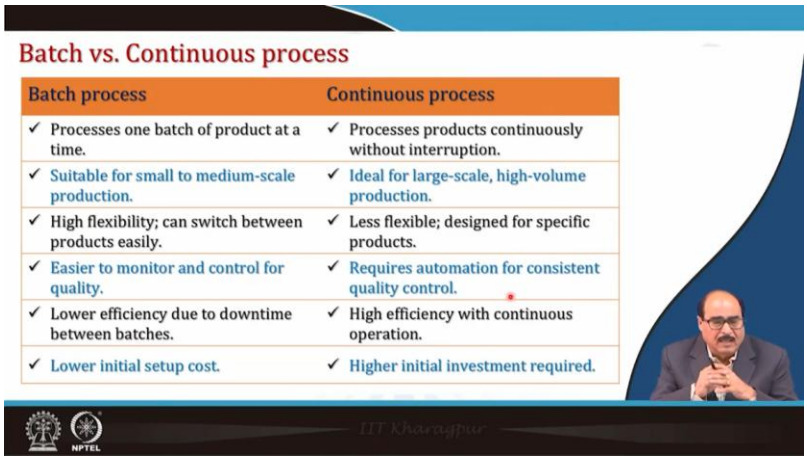



Then spray freeze drying, it retains delicate aromas and nutrients like probiotics, coffee, other nutraceuticals. are dried by spray freeze drying. Osmotic dehydration, it is a low energy consumption is there in this process and there is a flavor infusion fruits, apple, berries etcetera is used by this osmotic drying. Hybrid drying combines method for efficiency and quality like high value foods like herbs, seafoods etcetera., hybrid drying is used. Ultrasound assisted drying enhances moisture diffusion and it is a faster drying fruit, vegetables, meats etcetera are dried using this. Infrared drying is an energy efficient, it minimizes oxidation process pasta, cereals, thin layer foods etcetera dried using this. Then instant controlled pressure drop drying, it improves porosity and therefore, results in very short drying time. Coffee, snacks, spices etcetera are used by this.

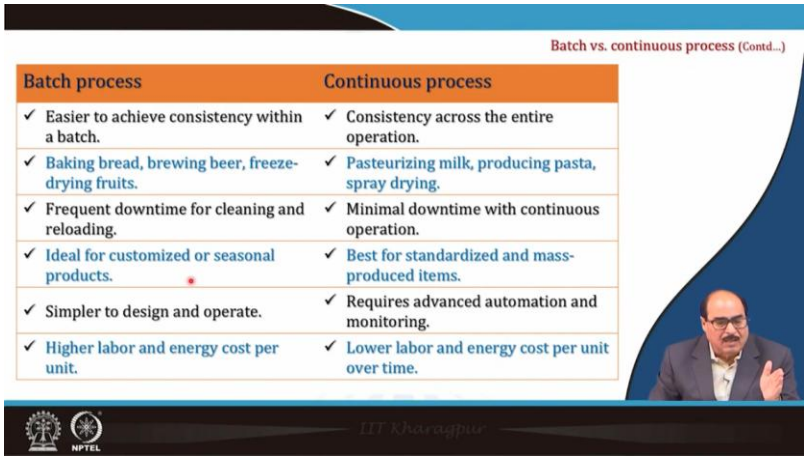



Then there is another process membrane process, like it is using membrane with varying pore size to separate on the basis of the size and shape. The filtration is defined as a

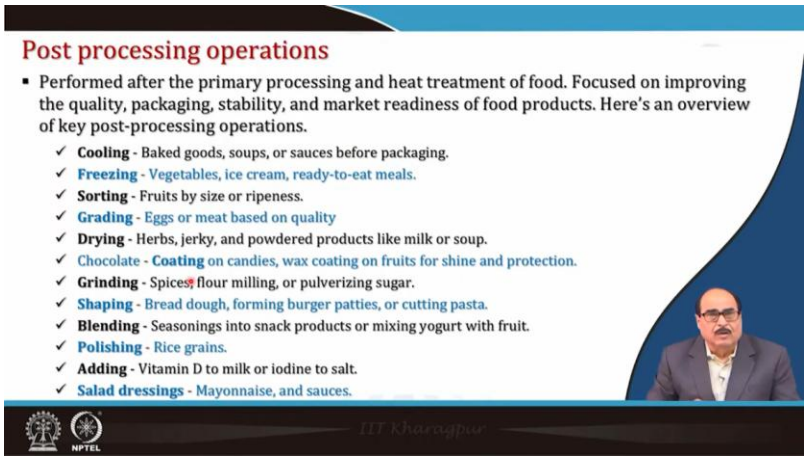
process of separating suspended solids from a liquid by causing the latter to pass through a membrane and which is called filter. So, it is pressure gradient there and the various solute particle on the basis of size they are separated. So, you see that the membrane which we have the depending upon the particles which gets separated it may be a micro filtration membrane, ultra filtration, nano filtration or reverse osmosis membranes etcetera. Details of this membrane technology I have already discussed in my earlier novel technology and food processing of the earlier NPTEL course.




Then let us talk about batch and continuous processes. Batch process, that is, it processes one batch of a product at a time whereas, continuous products in continuous process there is a manufactured without any interruption. Batch process is suitable for a small to medium scale production whereas, continuous process is ideal for a large-scale high-volume production. In batch process it is easier to monitor and control the quality whereas, the continuous process requires automation for consistent quality control. In the batch process it is the lower initial setup cost however, in the continuous process there is a high initial investment cost. batch process has high flexibility can switch between the products readily or easily whereas, the continuous process is generally less flexible and is designed for a specific product.




Also, in the batch process, it is easier to achieve consistency within a batch, whereas, in the continuous process, consistency across the entire operation will be there. In batch processes like baking bread, brewing beer, freeze-drying of fruits, etcetera, that is where the batch process may be used. Then, continuous process examples are pasteurization of milk, producing pasta, spray drying, etcetera. In batch processes, they are normally ideal for customized or seasonal products, whereas, continuous processes can be considered best for standardized and mass-produced products. Batch processes are generally simpler to design and operate, whereas the continuous process requires advanced automation and monitoring, etcetera. Batch processes have higher labor and energy costs per unit operation, whereas the continuous process results in lower labor and energy costs per unit work time.

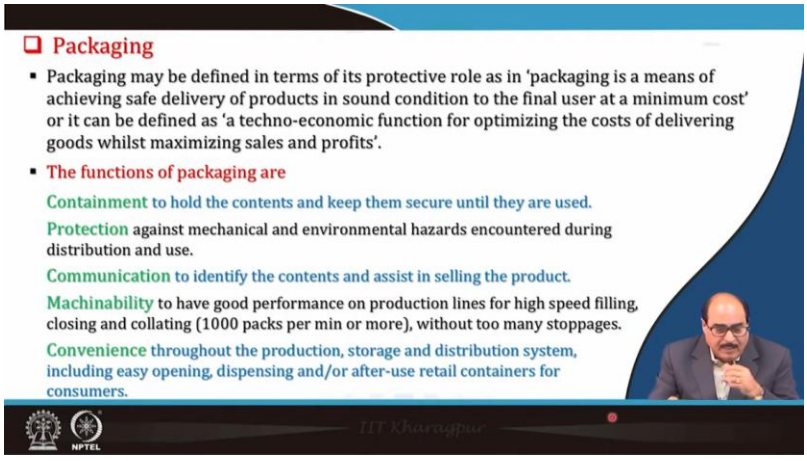



Now, the post-processing operations: once materials are used in one of these unit operations, the material is processed. So, after processing like heating, drying, or

whatever is required, post-process operations or pre-process operations may also be needed, depending on the food, which is being processed, the raw material ingredients, their nature, and finally, the final processed product, what material you are getting when it comes out of the processing chamber, whether it's a heating chamber, baking chamber, or any other chamber, what is the condition? So, we might require different operations like this, which is basically performed after the primary processing and heat treatment of food, and the focus here is to improve the quality, packaging stability, and market readiness of the food product.

An overview of the different post processing operations may be like cooling as it is done in the baked goods, soups, sauces before packaging that is when it is bread or cake when they are coming out of the baking ovens, it is allowed to cool before it is packaged. Similarly, freezing may be done for the vegetables, ice cream, ready meat before storage. sorting, grading, drying we already discussed, then in the case of chocolate there will be coating on candies wax coating on fruits for sign and protection, then grinding, shaping, Even polishing like in the case of rice grain after the milling that is outer layer of the bran is removed by polishing operation. Then even adding vitamin D to milk or iodine to salt or other fortificants in the food materials, salad dressing like mayonnaise and sausage etcetera are used.

So, these may be various unit operations depending and one has to select which unit operation is to be before processing, during processing, after processing. what are the operations should be there? So, that the purpose is to get the product in good shape, good size, good quality.

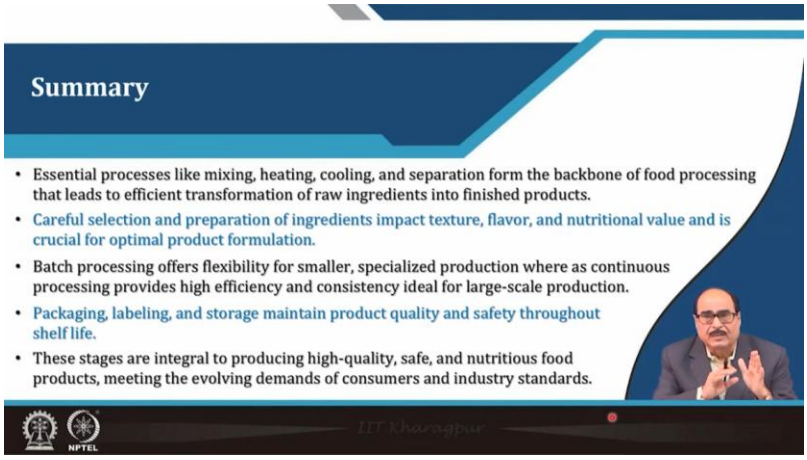


Then packaging another very very important operation that is packaging may be defined in terms of it is a protective role as in the packaging is a means of achieving safe delivery of product in sound condition to the final user at a minimum cost.

Functions of packaging may include different objective like even major function major objective of the packaging is to containment is to hold the content and keep them secure until they are used. Then protection is another very important function of the packaging. Protection against mechanical and environmental hazards encountered during distribution and use. Communication to identify the contents and assist in selling of the products that is packaging the labeling is used what does it contain inside the package etcetera all the information is given. Then machinability to have good performance on production lines for high speed filling, closing and collating without too many stoppages. Then convenience throughout the production, storage and distribution system including easy opening, dispensing and or after use retail for the consumers etcetera. So, the packaging plays a very very important role even in packaging of the ingredients, packaging of the finished goods. Well, other things they are all very important that they have to be taken care of done properly.


Then handling, storage and distribution. After the material is processed packaged then it to be handled properly, it is conveyed to the particular warehouse, storage etc. So, here again the correct handling of the food ingredients and packaging material from suppliers, through the production process and during distribution to the consumer is essential to optimize product quality and to minimize cost. Improvements in material handling technologies have led to substantial increase in the production efficiencies, and are used

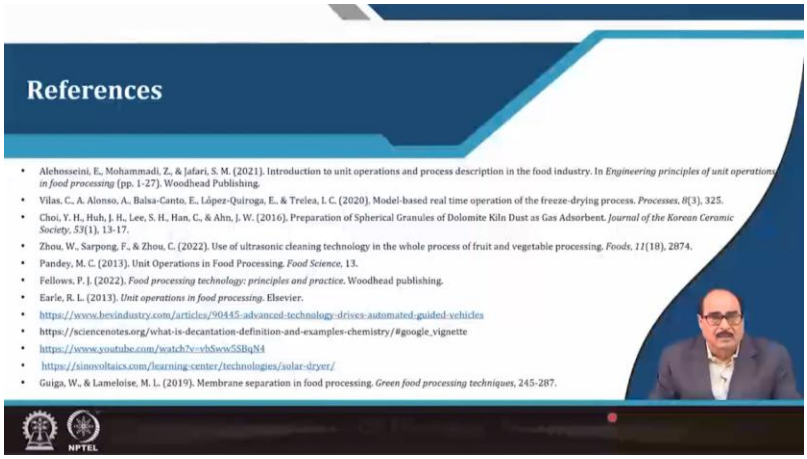
at all stages in a food manufacturing process. Including like this harvest and transportation to the raw material stores. Preparation, procedures and movement of food through a process or within a factory. Collection and disposal of the process wastes. Collation of the packaged foods to move or and movement to the finished product and warehouse. Distribution or wholesalers and retailers etcetera. So, all these are the various stages and which include that is the handling, storage and distribution in the value chain.




So, in the next I will tell you that I briefly described an overview, that is what are the various operations that are conducted may be that depending upon the food the ingredient. The objective of the processes is to determine the end product; one must properly select these operations and conduct them. So, essential processes like mixing, heating, cooling, and separation form the backbone of food processing. These lead to the efficient transformation of raw ingredients into finished products. Careful selection and preparation of the ingredients impact texture, flavor, and nutritional value, which is crucial for optimal product formulation. Batch processing offers flexibility for smaller, specialized production.

Whereas continuous processing provides high efficiency and consistency, ideal for large-scale production. Packaging, labeling, and storage maintain product quality and safety throughout the shelf life. These stages are integral to producing high-quality, safe, and nutritious food products, meeting the evolving demands of consumers and industry standards. The objective here is to provide consumers with food that is good in quality, nutritious, and safe to consume. This should be achieved through proper selection of process operations and ingredients.

Proper packaging and execution of all stages in the processing and supply value chain are also essential.




These are the references used for this lecture.


Thank you very much for your patient listening. Thank you.