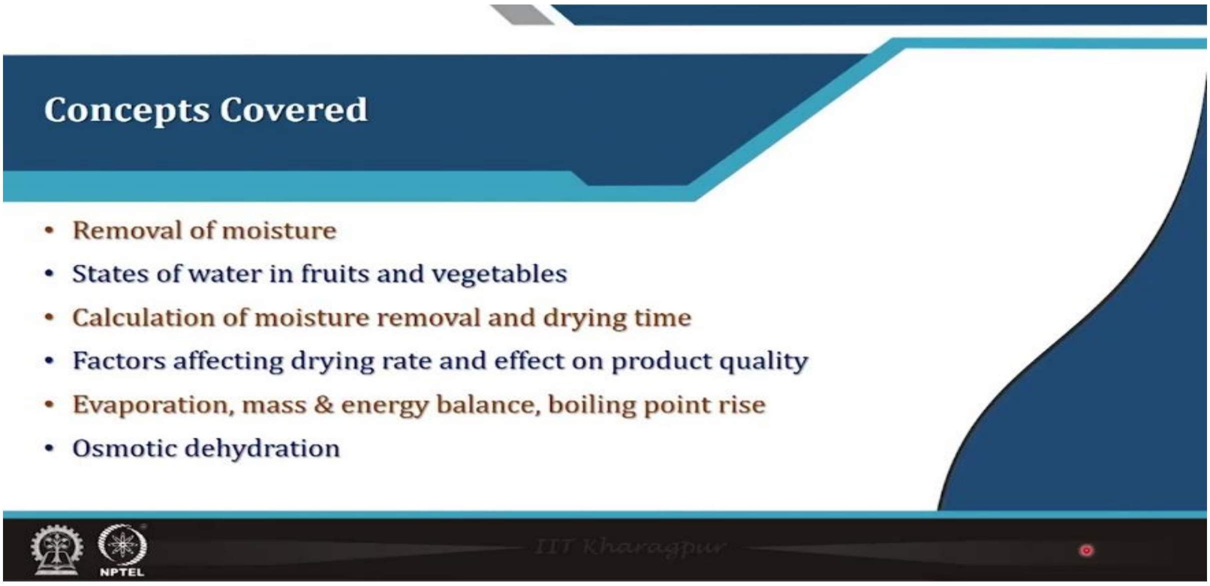
**Post-Harvest Operations and Processing of Fruits,**
**Vegetables, Spices and Plantation Crop Products**

**Professor H N Mishra**
**Agriculture and Food Engineering Department**
**Indian Institute of Technology Kharagpur**

**Lecture 12**

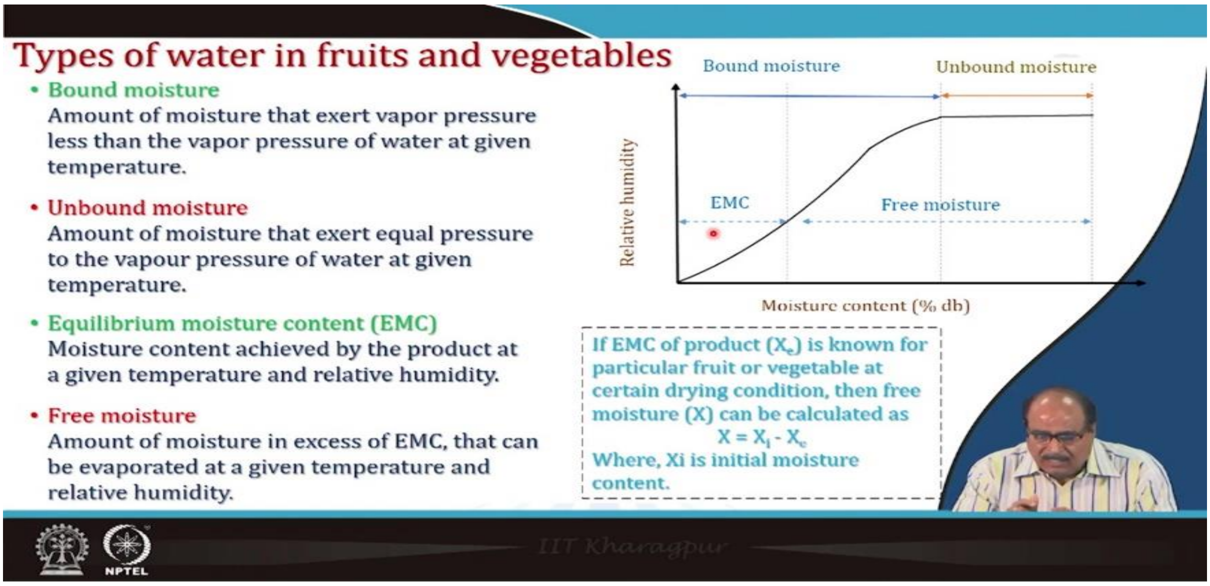
## Processing by Removal of Water

In this lecture the processing and preservation of fruits and vegetable by removal of water is explained. The concepts covered are types of water present in fruits and vegetable, principles of removal of water, its benefits, calculation of moisture removal and drying time factors affecting drying rate and its effect on products quality, evaporation mass and energy balance or boiling point rise and its apex and drying process concentration process. Basic concepts of reverse osmosis which is used for osmotic concentration and osmotic dehydration of fruits and vegetables are also discussed.




## Types of Water in Fruits & Vegetables

Different types of water that are present in the fruits and vegetable are bound water, unbound water, equilibrium moisture content and the free moisture. Bound water is the amount of moisture that exerts vapor pressure less than the vapor pressure of water at given temperature. Unbound water is the amount of moisture that exert equal pressure to the vapor pressure of water at given temperature.



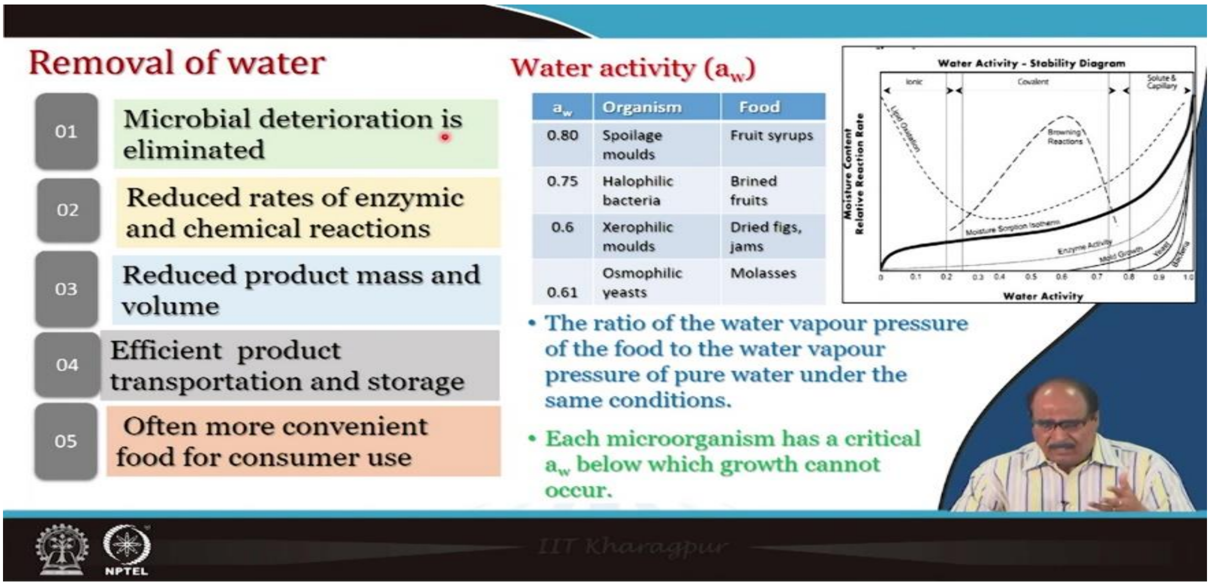

Equilibrium moisture content (EMC) is the moisture content achieved by the product at a given temperature and relative humidity. Free moisture is the amount of moisture in excess of EMC that can be evaporated at a given temperature and relative humidity. If EMC of product (Xe) is known for particular fruit or vegetable at certain drying condition, then free moisture (X) can be calculated as

X = Xi - Xe

Where, Xi is initial moisture content.

**Removal of Water**

The free water or unbound water gives the commodity its water activity. Water activity is related to various chemical and biochemical reactions. It influences the instability of the

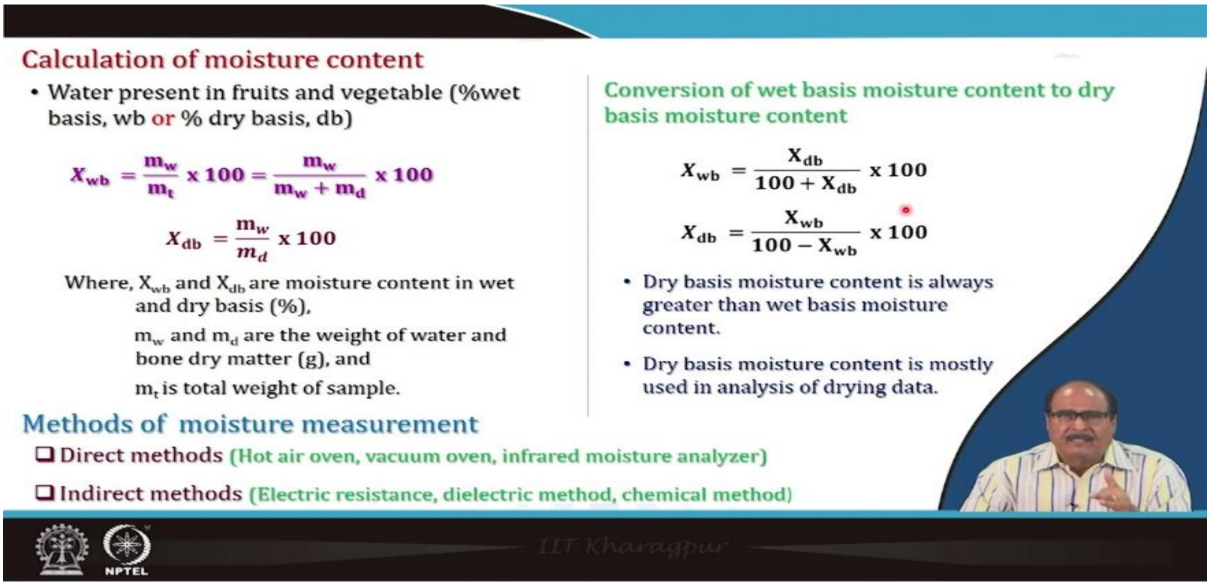


products and microbial growth ash shown in the figure. The table shows the minimum water activity at which the various microorganisms can grow in different fruit products.

Water activity is the ratio of the water vapor pressure of the food to the water vapor pressure of pure water under the same conditions. Each microorganism has a critical $a_w$ below which growth cannot occur. In the water removal process water activity of the commodity is lowered, so that the microorganism growth and other chemical reactions are suppressed.

The benefits of the removal of water are microbial deterioration elimination, reduction in rates of enzymic and chemical reactions, reduction in product mass and volume, efficient product transportation and storage and often more convenient food for consumer use.

**Calculation of Moisture Content**




The water present in fruits and vegetables are generally expressed either onn wet basis (wb) or on dry basis (db).

$$X_{wb} = \frac{m_w}{m_t} \times 100 = \frac{m_w}{m_w + m_d} \times 100$$

$$X_{db} = \frac{m_w}{m_d} \times 100$$

Where, $X_{wb}$ and $X_{db}$ are moisture content in wet and dry basis (%),

$m_w$ and $m_d$ are the weight of water and bone dry matter (g), and

$m_t$ is total weight of sample.

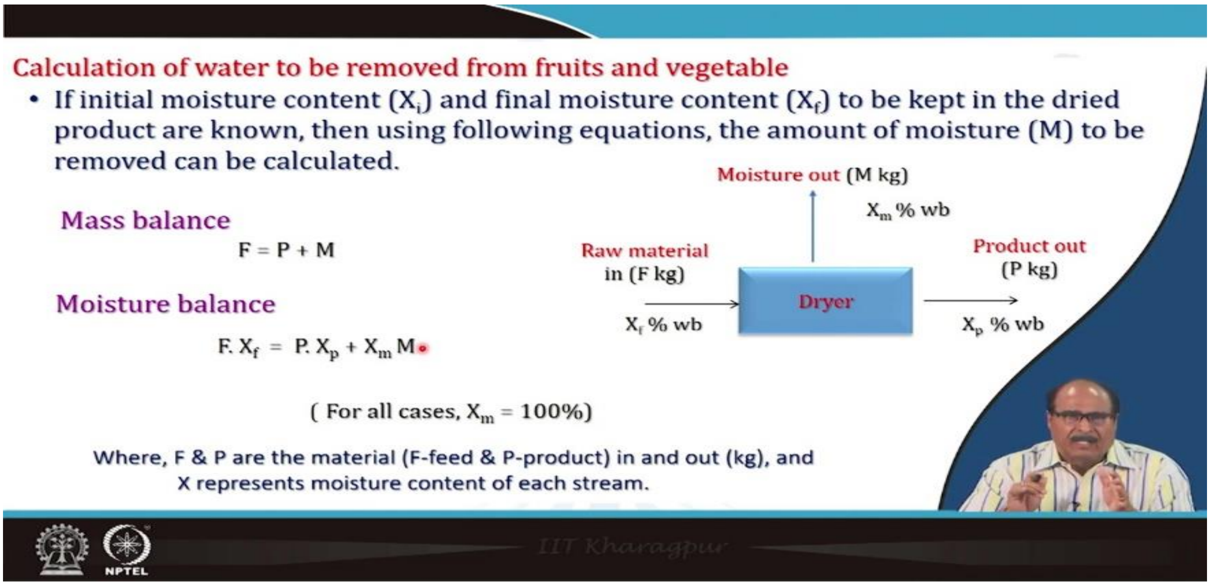
**Conversion of wet basis moisture content to dry basis moisture content**

$$X_{wb} = \frac{X_{db}}{100 + X_{db}} \times 100$$

$$X_{db} = \frac{X_{wb}}{100 - X_{wb}} \times 100$$

Methods of moisture measurement are direct methods such as hot air oven, vacuum oven, infrared moisture analyzer and indirect methods such as electric resistance, dielectric method, and chemical method.

**Calculation of Water to be Removed from fruits and vegetables:**




If initial moisture content ($X_i$) and final moisture content ($X_f$) to be kept in the dried product are known, then using following equations, the amount of moisture (M) to be removed can be calculated.

In the figure it's shown that in F kg of the raw material is put into the dryer and the raw material has moisture content Xf% wet basis and after the drying process is over M kg of the moisture is removed and the product obtained is P kg with Xp % wet basis. The mass balance equation is,

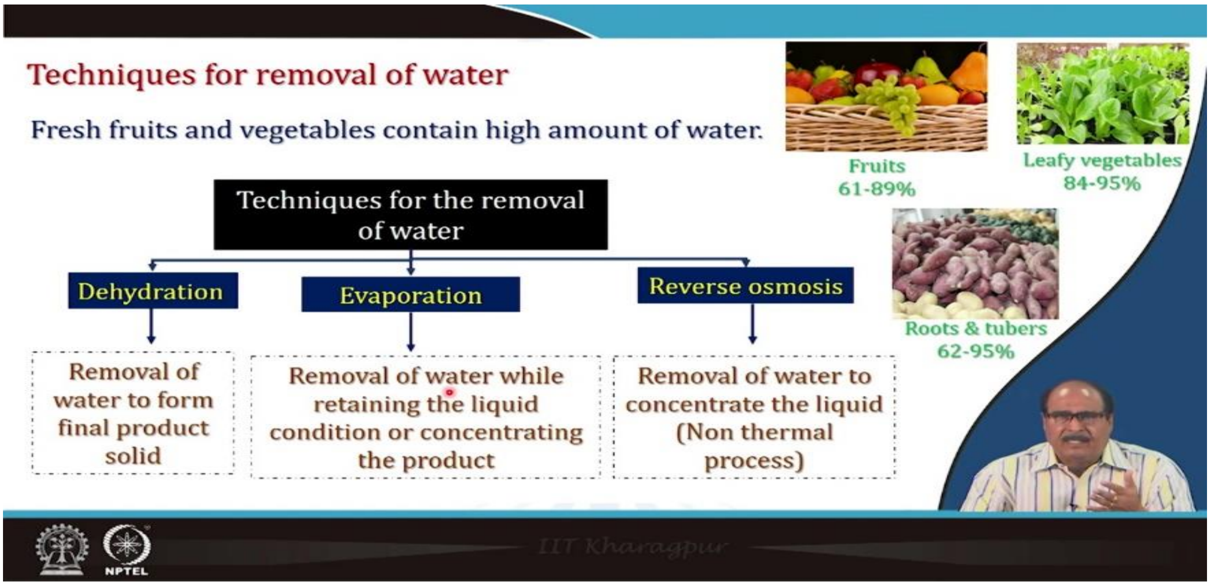
$$F = P + M.$$

The moisture balance equation is

$$F. X_f = P. X_p + X_m M$$

( For all cases, Xm = 100%), where, F & P are the material (F-feed & P-product) in and out (kg), and X represents moisture content of each stream.

**Techniques for Removal of Water**

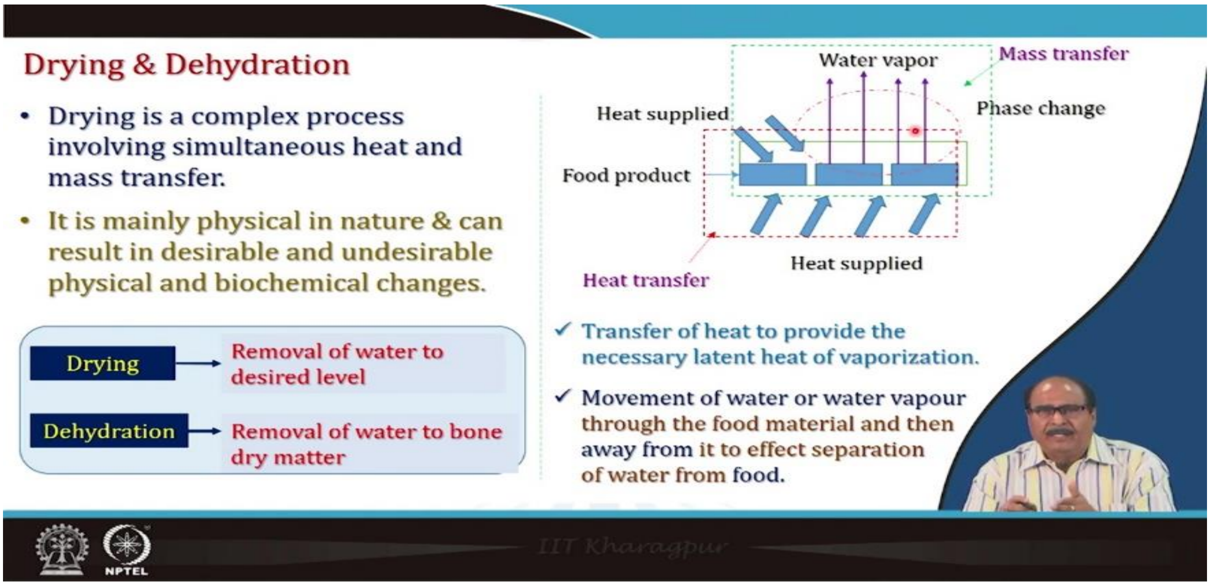



Fresh fruits and vegetable contain g high amount of water. Fruits contain about 61 – 89% moisture, vegetables contain 84 – 95% moisture and roots and tubers contain 62 – 95% moisture. Dehydration causes removal of water to form final product as solid, while evaporation can be used for removal of water while retaining the liquid condition or concentrating the product. Reverse osmosis can be used for removal of moisture to concentrate the liquid, which is a non-thermal process that results in better product quality.

**Drying and Dehydration**

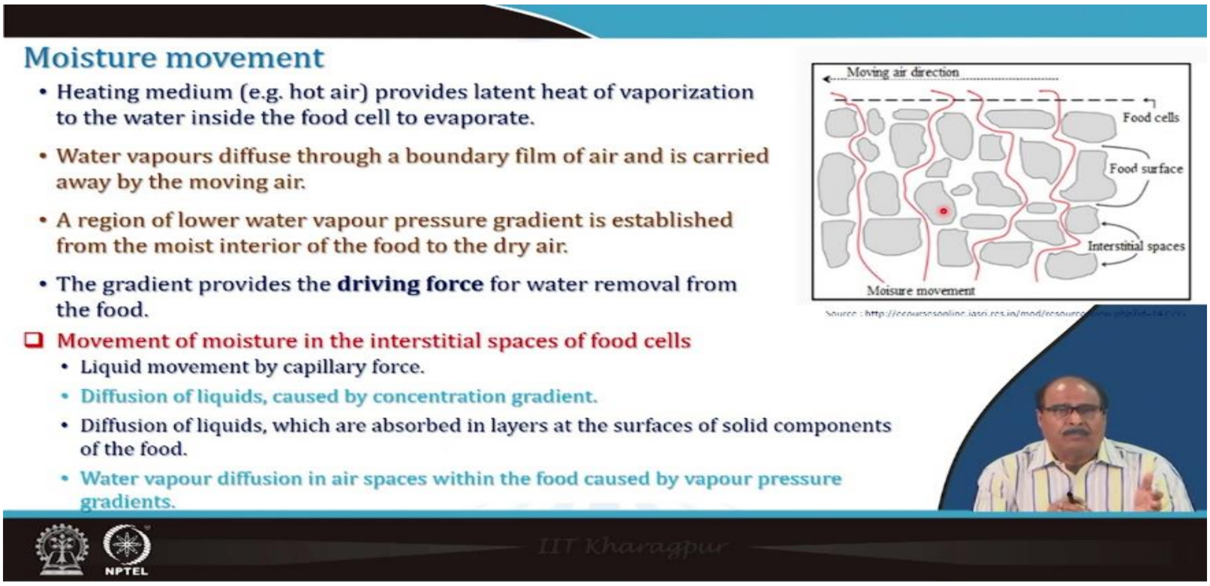
Drying is a complex process involving simultaneous heat and mass transfer. It is mainly physical in nature & can result in desirable and undesirable physical and biochemical changes. Drying is removal of water to desired level, while dehydration is removal of water to bone dry matter.

As shown in figure, heat is supplied to food product to cause phase change of water to vapour which is removed by mass transfer. The transfer of heat provide the necessary latent heat of vaporization and movement of water or water vapor through the food material and then away from it to effect separation of water from the food.




**Moisture Movement**

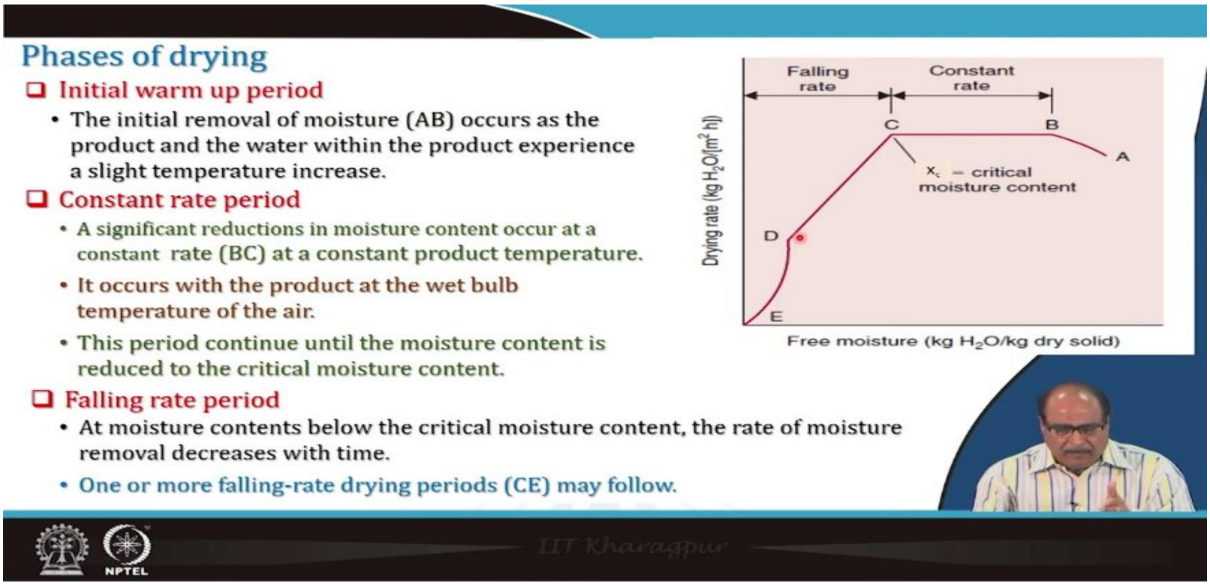
The figure in the slide shows the flow of heat and movement of moisture within the material as well as to outside the material. Heating medium (e.g. hot air) provides latent heat of




vaporization to the water inside the food cell to evaporate. Water vapours diffuse through a boundary film of air and is carried away by the moving air. A region of lower water vapour pressure gradient is established from the moist interior of the food to the dry air. The gradient provides the driving force for water removal from the food.

Movement of moisture in the interstitial spaces of food cells is through liquid movement by capillary force, diffusion of liquids, caused by concentration gradient, diffusion of liquids, which are absorbed in layers at the surfaces of solid components of the food, and water vapour diffusion in air spaces within the food caused by vapour pressure gradients.

**Phases of Drying**



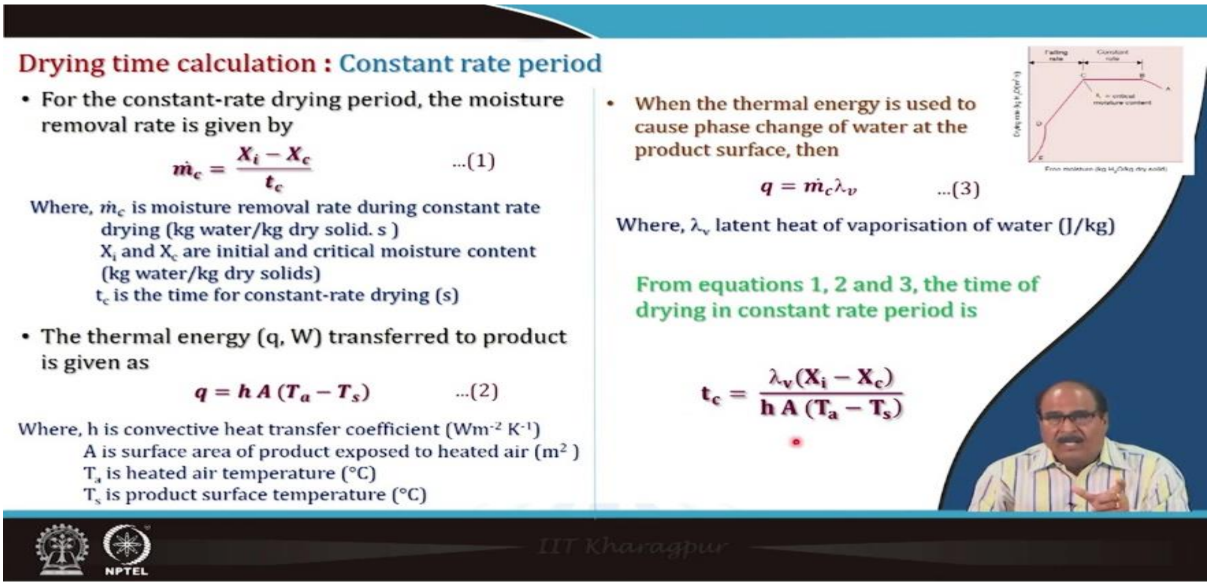

Depending upon the moisture content available in the material drying may occur in various phases. In initial warm up period, the initial removal of moisture (AB) occurs as the product and the water within the product experience a slight temperature increase. In constant rate period, a significant reduction in moisture content occurs at a constant rate (BC) at a constant product temperature. It occurs with the product at the wet bulb temperature of the air. This period continue until the moisture content is reduced to the critical moisture content. During falling rate period, at moisture content below the critical moisture content the rate of the moisture removal decreases with time. Depending upon the commodity one or more falling rate drying periods (CE) may follow.

**Drying Time Calculation: Constant Rate Period**

For the constant rate period drying, that moisture removal rate is given by

$$\dot{m}_c = \frac{(X_i - X_c)}{t_c}$$

where, $\dot{m}_c$ is moisture removal rate during constant rate drying (kg water/ kg dry solid), $X_i$ and $X_c$ are initial and critical moisture content (kg water / kg dry solids), $t_c$ is the time for constant-rate drying (s).




The thermal energy (q, W) transferred to product is given as,

$$q = hA\,(T_a - T_s)$$

Where, h is convective heat transfer coefficient ($Wm^{-2} K^{-1}$), A is surface area of product exposed to heated air ($m^2$), $T_a$ is heated air temperature (°C) and $T_s$ is product surface temperature (°C).

When the thermal energy is used to cause phase change of water at the product surface, then

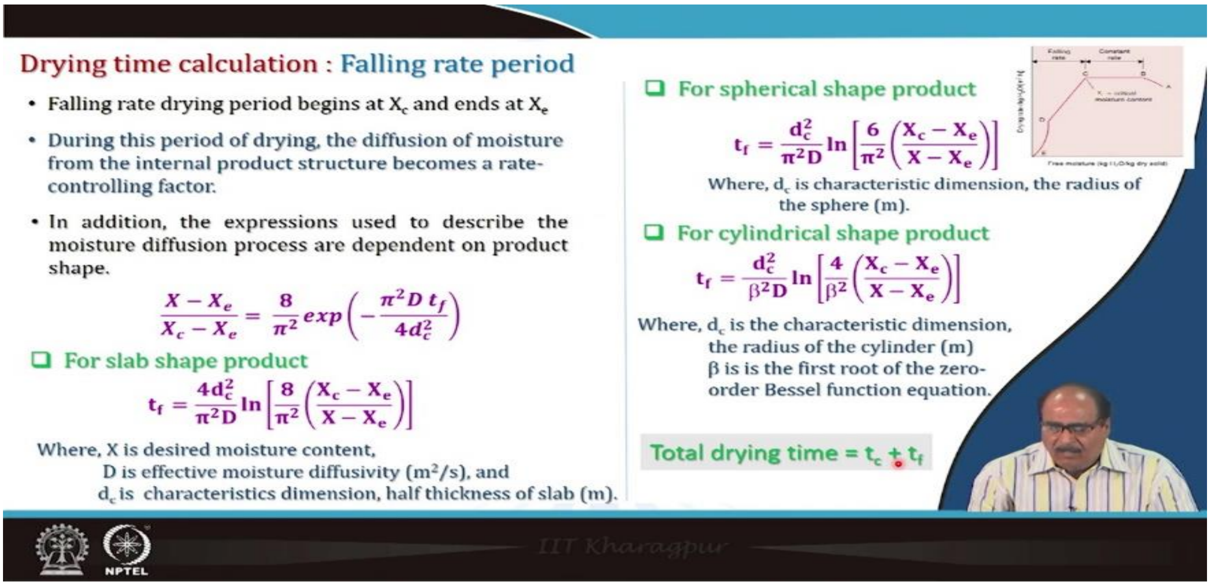
$$q = \dot{m}_c \lambda_v$$

Where, $\lambda v$ latent heat of vaporisation of water (J/kg). From equations 1, 2 and 3, the time of drying in constant rate period is

$$t_c = \frac{\lambda_v (X_i - X_c)}{hA(T_a - T_s)}$$

**Drying Time Calculation: Falling Period**

Falling rate drying period begins at Xc and ends at Xe. During this period of drying, the




diffusion of moisture from the internal product structure becomes a rate-controlling factor. In addition, the expressions used to describe the moisture diffusion process are dependent on product shape.

$$\frac{X - X_e}{X_c - X_e} = \frac{8}{\pi^2}(-\frac{\pi^2 D t_f}{4d_c^2})$$

For slab shaped product the equation is re-written as,

$$t_f = \frac{4d_c^2}{\pi^2 D}\ln[\frac{8}{\pi^2}\left(\frac{X_c - X_e}{X - X_e}\right)]$$

Where, X is desired moisture content, D is effective moisture diffusivity ($m^2$/s), and $d_c$ is characteristics dimension, half thickness of slab (m).

For spherical shaped product,

$$t_f = \frac{d_c^2}{\pi^2 D}\ln[\frac{6}{\pi^2}\left(\frac{X_c - X_e}{X - X_e}\right)]$$

Where, $d_c$ is characteristic dimension, the radius of the sphere (m).

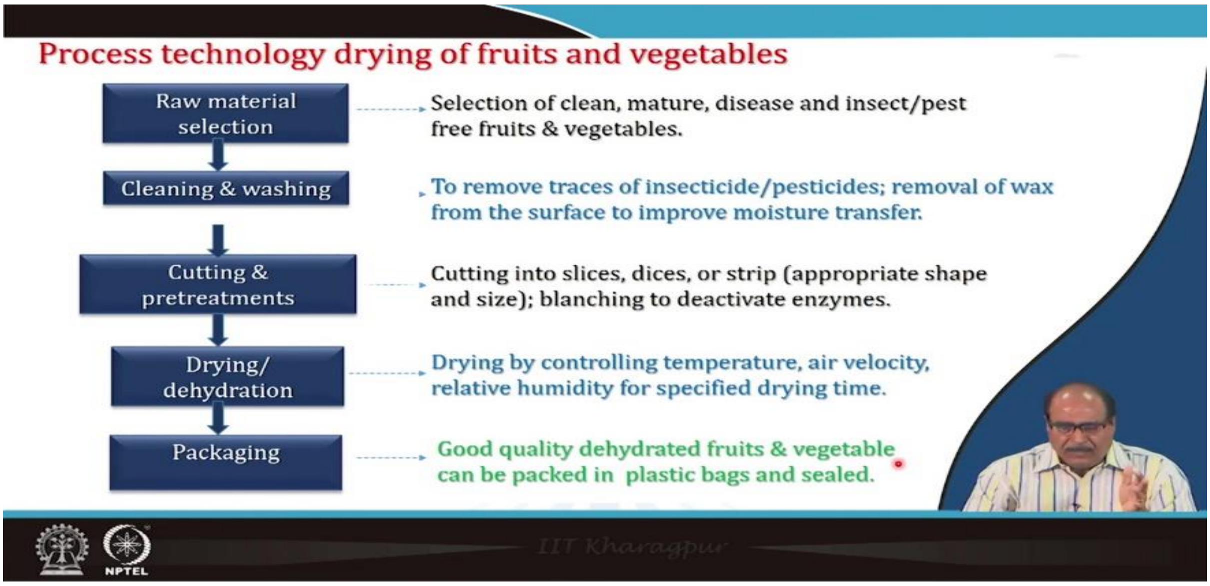
For cylindrical shaped product,

$$t_f = \frac{d_c^2}{\beta^2 D} \ln[\frac{4}{\beta^2}\left(\frac{X_c - X_e}{X - X_e}\right)]$$

Where, $d_c$ is the characteristic dimension, the radius of the cylinder (m), β is is the first root of the zero-order Bessel function equation.

Total drying time is represented by the equation, Total drying time = $t_c + t_f$

**Process technology for drying of fruits and vegetables**

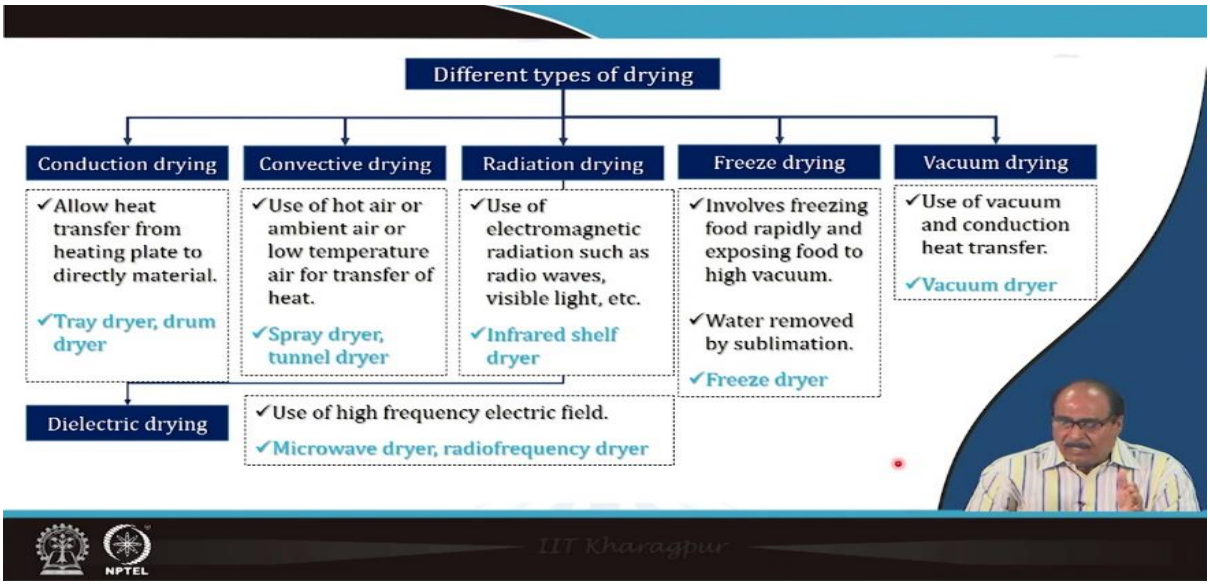



The process technology for drying of the fruits and vegetables included selection of raw materials, cleaning and washing, cutting and pretreatments, drying or dehydration and packaging. Raw material selection includes selection of clean, mature, disease and insect or pest free fruits and vegetables. They are subjected to various pretreatment like cleaning and washing to remove traces of insecticide/pesticides; wax from the surface to improve moisture transfer. It is followed by cutting and other pretreatment such as cutting into slices, dices, or strip (appropriate shape and size) and blanching to deactivate enzymes.

In different forms the product is dried or dehydrated drying by controlling temperature, air velocity, relative humidity for specified drying time. Good quality dehydrated fruits & vegetable obtained can be packed in plastic bags and sealed.

**Different Types of Drying**

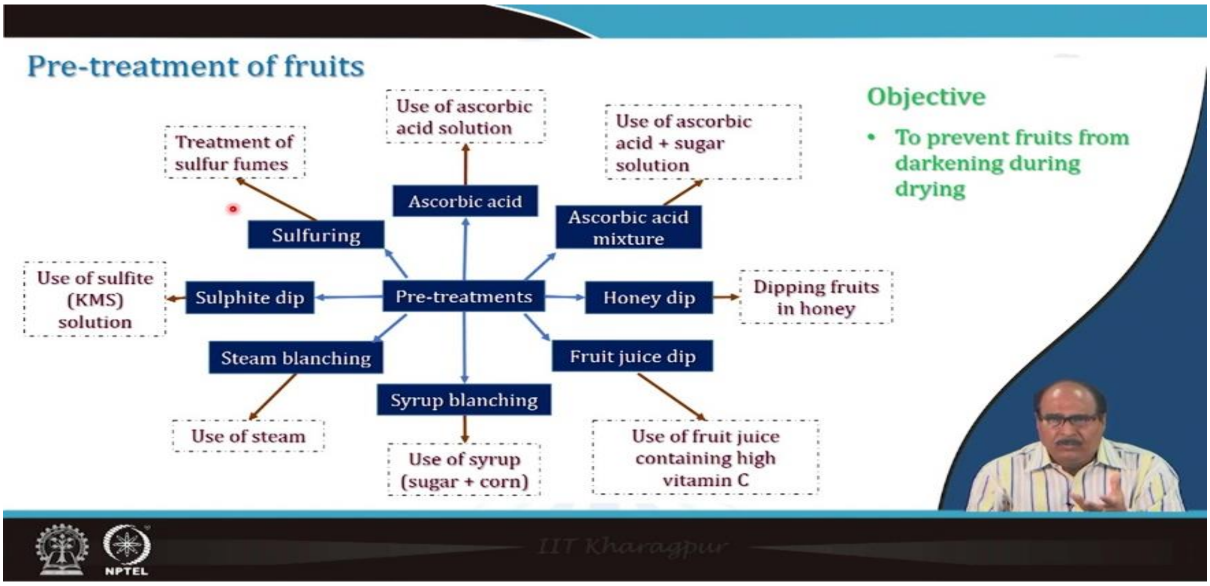
Different types of drying are conduction drying, which allows heat transfer from heating plate to directly on the material and dryers with conduction drying are tray dryer drum dryer etc. In convective drying, hot air or ambient air or low temperature air is used for transfer of heat. Example of this type of drying are spray dryer, tunnel dryers, et cetera.




Radiation drying uses electromagnetic radiation such as radio waves or visible light etc for removal of the moisture like infrared shelf dryer. Dielectric heating uses high frequency electric field like microwave dryer and radiofrequency dryer. Freeze drying involves freezing food rapidly and exposing food to high vacuum. Water is removed by sublimation. In vacuum drying vacuum and conduction heat transfer is used for water removal as in vacuum dryers.

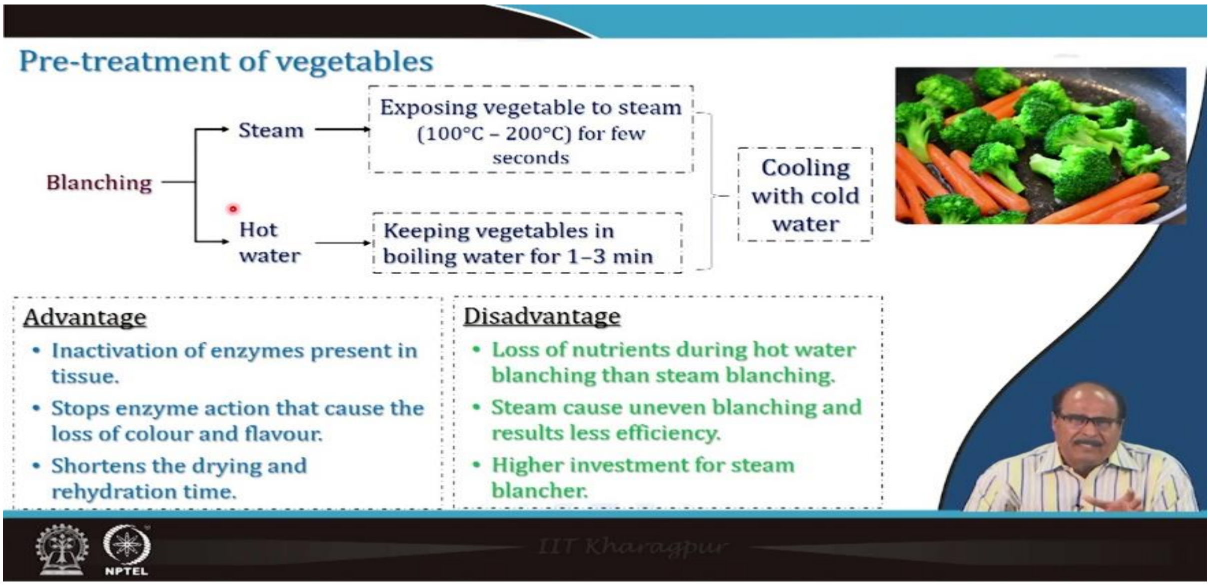
**Pretreatment of Fruits**

Different pretreatments are used to prevent the fruits from darkening during drying process. The various pretreatments used are steam and syrup blanching, fruit juice or honey dip, treatment with ascorbic acid and sulfur. Blanching is used to inactivate the enzyme in fruits. Sugar and corn syrup is used for syrup blanching. In case of fruit juice dip, fruit juices containing high amount of vitamin C is used. Use of ascorbic acid and sugar solution mixture or just ascorbic acid, treatments with sulfur fumes and use of KMS solution are various pretreatment methods used.



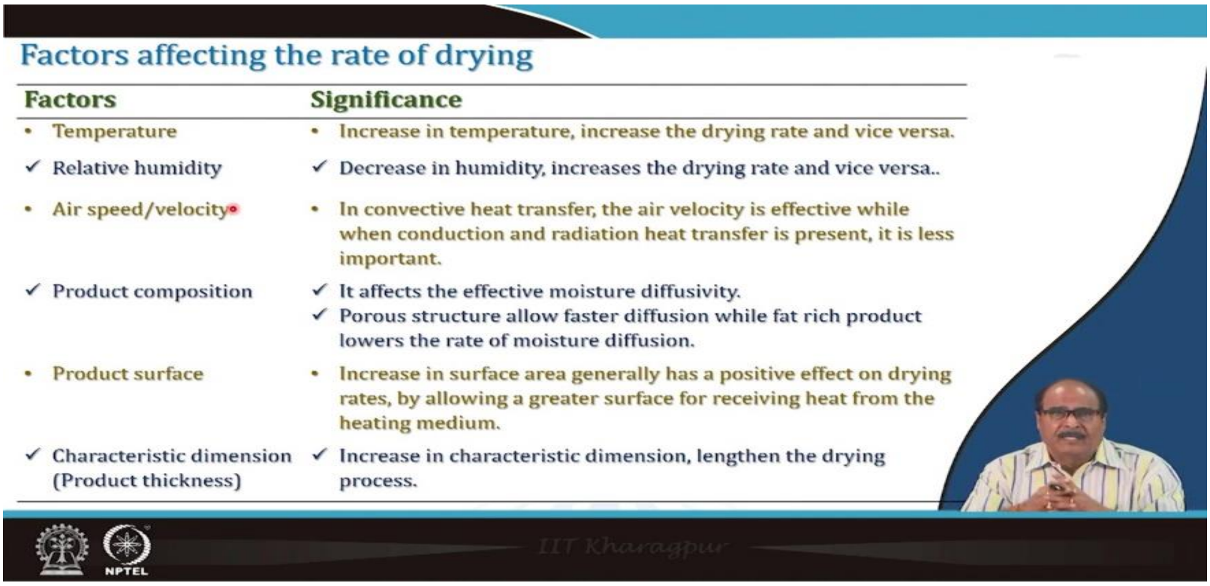

## Pretreatment of Vegetables

For vegetables, commonly steam blanching or hot water blanching is done to inactivate the enzymes which are responsible for the enzymatic browning of the product. The commodity is exposed to steam (100°C – 200°C) for few seconds in steam blanching and kept in boiling water for 1 – 3 min in hot water blanching and cooled down using cold water. The advantages of blanching are inactivation of enzymes present in tissue, stops enzyme action that cause the loss of colour and flavour and shortens the drying and rehydration time. The disadvantages are loss of nutrients during hot water blanching than steam blanching, steam cause uneven blanching and results less efficiency, and higher investment for steam blancher.



## Factors affecting the rate of drying

Factors that influence the rate of the drying are temperature increase in which increases the drying rate and vice versa. Relative humidity will cause decrease in the rate of the drying and vice versa. In convective heat transfer, the air velocity is effective while when conduction and radiation heat transfer is present, it is less important. Product composition It affects the effective moisture diffusivity.

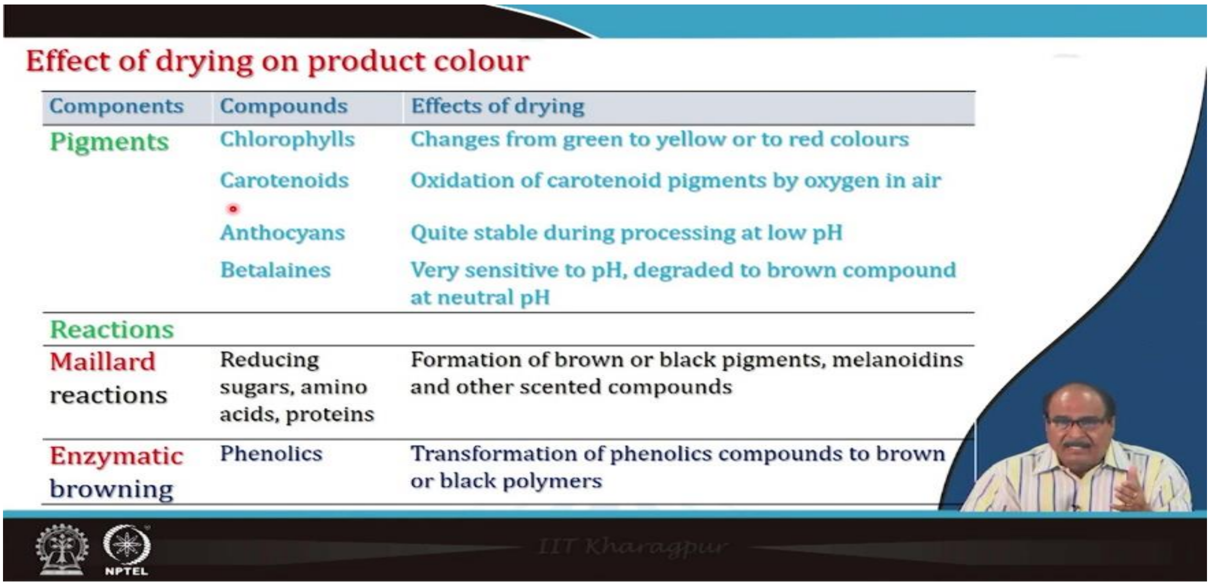



Porous structure allows faster diffusion while fat rich product lowers the rate of moisture diffusion. Increase in product surface area generally has a positive effect on drying rates, by allowing a greater surface for receiving heat from the heating medium. Increase in characteristic dimension (product thickness), lengthen the drying process.

## Effect of Drying on Product Colour

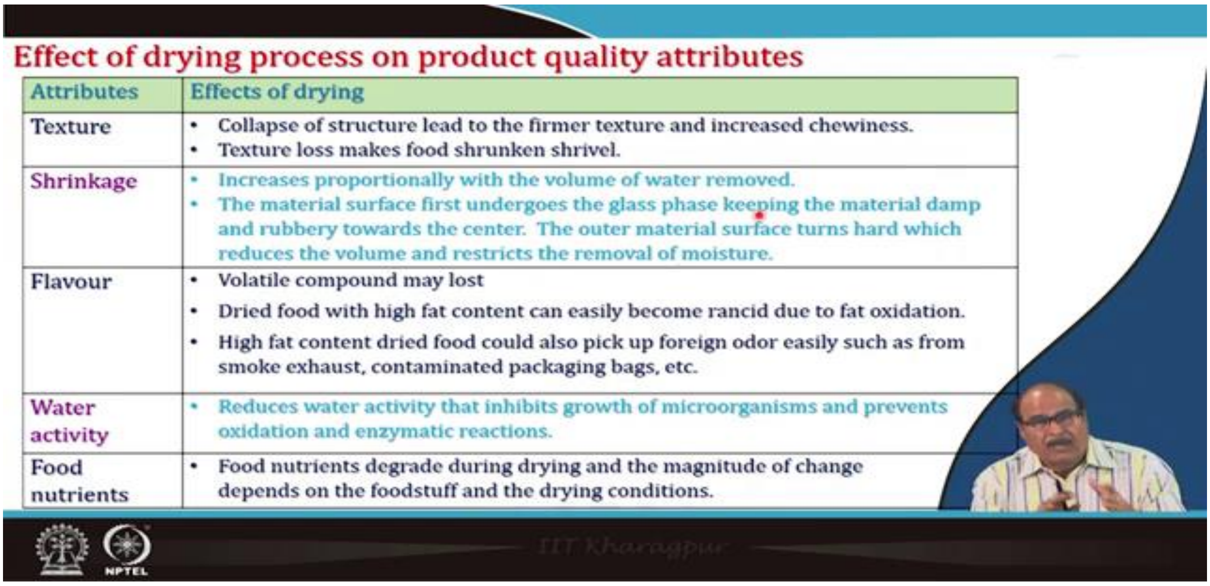
Drying influence the product color by affecting the pigment properties like chlorophylls is changed from green to yellow as it is converted into pheophytin, pheophorbide etc. Carotenoids are oxidized by oxygen in the air. Anthocyans are found to be quite stable during the processing at low pH. Betalaines are very sensitive to pH and degrade to brwon compound at neutral pH, during the heating process.

Similarly, Maillard reaction and enzymatic browning reactions also affects the color of the product. In Maillard reaction amino acids and protein reacts with reducing sugar to form brown or black pigments, melanoidins and other scented compounds. In enzymatic browning phenolics compounds are transformed to brown or black polymers.



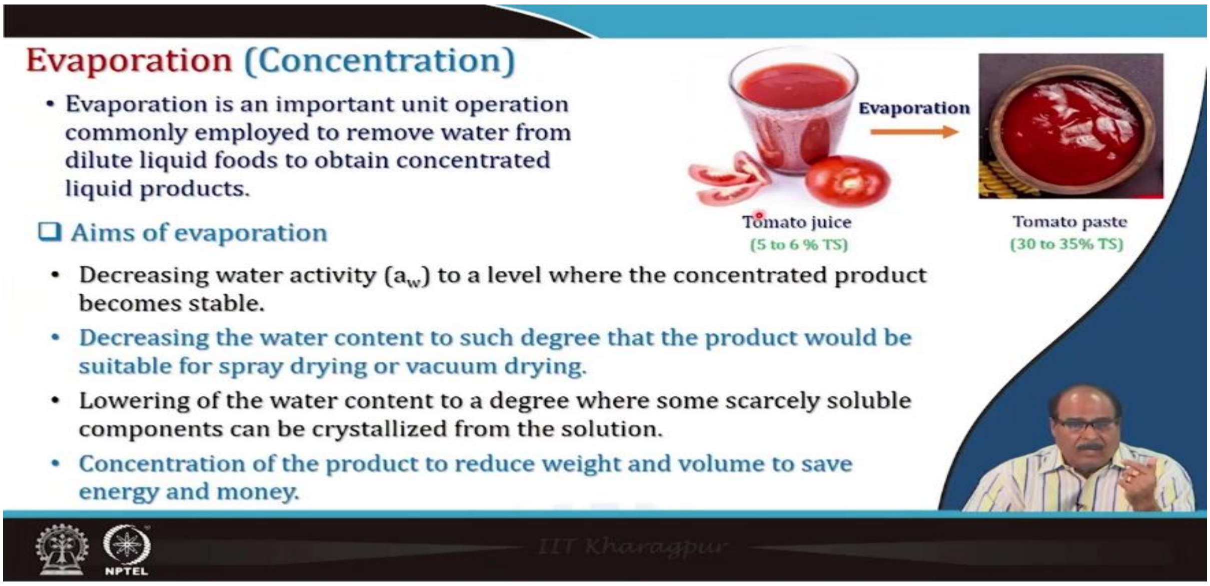

**Effect of drying process on product quality attributes**

Drying causes collapse of structure lead to the firmer texture and increased chewiness. Texture loss makes food shrunken shrivel. Shrinkage increases proportionally with the volume of water removed. The material surface first undergoes the glass phase keeping the material damp and rubbery towards the center.



The outer material surface turns hard which reduces the volume and restricts the removal of moisture. Flavor is affected as volatile compounds are lost. Dried food with high fat content can easily become rancid due to fat oxidation. High fat content dried food could also pick up foreign odor easily such as from smoke exhaust, contaminated packaging bags, etc. Drying reduces water activity that inhibits growth of microorganisms and prevents oxidation and enzymatic reactions. Food nutrients degrade during drying and the magnitude of change depends on the foodstuff and the drying conditions.

**Evaporation (Concentration)**

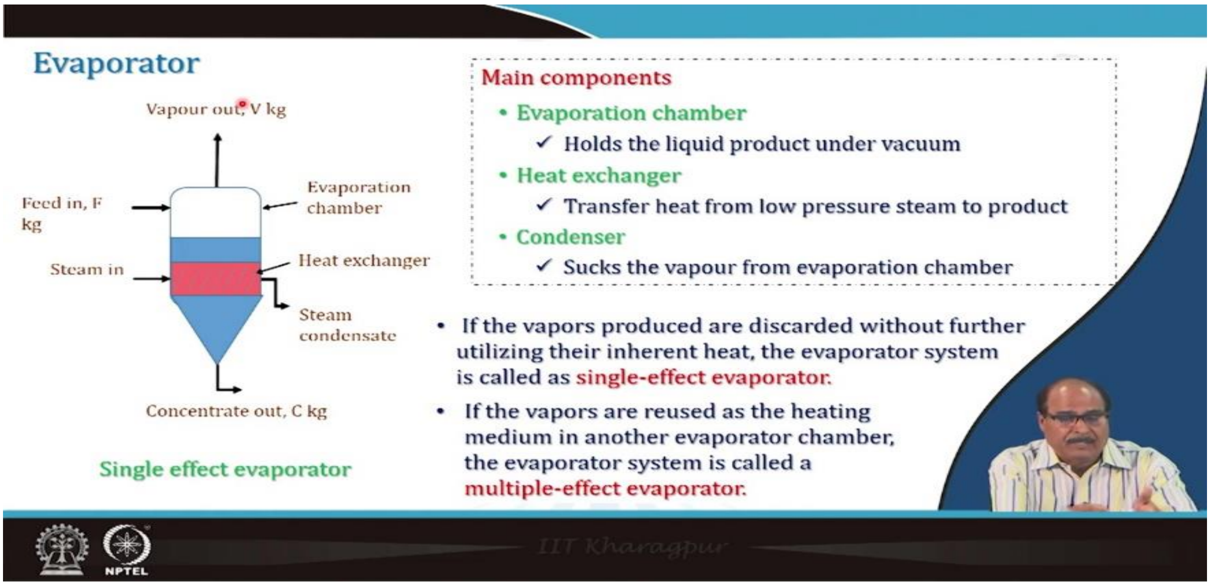



Evaporation is an important unit operation commonly employed to remove water from dilute liquid foods to obtain concentrated liquid products. For example, tomato juice for long term storage is converted into paste or puree with higher total solids of 30 to 35% by evaporation.

Aims of evaporation are decreasing water activity (aw) to a level where the concentrated product becomes stable. Decreasing the water content to such degree that the product would be suitable for spray drying or vacuum drying. Lowering of the water content to a degree where some scarcely soluble components can be crystallized from the solution. Concentration of the product to reduce weight and volume to save energy and money.

**Evaporator**

Concentration is done in a evaporator. The schematic diagram of the single effect evaporator shows the operation of evaporator. The feed F kg is fed into the evaporator and V kg of vapor is removed resulting in C kg at the concentrate. The amount of water removed can be calculated by mass balance and energy balance. The main components of evaporator are evaporation chamber which holds the liquid product under vacuum, heat exchanger which transfer the heat from low presser steam to the product and condenser that sucks the vapor from the evaporation chamber.




If the vapors produced are discarded without further utilizing their inherent heat, the evaporator system is called as single-effect evaporator. If the vapors are reused as the heating medium in another evaporator chamber, the evaporator system is called a multiple-effect evaporator.

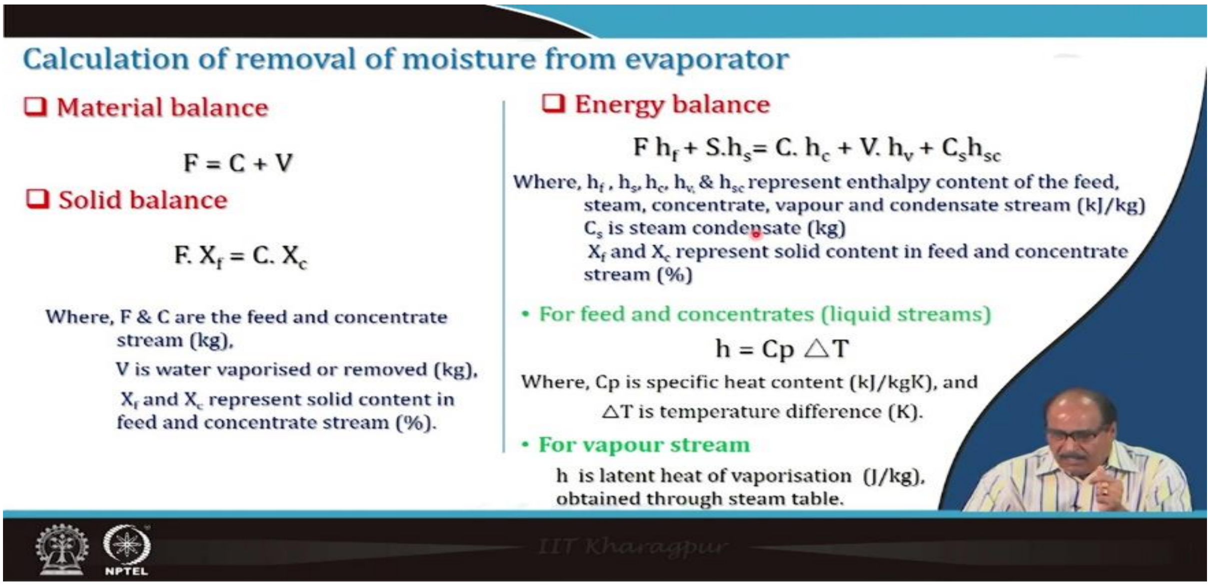
**Calculation of removal of moisture from evaporator**

The calculation of the removal of moisture from the evaporator is done using moisture balance,

$F = C + V$

And solid balance, $F.\ X_f = C.\ X_c$

Where, F & C are the feed and concentrate stream (kg), V is water vaporised or removed (kg), $X_f$ and $X_c$ represent solid content in feed and concentrate stream (%).




Energy balance can be found out by the equation,

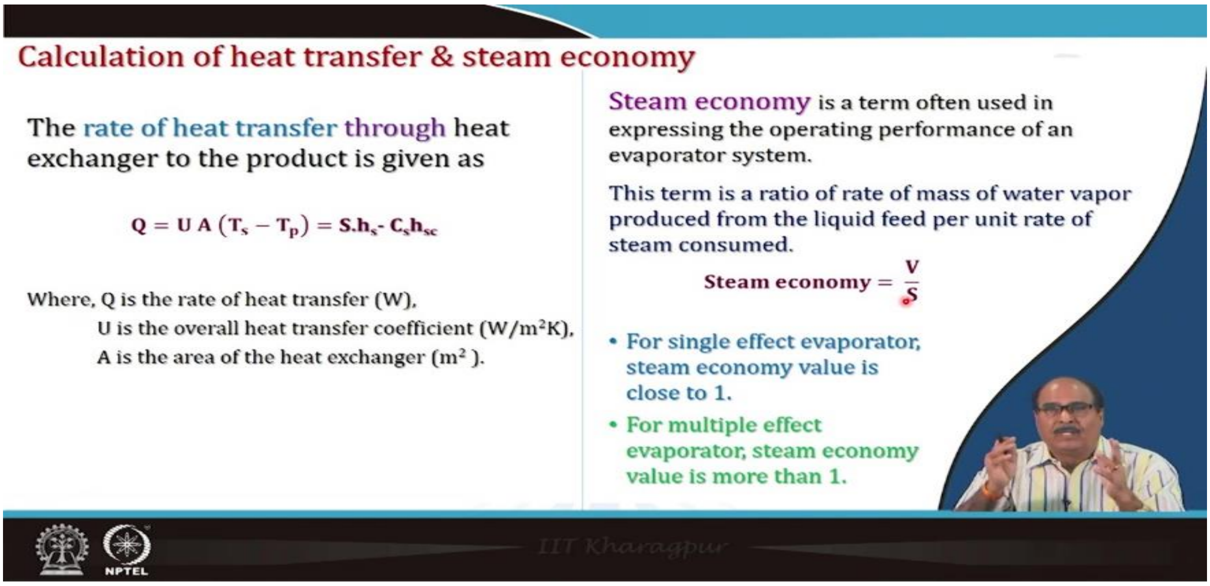
$F\,h_f + S.h_s = C.\,h_c + V.\,h_v + C_s h_{sc}$

Where, $h_f$ , $h_s$, $h_c$, $h_v$, & $h_{sc}$ represent enthalpy content of the feed, steam, concentrate, vapour and condensate stream (kJ/kg), $C_s$ is steam condensate (kg), and $X_f$ and $X_c$ represent solid content in feed and concentrate stream (%).

For the feed and the concentrate in that liquid stream h = Cp △T, Where, Cp is specific heat content (kJ/kgK), and △T is temperature difference (K). For vapour steam h is latent heat of vaporisation (J/kg), obtained through steam table.

**Calculation of heat transfer & steam economy**

The rate of heat transfer through heat exchanger to the product is given as




$Q = UA(T_s - T_p) = S.h_s - C_s h_{sc}$

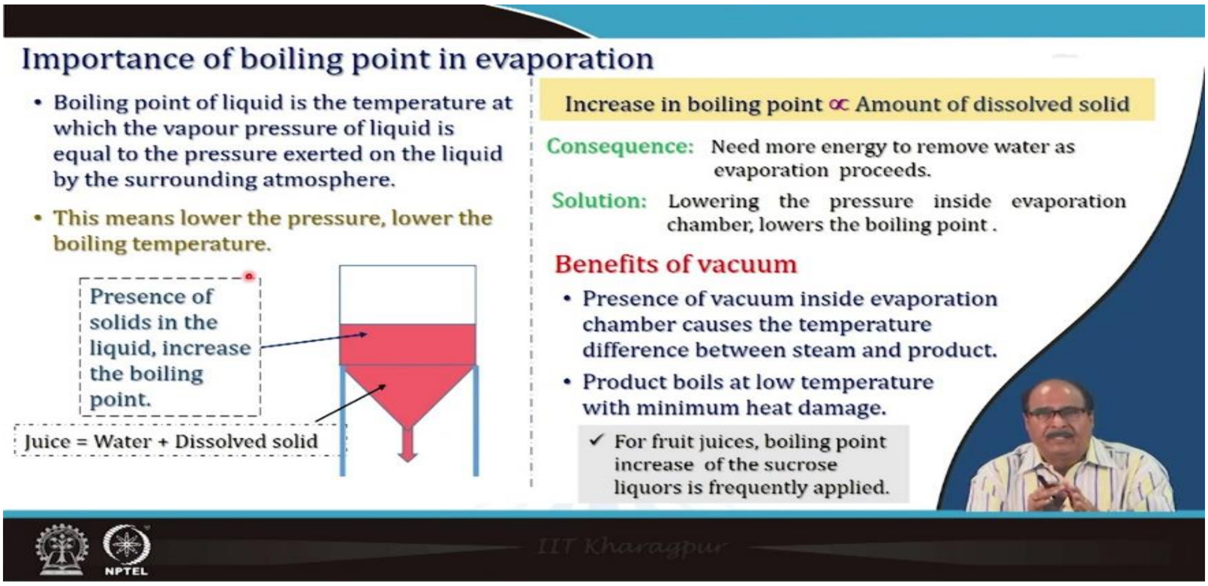
Where, Q is the rate of heat transfer (W), U is the overall heat transfer coefficient ($W/m^2K$), and A is the area of the heat exchanger ($m^2$ ).

Steam economy is a term often used in expressing the operating performance of an evaporator system. This term is a ratio of rate of mass of water vapor produced from the liquid feed per unit rate of steam consumed. It is given by the equation,

Steam economy = V/S

For single effect evaporators steam economic value is one. For multiple effect evaporator steam economic value is more than one.

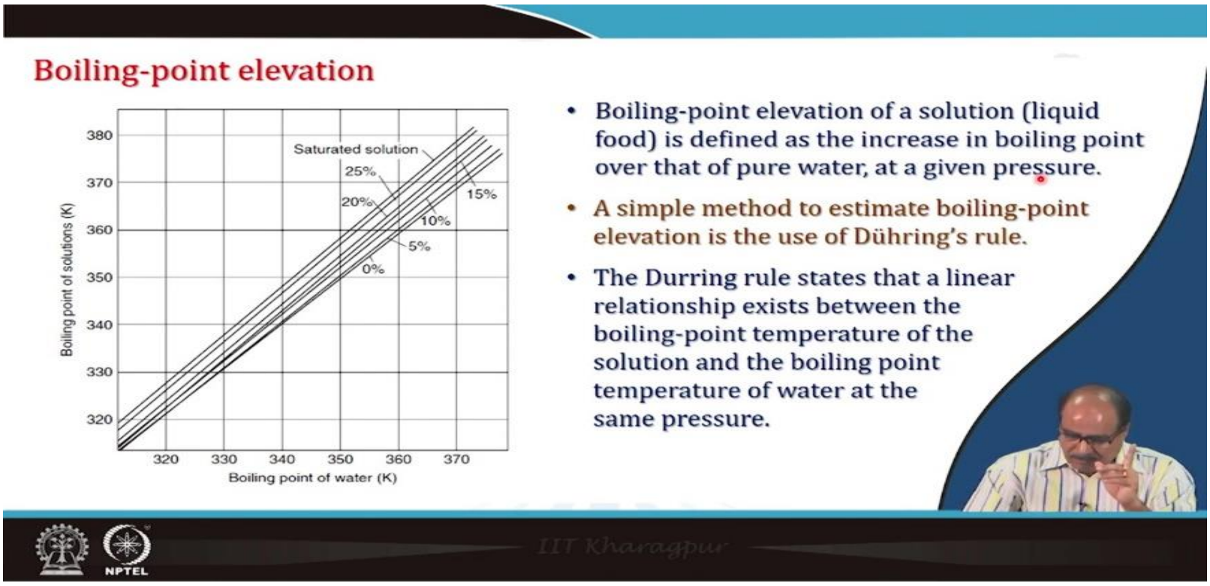
**Importance of boiling point in evaporation**




Boiling point of liquid is the temperature at which the vapour pressure of liquid is equal to the pressure exerted on the liquid by the surrounding atmosphere. This means lower the pressure, lower the boiling temperature.  The Presence of solids in the liquid, increase the boiling point. The boiling point of juice is boiling point of water elevated by dissolved solids.

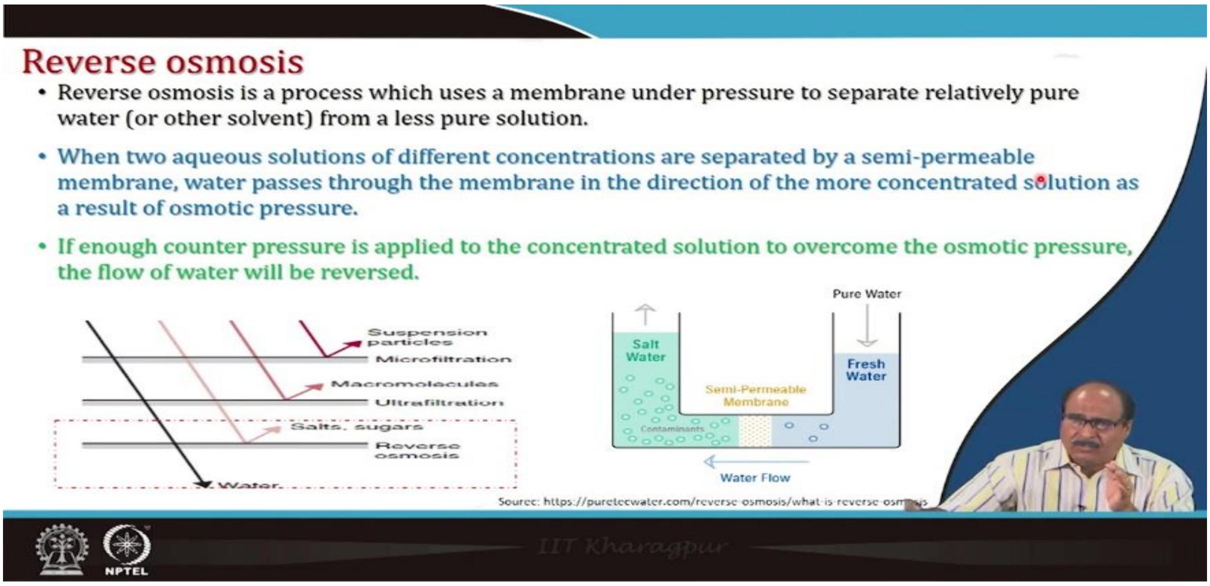
Increase in boiling point is proportional to the amount of dissolved solids present in it. Thus, more energy is needed to remove water as evaporation proceeds. This could be overcome by lowering the pressure inside evaporation chamber as it lowers the boiling point. The benefits of vacuum evaporation are, presence of vacuum inside evaporation chamber causes the temperature difference between steam and product. Product boils at low temperature with minimum heat damage. For fruit juices, boiling point increase of the sucrose liquors is frequently applied.

**Boiling point elevation**




Boiling point elevation of a solution (liquid food) is defined as the increase in the boiling point over that of the pure water at a given pressure. A simple method to estimate boiling point elevation is the use of Dühring's rule. The Dühring's rule states that a linear relationship exists between the boiling point temperature of the solution and the boiling point temperature of the water at the same pressure. The figure given shows the linear relationship between boiling point of water and boiling point of the solutions.

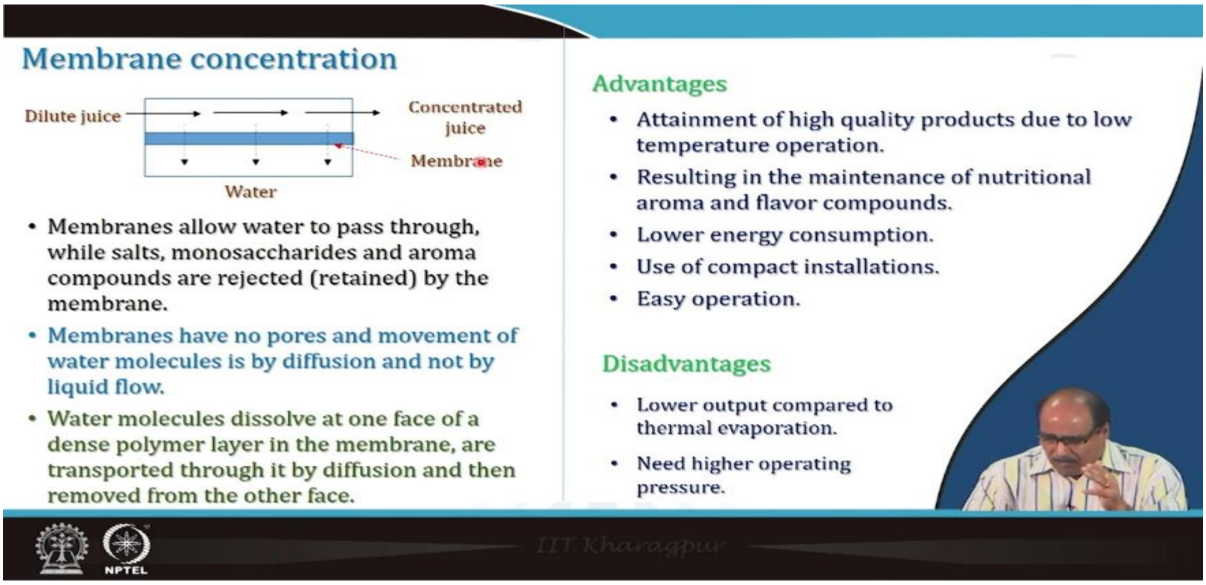
**Reverse Osmosis**



Reverse osmosis is a process which uses a membrane under pressure to separate relatively pure water (or other solvent) from a less pure solution. When two aqueous solutions of different concentrations are separated by a semi-permeable membrane, water passes through the membrane in the direction of the more concentrated solution as a result of osmotic pressure. If enough counter pressure is applied to the concentrated solution to overcome the osmotic pressure, the flow of water will be reversed.

This method is used in production of sweet pickles where the fruit pieces are immersed into concentrated sugar solutions. Due to osmosis the water from fruits diffuses out of the cell of and water is removed resulting in fruit slices firmer texture with more sugar content.

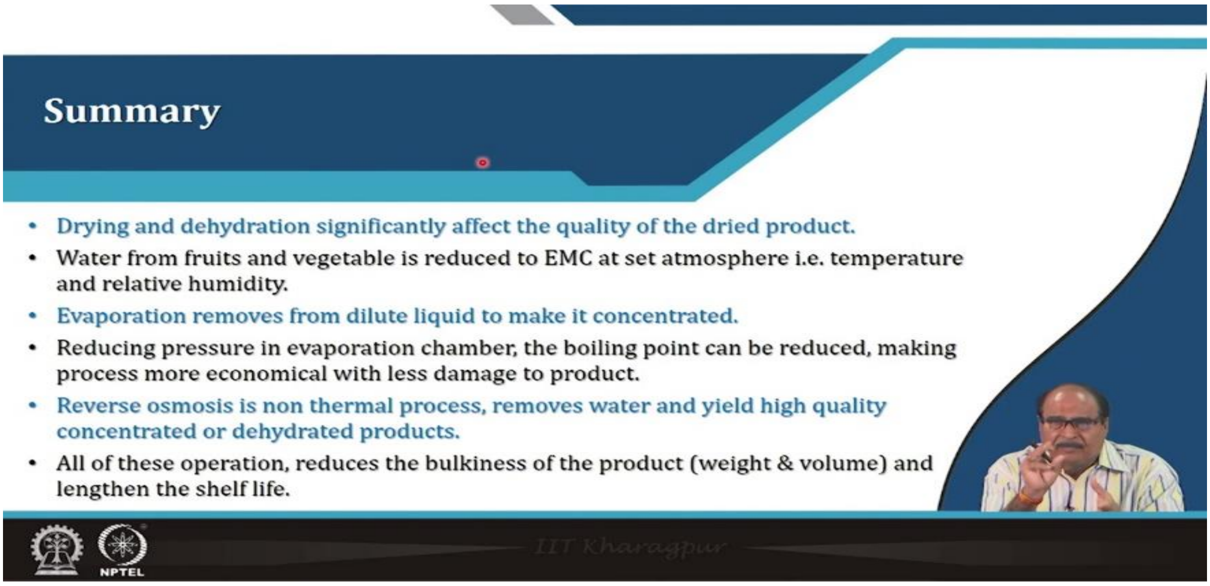
**Membrane Concentration**




Membrane concentration allows diffusion of water through membranes from dilute juice to form concentrated juice. Membranes allow water to pass through, while salts, monosaccharides and aroma compounds are rejected (retained) by the membrane. Membranes have no pores and movement of water molecules is by diffusion and not by liquid flow. Water molecules dissolve at one face of a dense polymer layer in the membrane, are transported through it by diffusion and then removed from the other face. The advantages of membrane processing are obtaining of high-quality products due to low temperature operation. Resulting in the maintenance of nutritional aroma and flavor compounds, lower energy consumption, use of compact installations and easy operation. Disadvantages are lower output compared to thermal evaporation and need higher operating pressure.

**Summary**

The summary of the lecture are Drying and dehydration significantly affect the quality of the dried product. Water from fruits and vegetable is reduced to EMC at set atmosphere i.e. temperature and relative humidity. Evaporation removes from dilute liquid to make it concentrated.




Reducing pressure in evaporation chamber, the boiling point can be reduced, making process more economical with less damage to product. Reverse osmosis is non thermal process, removes water and yield high quality concentrated or dehydrated products. All of these operations, reduces the bulkiness of the product (weight & volume) and lengthen the shelf life.


The references for further reading are provided in the slide.