**Post Harvest Operations and**
**Processing of Fruits, Vegetables, Spices and Plantation Crop Products**
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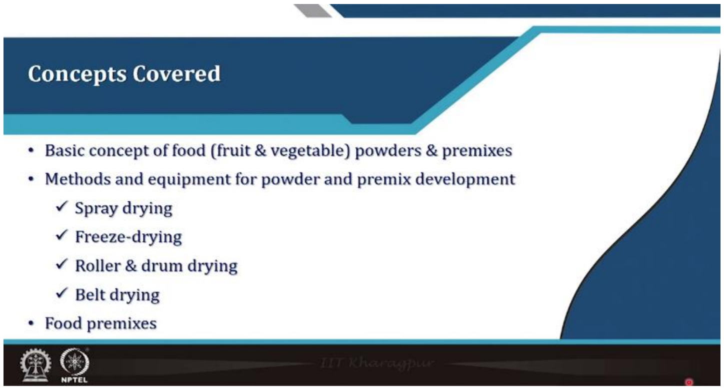
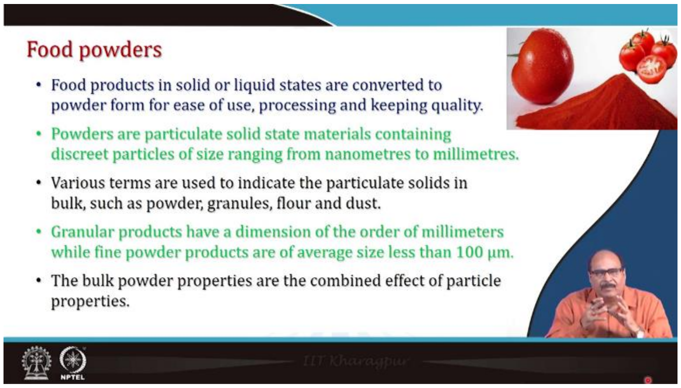
**Indian Institute of Technology, Kharagpur**
**Lecture 32**

This lecture discusses the different technologies for making food powders and premixes. These food powders and premixes will be studied in two parts.

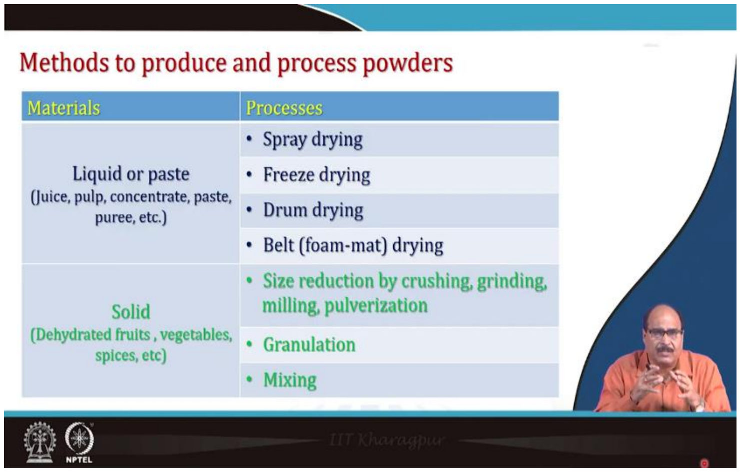



In the Part 1, the basic concept of fruits and vegetable powders and premix preparations will be discussed. In the Part 2, the methods and equipment for powder and premix development, the drying processes like spray drying, freeze drying, roller and drum drying, belt drying will be discussed. At the end, concepts about food premixes will be provided.



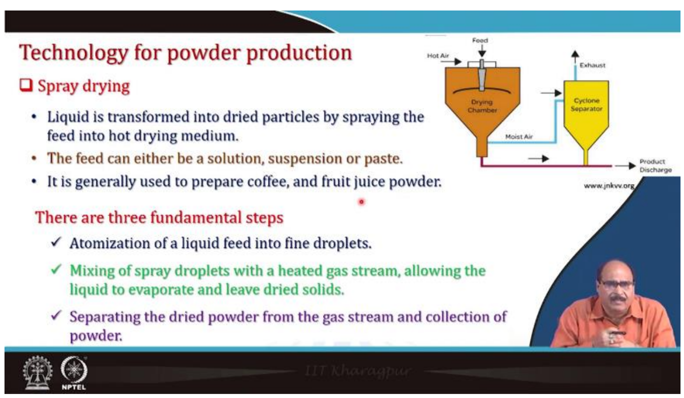

## Food powders

Food products in solid or liquid states are converted to powder form for ease of use, processing and keeping quality. Powders are particulate solid-state materials containing discrete particles of sizes ranging from nanometers to millimeters. Various terms are used to indicate the particulate solids in bulk, such as powder, granules, flour, and dust. Based on their sizes, they are named as either powder or granule or flour or dust. Granular products have a dimension of the order of millimeter, while fine powder products are of average size less than 100 µm. The bulk powder properties are the combined effect of the particle properties.




## Methods to produce and process powders

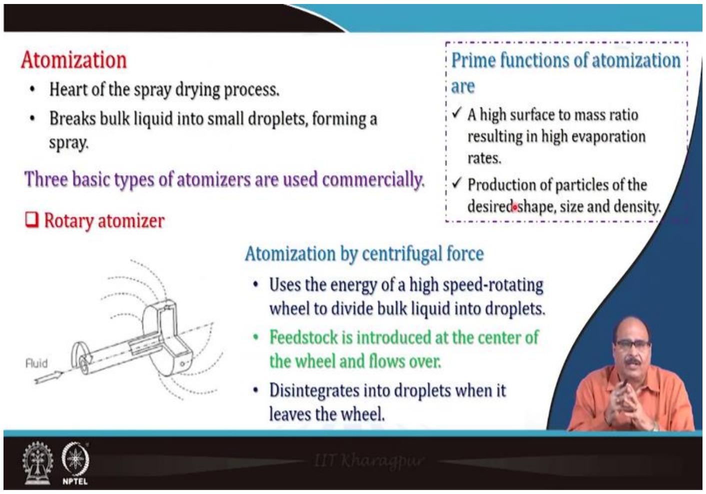
The materials may be in the liquid or paste form like juice, pulp, concentrate, paste, puree etc. For these, spray drying, freeze drying, drum drying, or belt drying or foam-bed drying etc. can be used to convert them into the free-flowing powder form. In other case, the material may be in the solid state like the dehydrated fruits, dehydrated vegetables, spices etc. These materials can be converted into powder by appropriate size reduction technology, i.e., by, crushing, grinding, milling, pulverization, then finally granulation, and mixing. These are the processes used for the preparation of powders.




## Technology for powder production

### Spray drying

It is a very popular method being used for the conversion of liquids into free-flowing powders. In the spray drying process, it can be seen from the figure, that there is a drying chamber, and there are certain atomizers and with the help of these atomizers, the liquid is fed into the fine droplets. Within the drying chamber, hot air comes in. In this chamber, the fine droplets come in contact with the hot air and the material gets dried. Then moist air i.e., the air which absorb the moisture, goes through the cyclone, and the dried product is collected from the bottom of the spray dryer. There are basically three fundamental steps in spray drying, i.e., atomization, then mixing up the spray droplet with the heated gas stream allowing the liquid to evaporate and leave the dried solids, and finally separating the dried powder from the gas stream, and collection of the powder.

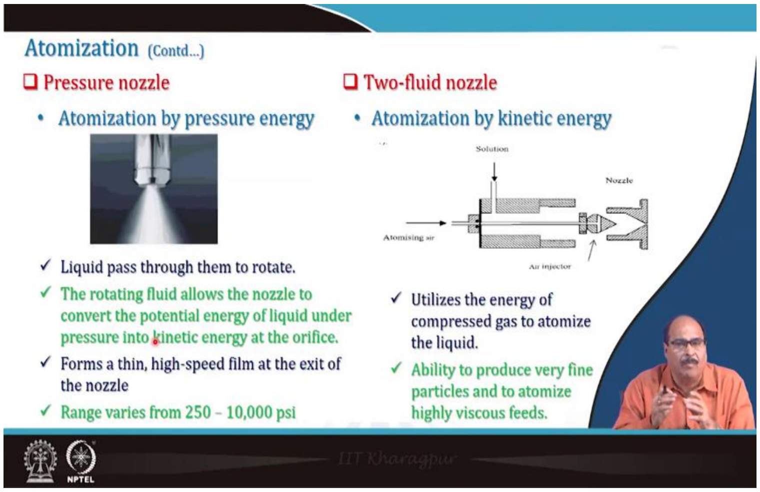



**Atomization**

The prime functions of the atomization process are a high surface to mass ratio resulting in high evaporation rates and production of particles of the desired shape, size, and density. There are three basic types of atomizers, which are used commercially.

**Rotary atomizer**

It can be seen from the figure, that the fluid goes through this rotary atomizer. It uses the energy of a high-speed rotating wheel to divide bulk liquid into fine droplets. Feedstock is introduced at the center of the wheel and it flows over and disintegrates into droplets, when it leaves the wheel.

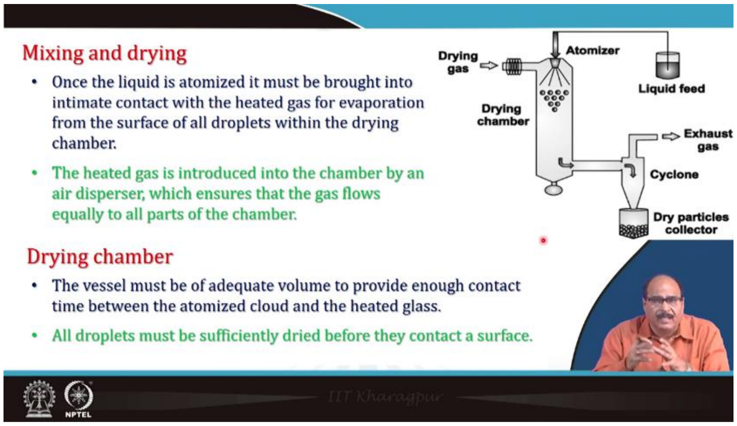


**Pressure nozzle**

The other atomizer is the pressure nozzle i.e., atomization by pressure energy. It can be seen from the figure, that the liquid passes through a nozzle, i.e., the rotating fluid allows the nozzle to convert the potential energy of the liquid under pressure into kinetic energy at the orifice. It forms a thin, high-speed film at the exit of the nozzle, and the range varies from around 250 to 10,000 psi.

**Two-fluid nozzle system**

Here basically, the principle is the atomization by kinetic energy. It can be seen from the figure, that, it utilizes the energy of the compressed gas to atomize the liquid and the ability to produce very fine particles and to atomize highly viscous fluid.

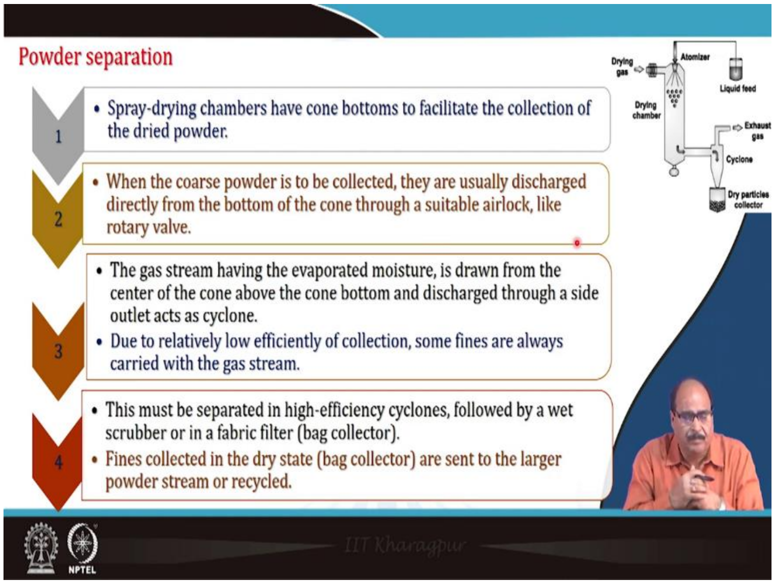



**Mixing and drying**

Once the liquid is atomized, it must be brought into the intimate contact with the heated gas for evaporation from the surface of all droplets within the drying chamber. The heated gas is introduced into the chamber by an air dispenser, which ensures that the gas flow equals to all parts of the drying chamber.

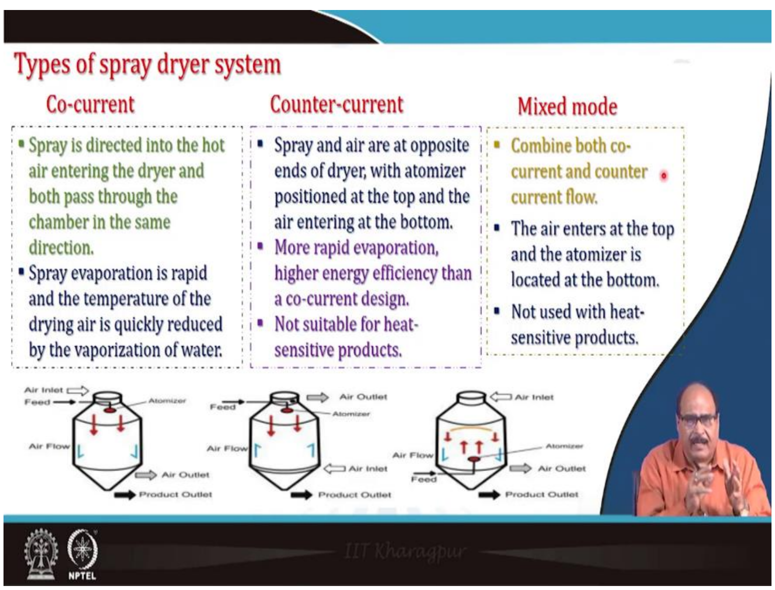
**Drying chamber**

The drying chamber must be of adequate volume to provide enough contact time between the atomized cloud and the heated glass. All droplets must be sufficiently dried before they contact a surface. This process is particularly used for fruits, vegetable juices drying etc. The conventional drying process like spray drying process is not suitable for liquid drying, since there, the drying time is in the fraction of minutes or few seconds. The temperature must be, in order to cause the complete evaporation. The temperature must be very high in the drying chamber. This process is not suitable particularly for the sugar containing juices drying. They are heat-sensitive. Their Tg value i.e., glass transition temperature value is less. If the temperature goes beyond the Tg value, the product will become sticky and its removal from the tank chamber will become difficult.



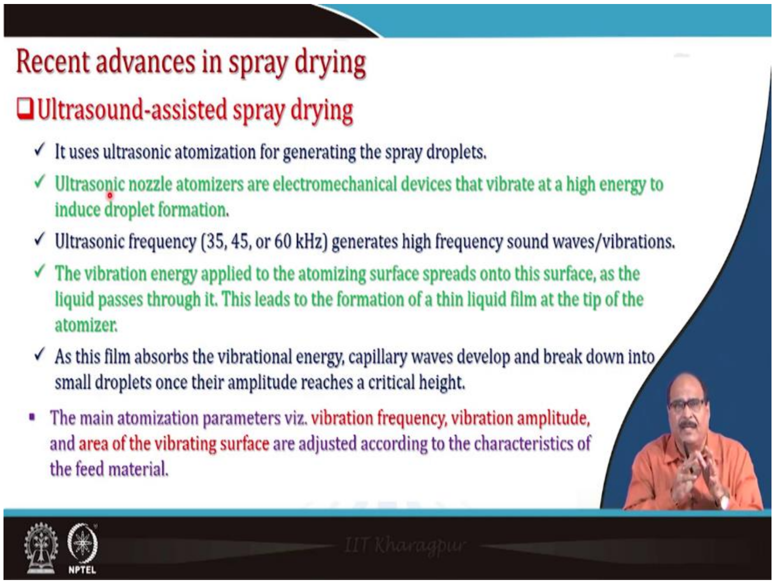

**Powder separation**

Spray-drying chambers have cone bottoms to facilitate the collection of the dried powder. When the coarse powder is to be collected, they are usually discharged directly from the bottom of the cone through a suitable airlock, like rotary valve. The gas stream having the evaporated moisture, is drawn from the center of the cone, above the cone bottom and discharged through a side outlet, which acts as a cyclone. This must be separated in the high efficiency cyclones, followed by a wet scrubber or in a fabric filter (bag collector). The fines are collected in the dry state (bag collector). They are sent to the larger powder stream or even recycled.




**Types of spray dryer system**

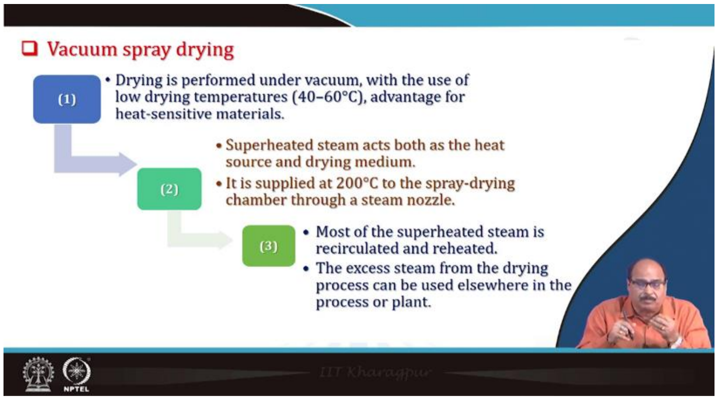
In the co-current system, spray is directed into the hot air entering the dryer and both pass through the chamber in the same direction. Spray evaporation is rapid, and the temperature of the drying air is quickly reduced by the vaporization of the water in this type of system. In the counter-current system, it can be seen form the figure, that the air is going from the bottom to the top. Air is introduced at the bottom, and the feed is introduced from the top. In the counter-current system, more rapid evaporation is there. There is higher energy efficiency than a co-current design. However, it is not suitable for heat-sensitive products like fruits and vegetable drying etc. In the mixed mode, the co-current as well as counter current flow are combined. The air enters at the top and the atomizer is located at the bottom. It is also not suitable for the heat-sensitive product. So, in that sense, it can be said that, for fruits and vegetables dehydration, the co-current system may be better.




**Recent advances in spray drying**

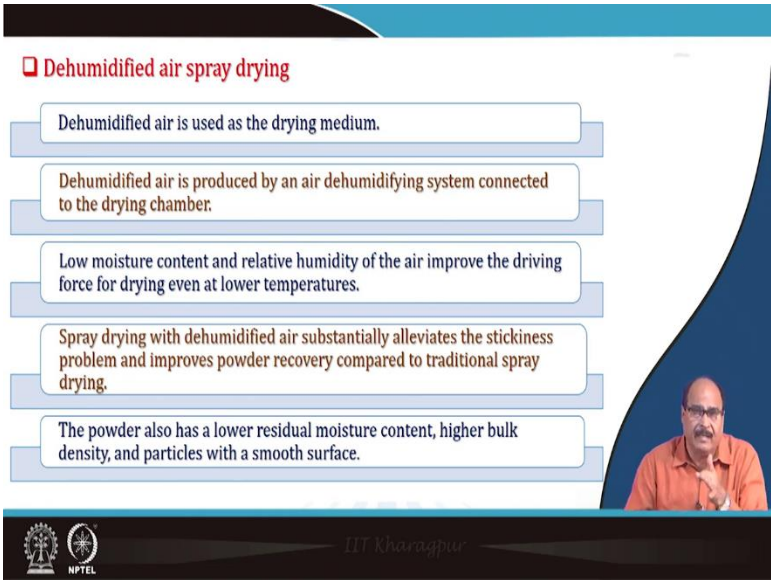
**Ultrasound-assisted spray drying**

It uses ultrasonic atomization for generating the spray droplets. Ultrasonic nozzle atomizers are electromechanical devices that vibrate at a high energy to induce droplet formation. The vibration energy applied to the atomizing surface, spreads onto the surface, as the liquid passes through it and this leads to the formation of a thin film at the tip of the atomizer. As this film absorbs the vibrational energy, capillary waves develop and break down into small droplets, once their amplitude reaches a critical height. The main atomization parameters viz. vibration frequency, vibration amplitude and area of the vibrating surface are adjusted according to the characteristics of the feed material.



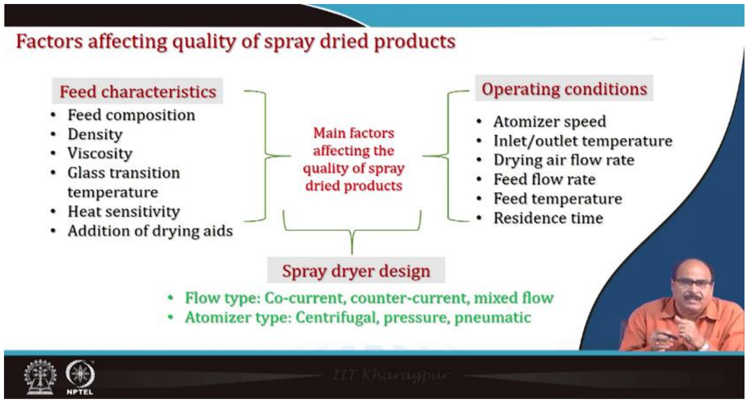

**Vacuum spray drying**

Here, the drying is performed under vacuum with the use of low drying temperature like 40 to 60 °C. It is advantageous for the heat-sensitive material. The superheated steam acts both as the heat source and drying medium. It is supplied at 200 °C to the spray-drying chamber through a steam nozzle. Most of the superheated steam is recirculated and reheated. The excess of steam from the drying process can be used elsewhere in the process or plant.



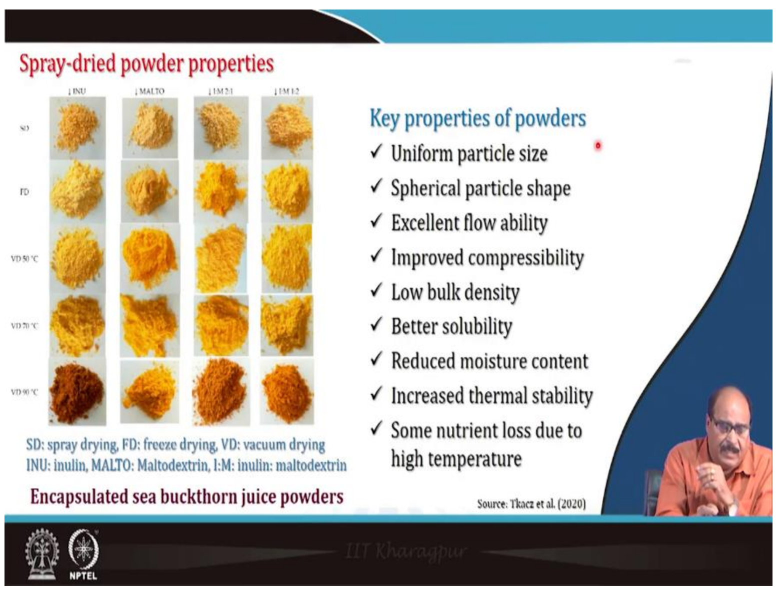

**Dehumidified air spray drying**

Dehumidified air is used as the drying medium in this case. Dehumidified air is produced by an air dehumidifying system connected to the drying chamber. Low moisture content and relative humidity of the air improve the driving force for drying even at lower temperatures. Spray drying with the dehumidified air, substantially alleviates the stickiness problem and it improves the powder recovery compared to the traditionally spray drying. The powder also has a lower residual moisture content, higher bulk density, and particles with a smooth surface.




**Factors affecting the spray dried products**

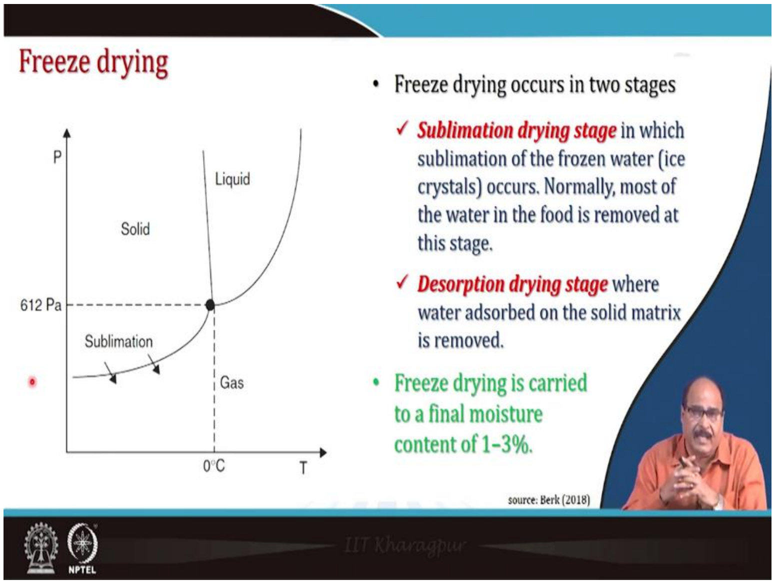
There is feed characteristics, like feed composition, density, viscosity, glass transition temperature, heat sensitivity, addition of drying aids etc. or operating conditions of the spray dryer like atomizer speed, inlet/outlet temperature, drying air flow rate, feed flow rate, feed temperature, residence time, humidity of the drying air etc. are the factors that affect the spray drying products. Spray dryer design, like that flow type, like co-current, counter current, mixed flow, or atomizer type, like centrifugal atomizer, pressure atomizer, pneumatic etc. are all factors that affect the quality of the spray dried products.




**Spray-dried powder properties**

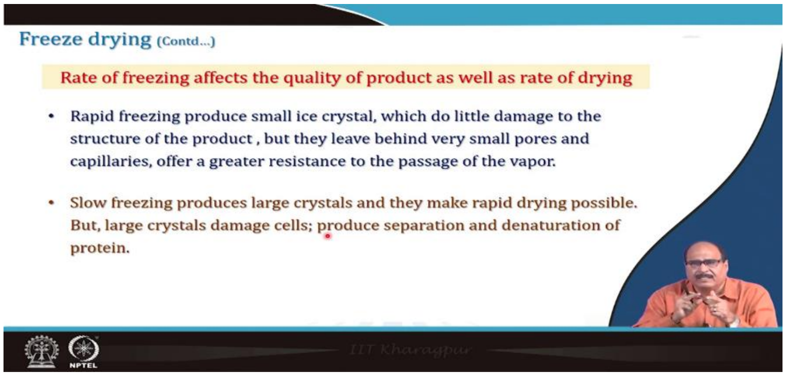
Here a comparison has been shown. A comparison between the spray dried powder with freeze-dried powder, and vacuum dried powder has been shown. The materials are the inulin or maltodextrin or a mixture of inulin and maltodextrin. Vacuum drying occurs at 50 °C, 70 °C and 90 °C. Here the color difference can be seen at different conditions. Encapsulated sieve of corn juice powder is a very good example of spray-dried powder.

The key properties of the powder are the uniform particle size, its spherical particle shape, excellent flowability, improved compressibility, low bulk density, better solubility, reduced moisture content, increased thermal stability and even if properly controlled, there should be least loss of the nutrients. If there is high temperature, there will be some losses.



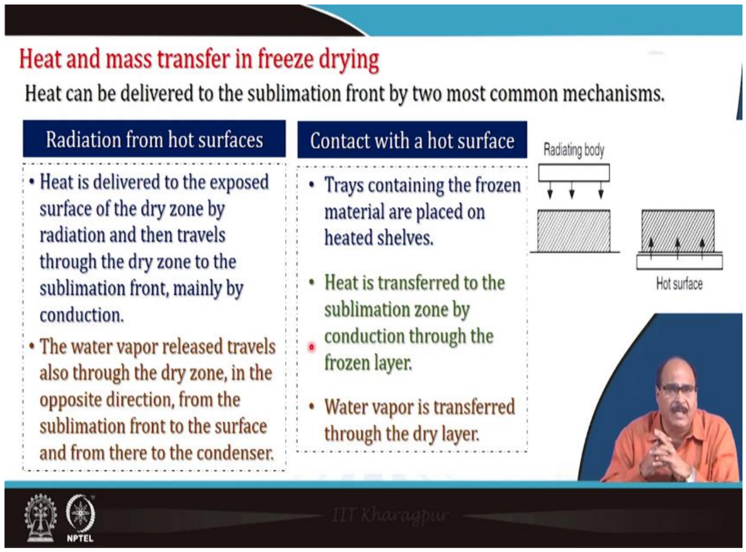

**Freeze drying**

It is an ideal method for drying of heat-sensitive materials. For fruits, vegetable, juices etc., even for the instant coffee, the freeze-drying process is used. The freeze-drying diagram has been shown in the figure. In the freeze drying, the material is first frozen and then the ice or water in the ice form is sublimed directly. If the triple point is maintained, then directly, a solid can be removed in the form of a gas. Freeze-drying occurs in two stages. One in the sublimation drying stage, in which the sublimation of the frozen water like ice crystals occurs normally. Most of the water in the food is removed at this stage. Then, also there is a second stage, the desorption drying stage, where water absorbed on the solid matrix is removed. Freeze drying is carried to a final moisture content of about up to 1-3%.



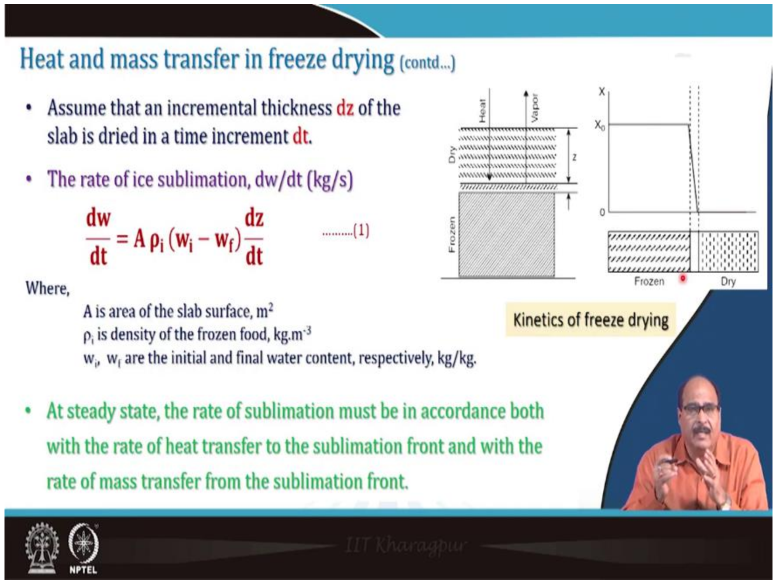

**Rate of the freezing affects the quality of products as well as rate of the drying process.**

Rapid freezing produces small ice crystals, which do little damage to the structure of the product, but they leave behind very small pores and capillaries and offer a greater resistance to the passage of the vapor. Whereas, the slow freezer produces large crystals and they make rapid drying possible, but the large crystals damage the cells, produces separation and denaturation of the protein etc.




**Heat and mass transfer in the freeze drying**

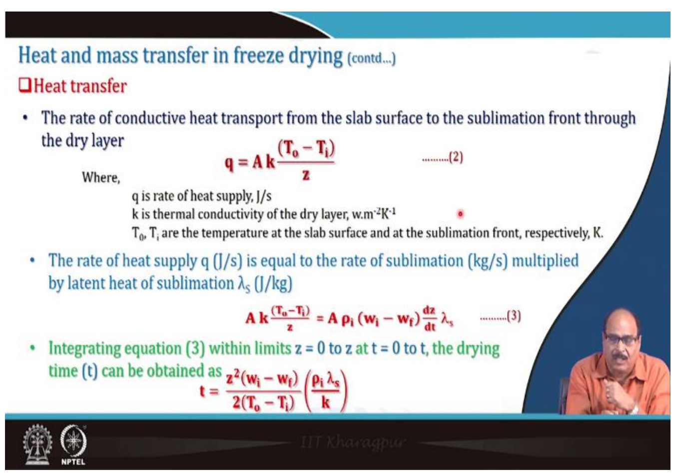
Heat can be delivered to the subliming front by two most common mechanisms. One is the radiation from the hot surfaces, i.e., where heat is delivered to the exposed surface of the dry zone by radiation, and then travels through the dry zone to the sublimation front, mainly by conduction. The water vapor released travels through the dry zone, in the opposite direction, from the sublimation front to the surface and then from there to the condenser. The second way is the contact with a hot surface. It can be seen in the figure that the material, the frozen mass is in direct contact with a hot surface. The trays containing the frozen material are placed on the heated shelves, heat is transferred to the sublimation zone by conduction through the frozen layer and water vapor is transferred through the dry layer.




An assumption can be done, that an incremental thickness dz of the slab is dried in a time increment of dt. It is shown in the figure. There is a frozen layer, dry layer. Heat is supplied from the frozen layer, water-vapor directly, ice in the vapor form, it goes out and the thickness of the layer is z. The rate of the sublimation i.e.,

$$\frac{dw}{dt} = A\,\rho_i\,(w_i - w_f)\frac{dz}{dt}$$

Here, A is the slab surface area. $\rho_i$ is the density of the frozen food and $w_i$ and $w_f$ are the initial and final water content, respectively. At steady state, the rate of sublimation must be in accordance both with the rate of the heat transfer to the sublimation front and with the rate of mass transfer from the sublimation front.



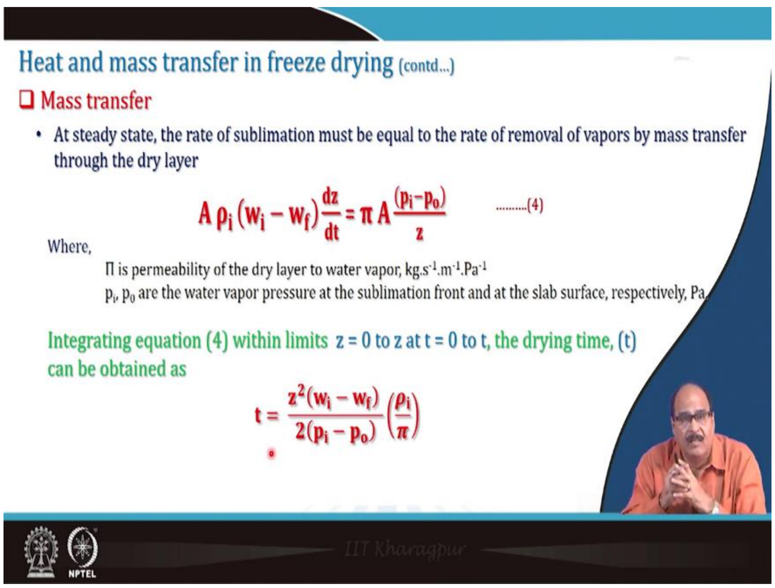

**Heat transfer**

The rate of conductive heat transport from the slab surface to the sublimation front through the dry layer.

$$q = A\,k\,\frac{(T_0 - T_i)}{z}$$

where q is the rate of heat supply, k is the thermal conductivity of dry layer and the $T_0$ and $T_i$ are the temperature at the slab surface at the sublimation front, respectively. The rate of heat supply, q, is equal to the rate of sublimation multiplied by latent heat of sublimation. This is according to the equation (3). Integrating equation (3) within the limits z is equal to from 0 to z, at t from 0 to t, the drying time (t) can be obtained.

$$t = \frac{z^2(w_i - w_f)}{2\,(T_0 - T_i)}\left(\frac{\rho_i\,\lambda_s}{k}\right)$$

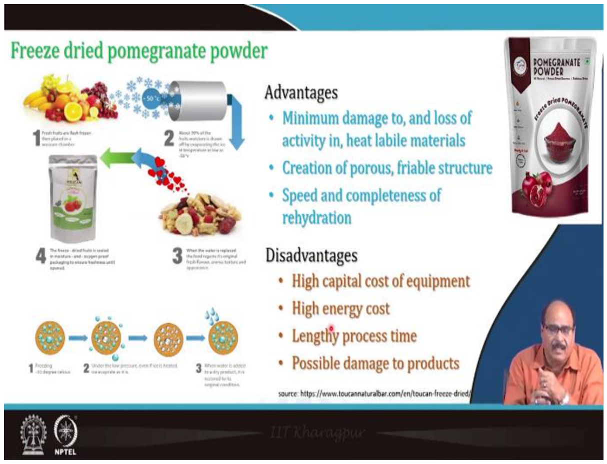



**Mass transfer**

A steady state, the rate of sublimation must be equal to the rate of removal of vapors by mass transfer through the dry layer. This can be represented by the equation (4). The integrating equation (4) within the limits z is equal to 0 to z, at t from 0 to t, the drying time, (t).

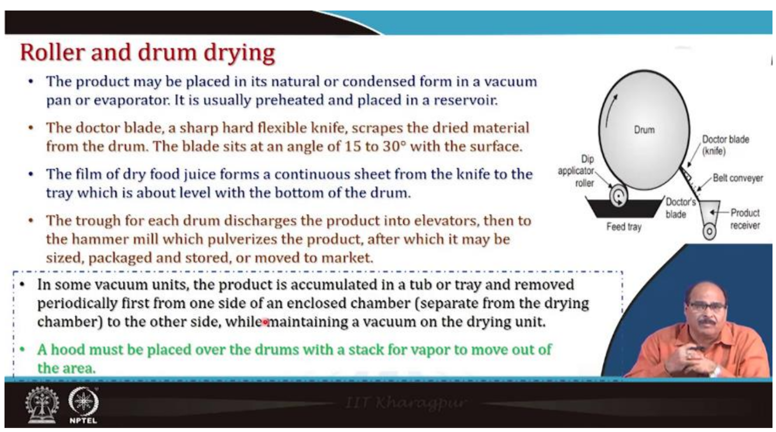
$$t = \frac{z^2(w_i - w_f)}{2\,(p_i - p_0)}\left(\frac{\rho_i}{\pi}\right)$$

where π is the permeability of the dry layer to water vapor, and $p_i$ and $p_0$ are the water vapor pressure at the sublimation front and at the slab surface, respectively. Using this equation, the drying time can be calculated.



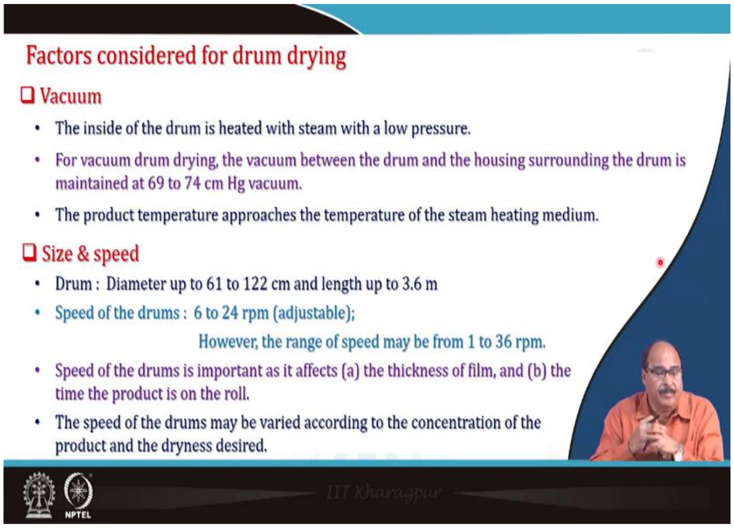

## Freeze dried pomegranate powder

Here, a case study has been in the figure. In case of freeze-dried pomegranate powder, the fresh material i.e., the pomegranate is taken first, converted into the juice, and it is concentrated. The concentrated juice is put into the freeze dryer. It is dried then. It is in the thick-form. It is further pulverized. Then freezing is done at -30 °C. Then under the low pressure, once it is heated, ice evaporates, and the water is added to a dried product, it is restored to its original condition. The advantages of this process are minimum damage and loss of the activity in the heat labile materials. There is creation of pores. A friable structure can be obtained. Speed and completeness of the rehydration occurs. However, the major disadvantages are like it is a very high capital cost of the equipment. High energy cost is required in this process. It requires a lengthy process time, and possible damage to the product occurs in this process.




## Roller and drum drying

The product may be placed in its natural or condensed form in a vacuum pan or evaporator. There is a drum. These drums are internally heated. It may be single drum, twin drums, three drums etc. Feed material of the feed tray of suitable consistency is put and the drums move. After that, it takes the material and the drum is internally heated, so heat transfer takes place. Finally, there is a doctor blade, a sharp hard flexible knife, scraps out the dried material, and the then the material is taken in a conveyor belt. The product is pulverized. In some vacuum units, the product is accumulated in a tub or tray, and then removed periodically, first from one side of the enclosed chamber to the other side, while maintaining a vacuum and on the drying unit. A hood must be placed over the drums with a stack of vapours to move out of the area.



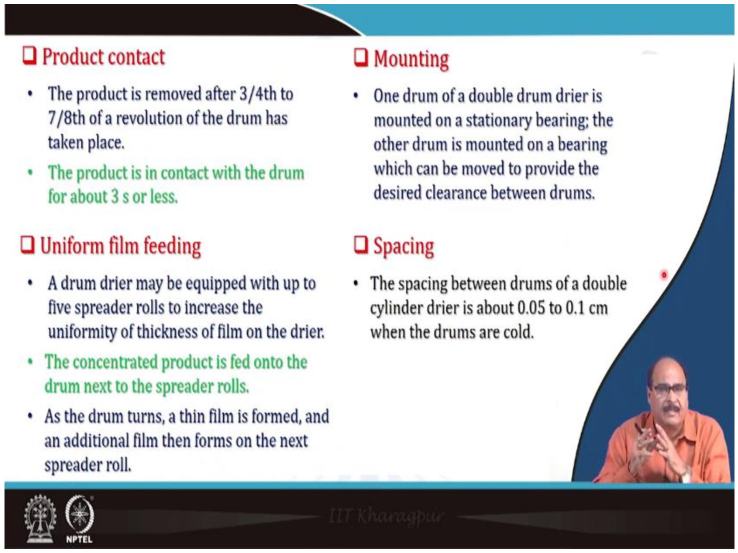

**The factors considered for the drum drying**

**Vacuum**

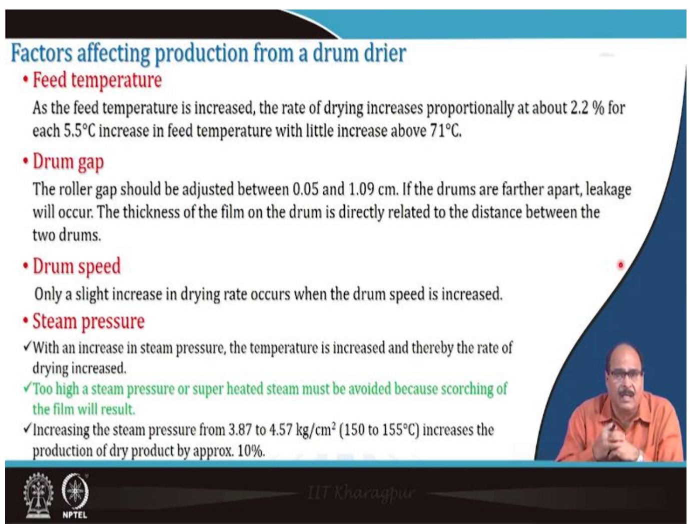
For vacuum drum drying, the vacuum between the drum and the housing surrounding the drum is maintained between 69 to 74 cm Hg vacuum. The product temperature approaches the temperature of the steam heating medium. In the case of vacuum, the inside of the drum is heated with the steam with a low pressure.

**Size and speed**

The diameter of the drum may be up to 61 to 122 cm, and length may be up to 3.6 m. Speed may be from 6 to 24 rpm. However, it is adjustable. It has to be adjusted depending upon the material characteristics. The speed of the drum is an important factor as it affects the thickness of the film as well as the time the product is on the roll. The speed of the drum may be varied according to the concentration of the product and the dryness desired.

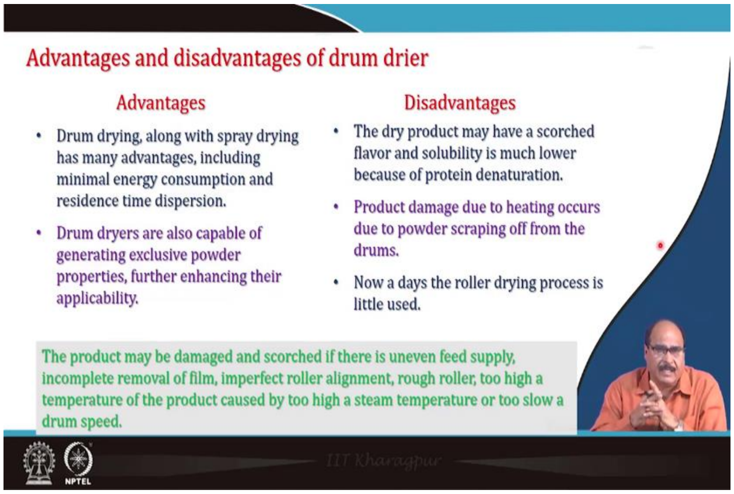



The other factors include product contact, uniform film feeding, mounting, spacing etc. In mounting, the one drum of a double drum drier is mounted on a stationary bearing; the outer drum is mounted on a bearing, which can be moved to provide the desired clearance between the drums. The spacing between the drums of a double cylinder dryer is about 0.05 to 0.1 cm when the drums are cold.



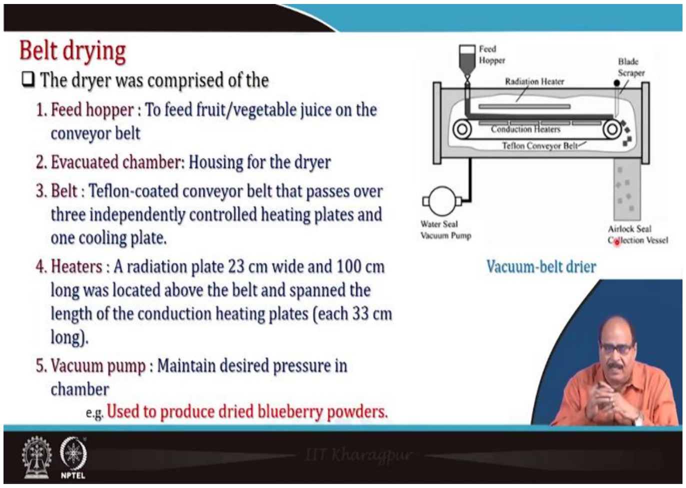

**Factors affecting production from a drum drier**

The factors, which influence the production from a drum dryer, can be the feed temperature, drum gap, drum speed and steam pressure etc. If the feed temperature is high, then drying rate will be high. The rate of drying increases proportionally at about 2.2 % for each 5.5 °C increase in the feed temperature. Similarly, the clearance between the gap, the speed at which the drum rotates, stream pressure, all these influences the production from drum driers.



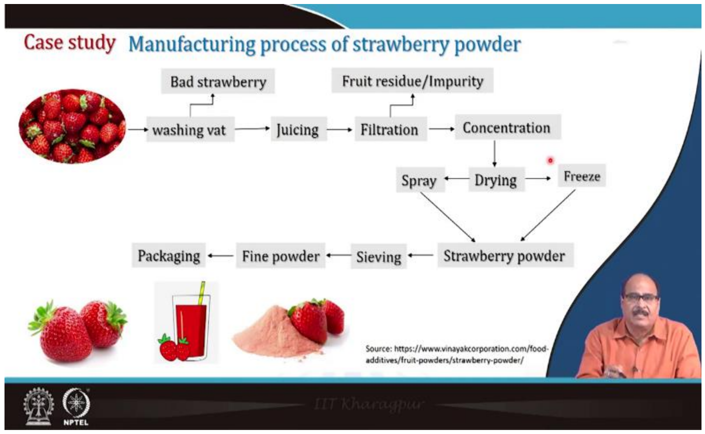

**Advantages and disadvantages of the drum drying**

The drum drying along with the spray drying processes have many advantages including minimal energy consumption, and residence time dispersion. Drum dryers are also capable of generating exclusive powder properties, further enhancing their applicability etc. There are disadvantages like the dry product may have a scorched flavor and solubility is much lower because of the protein denaturation. The product may be damaged as heating occurs due to powder scrapping off from the drums. The product may be damaged and scorched, if there is uneven feed supply, incomplete removal of film or imperfect roller alignment etc.




**Belt drying**

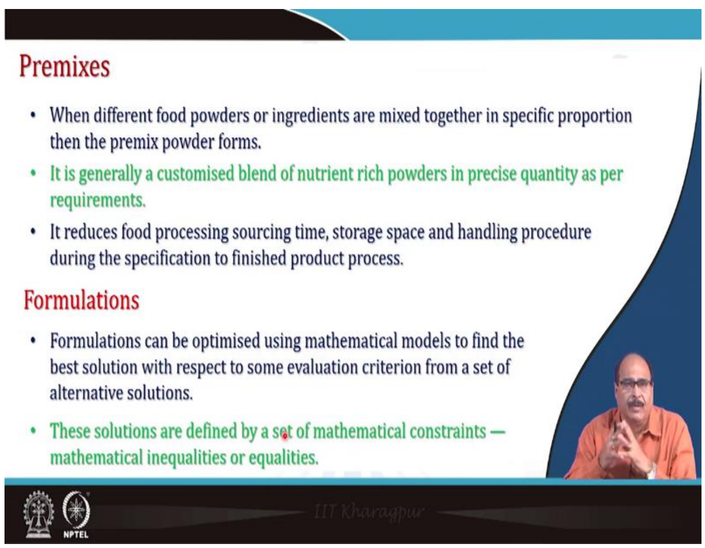
The drier comprises a feed hopper, evacuated chamber, a belt, heaters, vacuum pump etc. The belt material should be Teflon-coated conveyor belt, so that it is a non-sticky material. In case of heaters, a radiation plate 23 cm wide and 100 cm long is located above the belt and spanned the length of the conduction heating plates. Vacuum pump is a pump, which maintains the desired pressure inside the system.




**Case study**

**Manufacturing process of strawberry powder**

The figure shows the strawberry crushing, washing vat etc. The unwanted and bad quality material is removed. The juice is prepared, and it is concentrated and after that, it is either spray dried or freeze dried. Finally, the sprayed or freeze-dried powder is prepared and it is packaged suitably.

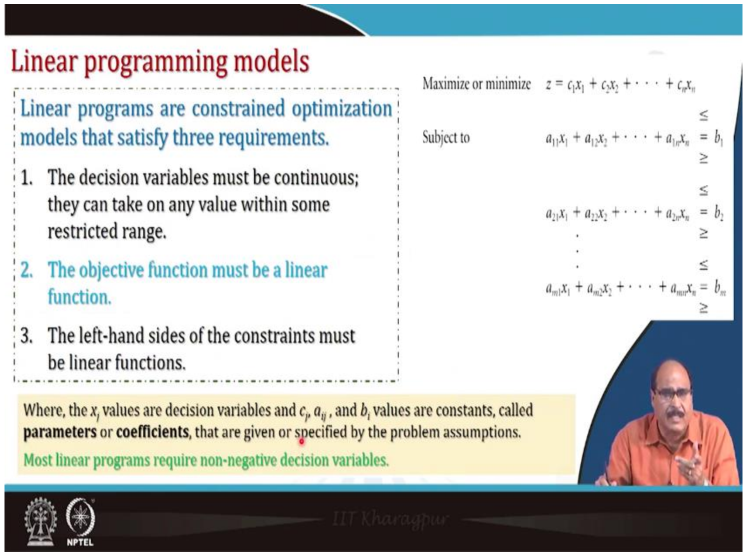



**Premixes**

When different food powders or ingredients are mixed together in a specific proportion, then the premix powder forms. It is generally customized blend of nutrient-rich powders in precise quantity as per the requirement. It reduces food processing sourcing time, storage space, and handling procedures during the specification to the finished products.

**Formulations**

Formulations can be optimized using mathematical models to find best solution with respect to some evaluation criterion from a set of the alternative solutions. These solutions are defined by set of mathematical constraints, may be mathematical inequalities or mathematical equalities etc.




**Linear programming models**

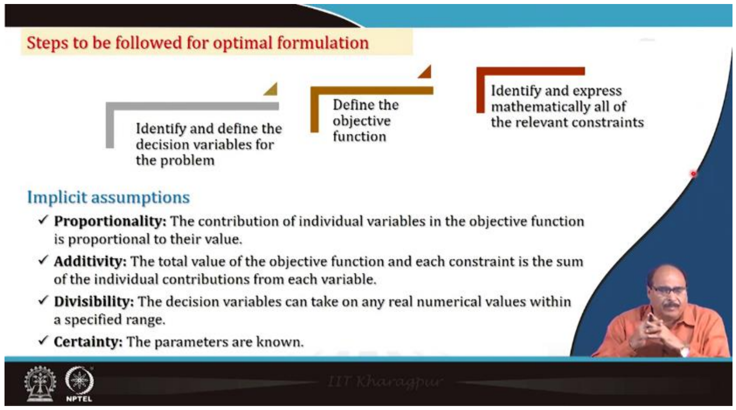
There are several mathematical models which are available, which are proposed. The linear programming model is one. Linear programs are constrained, optimization models, that satisfy three requirements. One is that the decision variables must be continuous, they can take on any value within some restricted range. The second one is that the objective function must be a linear function and the third one is that the left-hand sides of the constant must be linear functions. The figure shows the minimize or maximize of any particular value z.

$$\text{Maximize or minimize } Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n$$

$$\text{Subject to } a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = \geq \leq b_1$$

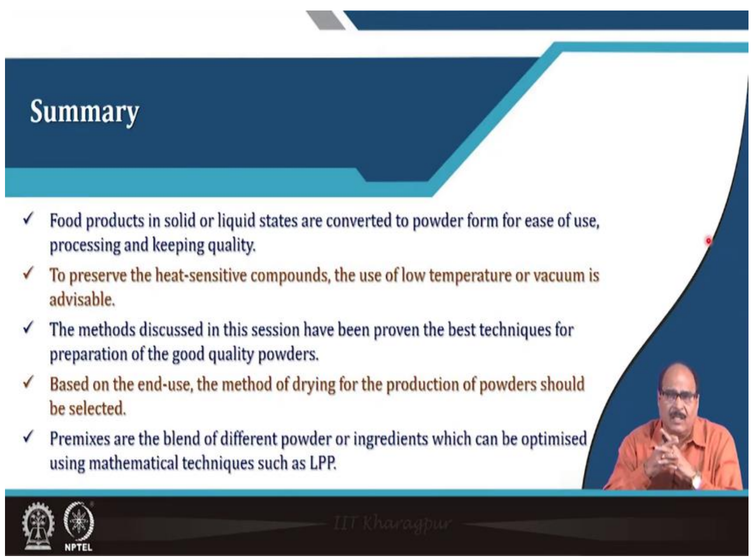
$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = \geq \leq b_2$$

where $x_i$ values are the decision variables, and $c_j$, $a_{ij}$ and $b_i$ values are constants. This is called parameters or coefficients, that are given or specified by the problem assumptions. Most linear programs require non-negative decision variables.



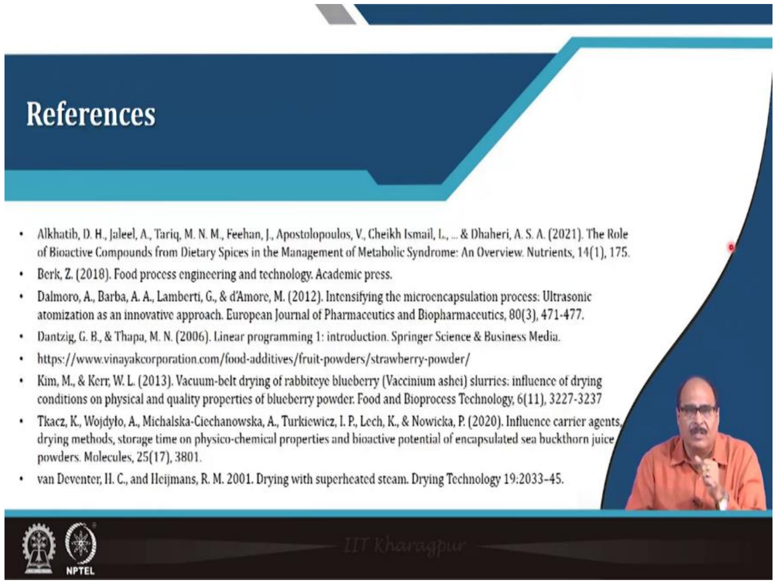

**Steps to be followed for optimal formulation**

The steps to be followed for formulation are identifying and define the defining variable for the problems, defining the objective function and finally, identifying and expressing mathematically all the relevant constraints and implementing implicit assumptions. Implicit assumptions may be proportionality i.e., the contribution of the individual in the objective function is proportional to their value, additivity i.e., the total value of the objective function and each constant is the sum of the individual contribution from each variable, divisibility i.e., the decision variable can take on any real numerical values within a specified range, and finally, certainty i.e., the parameters are known.




**Summary**

In this lecture, the different methods of making food powders, and particularly fruits and vegetable juice powder, fruits and vegetable pulp powder are discussed. Since, the heat-sensitive components have the low Tg values, they contain low melting components, use of low temperature or vacuum is advisable to preserve them. They should not be subjected to very high temperature in the drying process. Whether it is spray drying or drum drying or belt drying, they will create a problem of stickiness. Therefore, the proper care has to be taken in these kinds of drying processes. When the powder is obtained, this powder, using appropriate formulas and techniques, can be blended together in a definite proportion in order to get the desired product. This process is used for preparation of various soup premixes, various ready to serve vegetables juices etc. They are available in the market and they can be prepared by using these techniques.




The references used in this lecture are mentioned above.