Thermal Processing of Foods

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Lecture No 22

Various types of Dryers for Food Process Engineering

Good morning everyone, today's lecture and we are going to talk about the various types of dryers for food process engineering.

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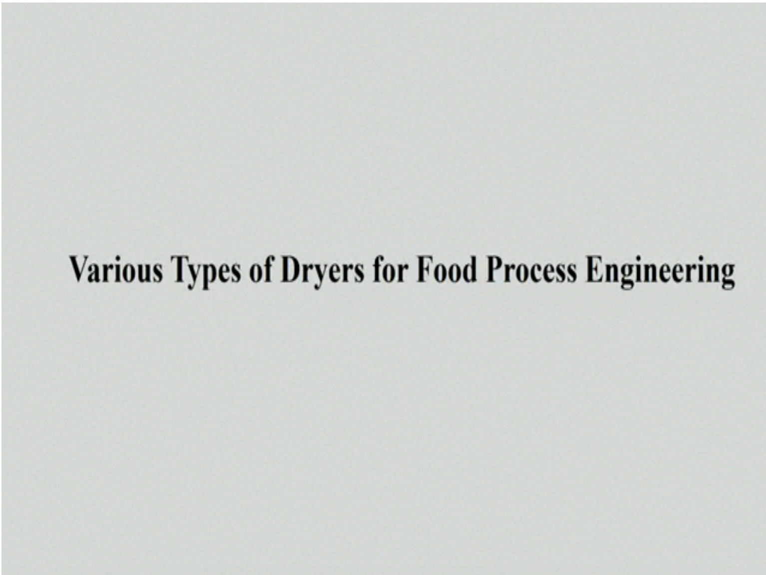

So this lecture and the previous lectures talks about the major processing equipment in for process industry. So one is dryers, the second one is the heat exchangers. So you also might have seen in many of the lectures we were talking about mainly in the continuous flow process heat exchanger, a plate type heat exchanger. And also we have seen design procedures as well. So these two lectures are about that.

So what are all various types of dryers used in food processing industry as well as the heat exchanging equipment used, which is nothing but a heat exchangers which are used in food industries. Before going into various types of dryers, we also going to see about the very basic mechanism of drying and how to calculate the drying time. Then after that we discuss three to four types of various dryers used in the food industries.

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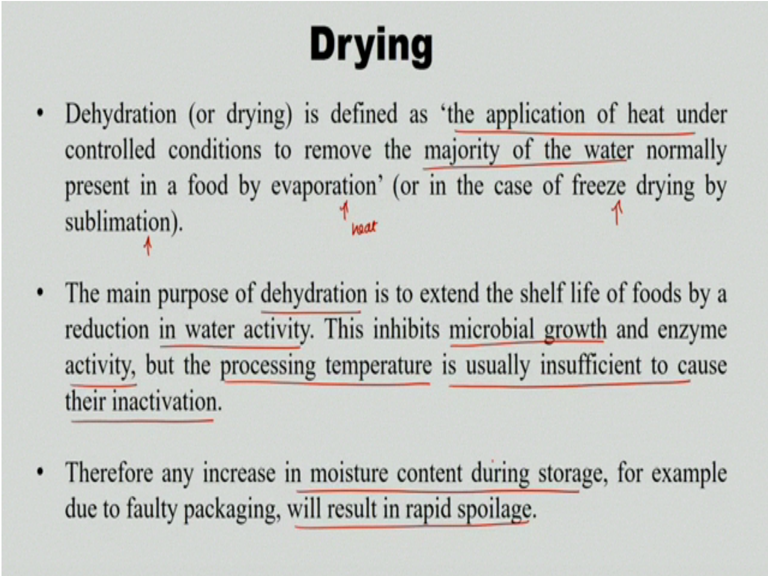

So the first the process of drying, what does it mean by drying? It is also called as dehydration. So, which is defined as the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation. So drying mains the application of heat under controlled conditions to remove the majority of the water. So this is very much important, normally present in the food by evaporation. So this is done at using heat.

So, if you use the freezing phenomena. So that is also called freezed drying. So there the mechanism is sublimation, by sublimation we do freeze-drying, but here by evaporation, the majority of the water is removed, because we are concerned about the thermal processing. So by applying heat how to evaporate the water from the surface of the food particle.

The main purpose of dehydration are drying is to extend the shelf life of foods by reduction in water activity. So we are doing here the water activity reduction. And it inhibits microbial growth and enzyme activity, but the process in temperature right, whatever the heat we apply that temperature, processing temperature is usually insufficient to cause their inactivation. So this is another important thing to remember, by drying we adjusted using the microbial growth or enzyme activities.

But we are not killing any microorganism because the processing temperature, which is applied in drying is not sufficient enough to inactivate the microorganisms. And any increase in moisture content during storage, for example due to faulty packaging, will result in rapid spoilage. So the drying near the main aim is to remove the moisture content, to reduce or do inhibits the microbial growth or enzyme activity. But since it is not inactivating so there is a possibility for recontamination.

So for example, after the storey, after the drying if the product is being stored in the storage unit, so that time if it grouts the moisture content, then the food may get spoiled right. So it cannot guarantee the spoilage during storage. It just that it removes the water by that way. It inhibits the microbial growth and enzyme activity. But after drying, so we need to take care of the further decontamination level.

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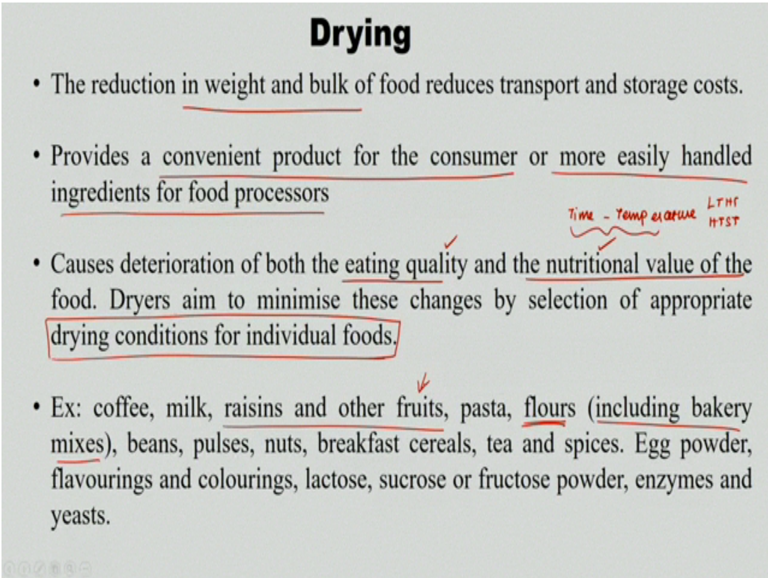

The reduction in weight and bulk of food reduces transport and storage costs. So that means, so if we remove the majority of water right and that reduces the weight of the product and also the bulk of food, bulk of food in the sense it tats. Because water density is thousand KG per metre cube. So it adds weight right. So that is reduced and it will be very easy for us to transport and storage.

And provides convenient product for the consumer or more easily handled ingredients for food processors. Obviously, if you remove the water content, the water activity of the food product is reduced. So in that way, it is convenient product for the consumer and also for the food processors, it is very easily handle able. Because the lot of weight of the product is reduced.

It causes the deterioration of both the eating quality and the nutritional value of the food right. Since we are applying the thermal process which is done by hardier at particular temperature. It also or it may cause deterioration for the eating quality and the nutritional value. Dryers aim to minimise these changes by selection of appropriate drying conditions for individual foods right.

So this is in my hand right, if you remember our earlier classes, we also talk about the time temperature combination right. The one of the major disadvantage in the thermal processing is nothing but a the temperature, high temperature due to which the nutritional value of the food gets deteriorated and sometimes it gives the overcooking. That is not appealing for the consumers to consume the food right.

So this temperature combination, time temperature combination I can play with. So that is a way we told the load temperature, high time process and high-temperature, short time process. So all the processes we have discussed to, how to play with time temperature combination to get or to regain the eating quality and nutritional value. The same thing is applicable here because, by the way, I can take care of my drying conditions for individual foods. I can give better eating quality and nutritional value for the food.

So, the examples for dried foods are coffee, milk, raisins and other fruits. This is very much famous dry fruits and pasta, flours, these flours includes the bakery mixes, beans, pulses, nods, breakfast cereals, tea and spices. And egg powder, flavourings and colourings, lactose, sucrose or fructose powder, enzymes and yeasts. So everything comes as a dried powder with and reduced water activity not to contaminate further.

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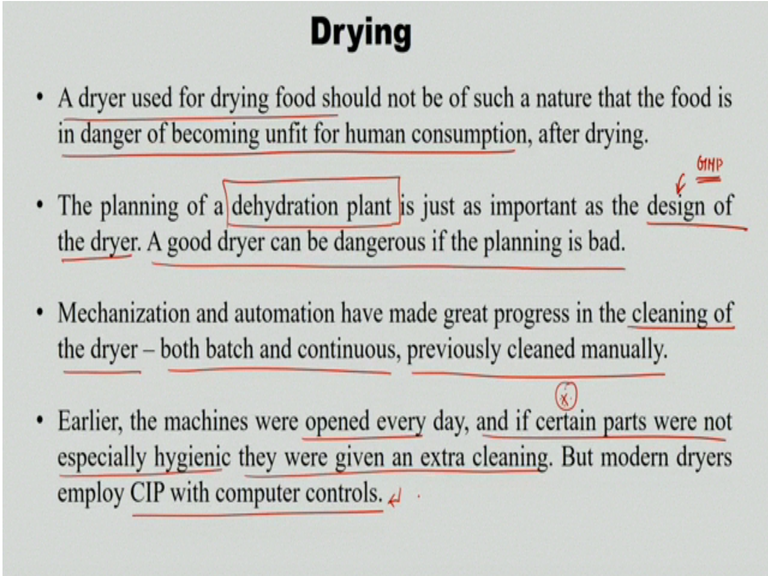

So then we told about the basics of drying, in the drying what are all the care should be given to get the better eating quality and not to degrade the nutritional value. And now we are going to see about the dryers right, the equipment used and what are all the measures I need to care about while selecting the particular dryer.

A dryer used for drying food should not be of such a nature that the food is in danger of becoming unfit for human consumption after drying. So this is also another thing, after drying it should not have any contamination or it should not be unfit for human consumption. And the planning of a dehydration plant is just as important as the design of the dryer. So this design of dryer we have while discussing in the previous lecture itself we told, there is something called GMP, the good manufacturing practices.

So any design of thermal equipment in the food processing should follow the good manufacturing practices. So now, it is told that it is not only the dryer and the dehydration plant itself. Because if there is any previous contamination in the dehydration plant. So this also affects the drying operation. For example, we are just keeping the food inside the dryer and taking out after the drying operation. The environment of the dehydration plant is not contamination free, then it will be a dangerous for drying operations as well. So a good dryer can be dangerous if planning is bad. So that means the plant is also should be contamination free.

Mechanization and automation have made great progress in the cleaning of the dryer, both batch and continuous, previously cleaned manually. So the cleaning operation right, this we discussed in the pasteurizer itself. The cleaning is very much important because we also told that the each particle should be at the particular pasteurization temperature.

If any food chunks, by chance left in the pasteurizer it will add as a seed for the contamination. Same thing here, previously these dryers were cleaned by manually. Now we are applying the automotive control that is nothing but a cleaning in place. So when you do the automation in the cleaning process. We also need to be ensuring the cleaning is done properly right.

Earlier, the machines were opened every day, and if certain parts were not especially hygienic they were given extra cleaning. So this is possible in the manual right. So we know certain parts need extra cleaning, earlier the machines were opened every day and wherever the extra care or extra cleaning is needed that was done manually. But in modern dryers we employ CIP with computer controls. But here also, if there is any parts of the dryer needs extra cleaning that can be done manually after the CIP with the computer control.

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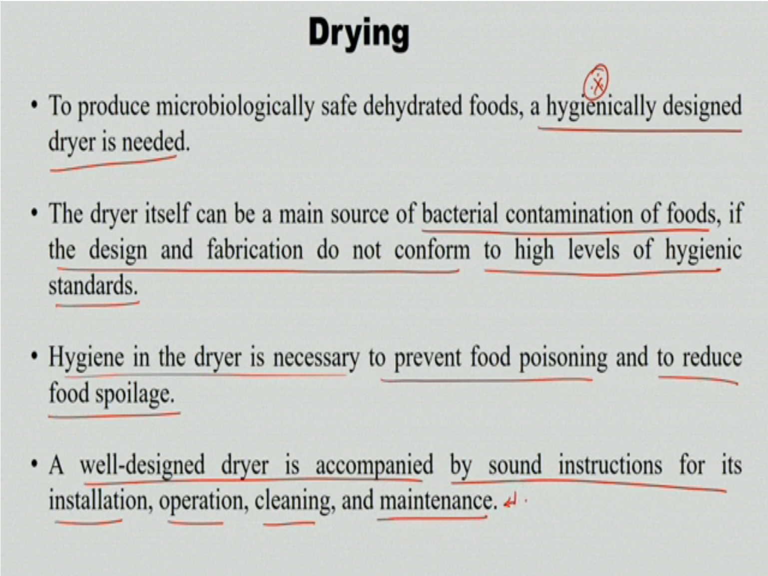

To produce microbiologically safe dehydrated foods, a hygienically designed dryer is needed. So this is important because all other industries, even chemical industries uses the dryers in very much frequent or in every almost all industry uses the dryers. But there, I need not take care of the hygienic part because the production of chemicals. So maybe purity is needed, but we do not much bother about the hygienic conditions in the dryer. But in food process industries the same dryers were used but the hygienic part I need to give extra care because the food is going to be consumed after the drying process.

The dryer itself can be main source of bacterial contamination of foods, if the design and fabrication do not confirm to high levels of hygienic standards. So while designing and fabrication itself we needed to take it because the bacteria contamination wherever it occurs, we have seen in the pasteurization as well as sterilisation itself, the holding tube, why it should be at some slope and also we have seen the valves and places where the possibility of milk chunks to be stay.

So that should be cleaned properly right, here also the bacterial contamination can occur in the dryer as well. Wherever there is room for crevices or dead areas right. So they have to be taken care while designing itself, design and fabrication should not leave such a crevices or dead areas for the bacterial contamination. Because if food chunks go and stay there, then it adds a further bacterial contamination.

Hygiene in the dryer is necessary to prevent food poisoning and to reduce the food spoilage. So, hygiene part is very much important. A well-designed dryer is accompanied by a sound instruction for its installation, operation, cleaning and maintenance. So this is to be designed, while design and fabricate dryer itself.

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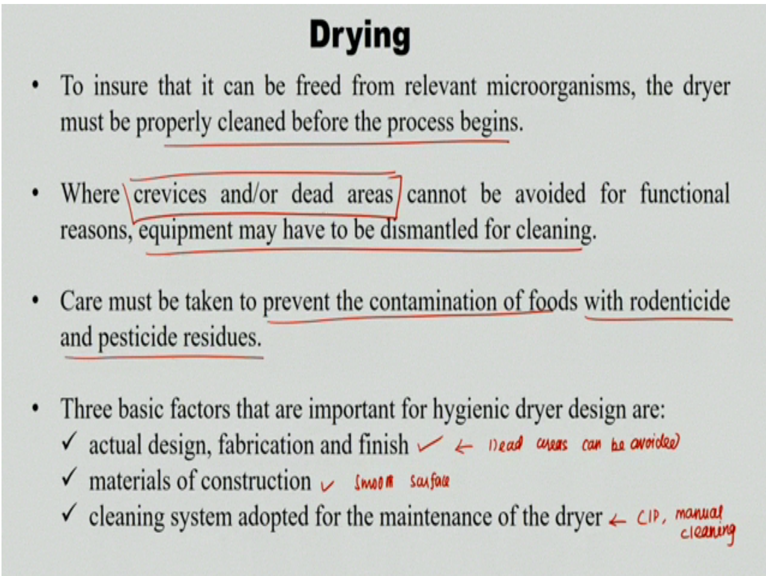

So to insure that it can be freed from relevant microorganisms, the dryer must be properly cleaned before process begins. Where crevices or and dead areas cannot be avoided for functional reasons, equipment may have to be dismantled for cleaning right. So we told while designing and fabricating dryer itself. We need to take care of these crevices or dead areas, but for functional reasons or functional flexibility of the dryer.

If these have to be there in the design of dryer, then we need to ensure the equipment can be easily dismantled for any extra cleaning. Because these areas need extra cleaning, if we are not able to provide that by CIP, at least we need to dismantle the unit for further cleaning by manual.

Care must be taken to prevent the contamination of foods with rodenticide and pesticides residues. Sometimes whatever we use for the cleaning itself may stay in the dryer, so that adds a further contamination of the food because that may be poisonous as well. So that also the care should be given there as well.

Three basic factors that are important for hygienic dryer design are actual design, fabrication and finish, this we told here itself, we can check whether any dead areas can be avoided, can be avoided and materials of construction. So this is we need to ensure this is smooth surface because any pits are crevices adds the further contamination. And cleaning system adopted for the maintenance of the dryer normally CIP is supplied. So, if needed there has to be a manual cleaning and the design of dryer should give the room for manual cleaning. Because it should be disassembled or dismantled for cleaning and it is easy to dismantle for manual cleaning. So this also another basic factor.

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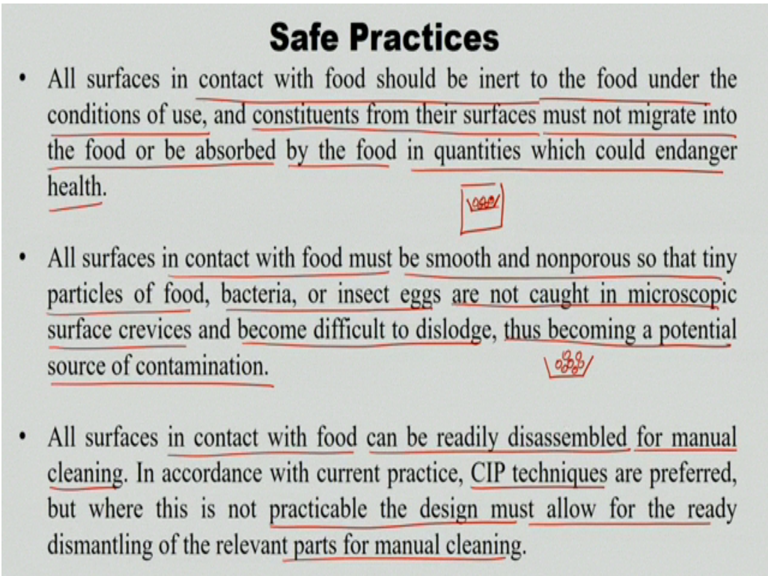

So the safe practices are also being ensured while designing a dryer. So one thing is the surfaces in contact with the food should be inert to the food under the conditions of use, and the constituents from their surface must not migrate into the food or be observed by the food in quantities which could endanger the health. So this is the where your food materials are kept inside the dryer where the place.

For example, we have a tray, in that tray your food materials are kept. So the surfaces should not react with the food material or any constituents from. For example, the food materials, some component in the food material will react with the material used in the tray right. So if there is any reaction between the food and the surface where the food particles are kept for drying there should not be any reaction or there should not be any corrosion which further leads the components transfer between the food material and the surface.

All surfaces in contact with the food must be smooth, nonporous. Because it should also avoid that any pores in the surface of the tray, where your food materials are kept right. So that particles of food, bacteria, or insect eggs are not caught in microscopic surface crevices and become difficult to dislodge, thus become a potential source of contamination.

So one thing we may be argued is like, even though it is porous or the surfaces is not smooth for functional reasons. Then there may be a cleaning which takes care of removing the food chunks from the pores or from the rough surface right. But, sometimes what may so happen is in the pores the food materials gets lodged and it cannot be cleaned properly, even if you apply manual cleaning. So as far as possible the surface where the food materials are kept should be very smooth and it should be nonporous.

All surfaces in contact with food can be readily disassembled for manual cleaning. In accordance with the current practice, CIP techniques are preferred with computer-control. But this is not practice able that design must follow for the ready dismantling of the relevant parts of the dryer for manual cleaning. So as we said here if certain parts need manual cleaning, so we supposed to give extra care or extra cleaning certain parts. Then the design of dryer should give the provision to dismantle or disassemble the dryer for extra cleaning.

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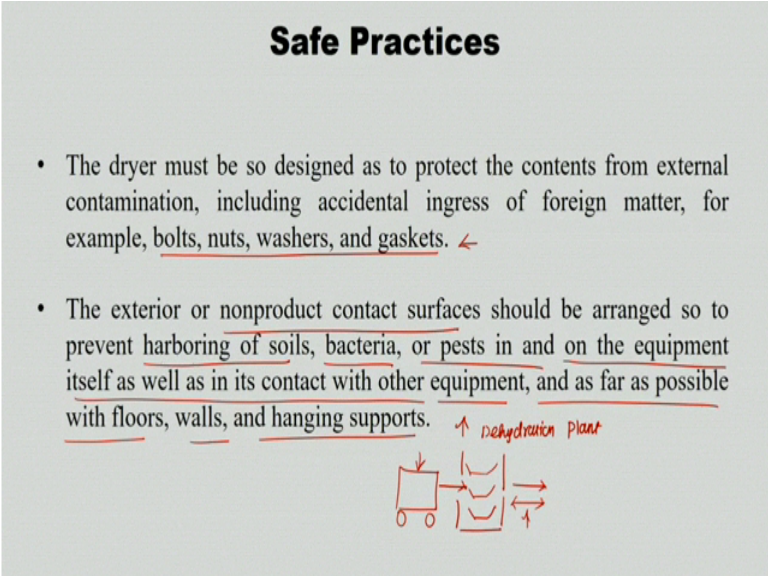

The dryer must be so designed as to protect the contents from the external contamination, including accidental ingress of foreign matter, for example, bolts, nuts, washers, gaskets. So this also should be contamination free because these are all the small components which are used in the dryers. It is not only the drying surface. The bolts, nuts, washers, gaskets are also should be contamination free.

The exterior or nonproduct contact surface should be arranged so to prevent harboring of soils, bacteria or pests in and on the equipment itself as well as in its contact with the other equipment, and as far as possible with the floors, walls, hanging supports. So this is where I told the dehydration plant itself. Okay, so certain dryers what we do is we have a the conveying mechanism right. So, with which the dryer trays where kept inside okay. So this is the way we start the trays inside the dryer.

So when these parts are coming from the outside to inside the dryer. So there may be a chance for contamination it brings right. So it is not only the particular dryer the whole environment of the dehydration plant should be contamination free. Otherwise when it is in contact with the outside surfaces or when it is contact with the other equipment. For example, after drying it will go to storage and distribution right.

So there also this line has to go to further storage and distribution unit. So in between also, there should not be any contamination. So for the dryer where the food materials comes from and after drying wet the food material goes that also should be contamination free to ensure the hygienic in the dryer.

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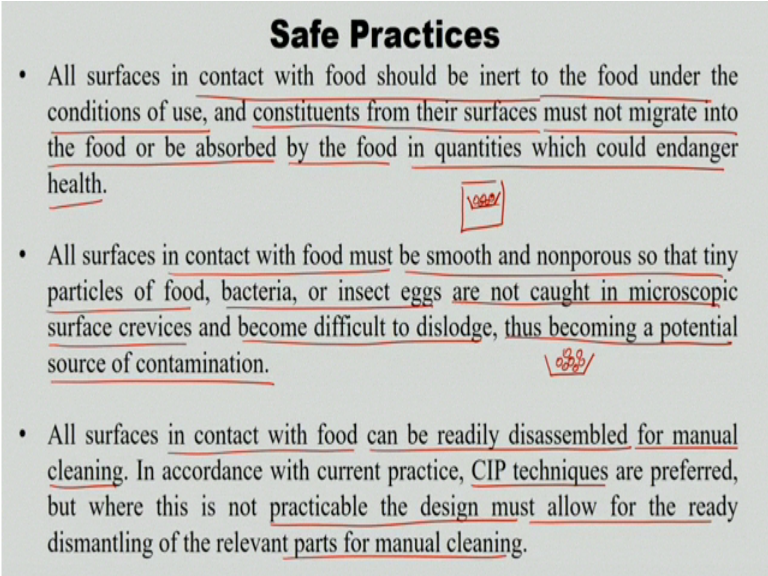

So we have seen five best safe practices, one is the surface that the food material is kept should not be reacting with the food material and the surface should be smooth and nonporous and when certain parts of the dryer needs extra manual cleaning for functional reasons. The CIP techniques or the design of dryer should ensure the dryer can be disassembled and dismantled very easily and further assembled add mantled without any difficulty.

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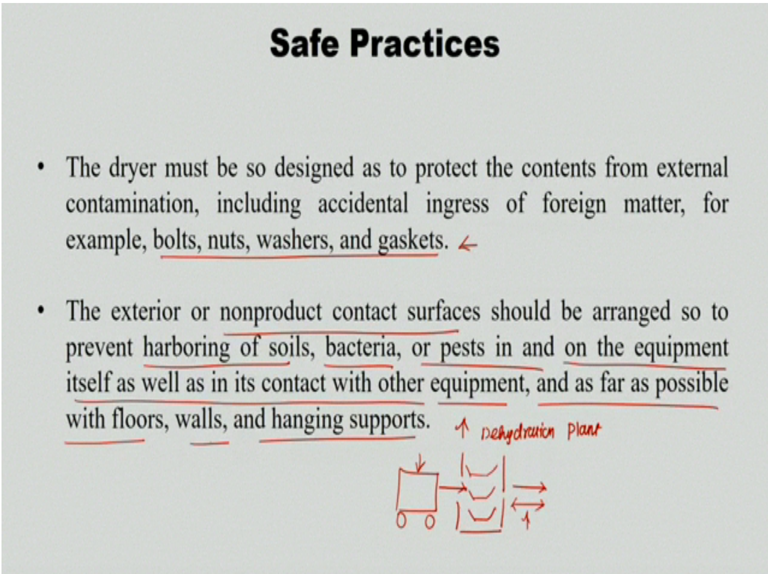

And also it is not only the drying surface and also the bolts, nuts, washers, gaskets also should be contamination free. And not only the dryer for the dryer where the materials comes from and from the dryer where the material goes that also should be soil free, bacteria free and pest free. In short, it should be contamination free.

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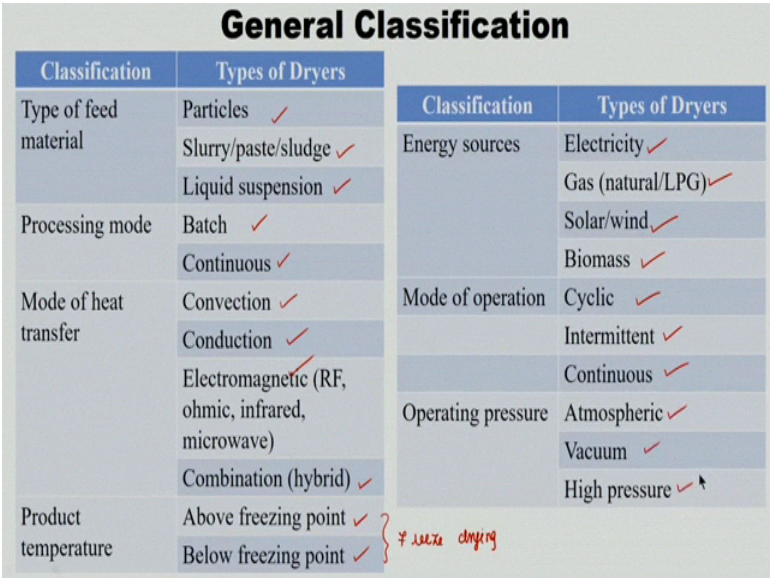

General Classification

Classification	Types of Dryers
Type of feed material	Particles
	Slurry/paste/sludge
	Liquid suspension
Processing mode	Batch
	Continuous
Mode of heat transfer	Convection
	Conduction
	Electromagnetic (RF, ohmic, infrared, microwave)
	Combination (hybrid)
Product temperature	Above freezing point
	Below freezing point

Classification	Types of Dryers
Energy sources	Electricity
	Gas (natural/LPG)
	Solar/wind
	Biomass
Mode of operation	Cyclic
	Intermittent
	Continuous
Operating pressure	Atmospheric
	Vacuum
	High pressure

So the general classification of dryers. So based on particles, slurry, liquid suspension the dryers can be choosed. In the processing mode whether we want batch or continuous mode. Based on the mode of heat transfer convection, conduction, electromagnetic radiation and combination of conduction, convection and electromagnetic radiation. Based on the product temperature above freezing point or below freezing point. This comes in the freeze-drying.

Okay, we have seen this is the sublimation and that above freezing point is nothing but the evaporation. And based on energy source electricity, gas, solar, wind, biomass. Based on mode of operation, cyclic, intermittent, continuous. And based on operating pressure, atmospheric, vacuum and high-pressure.

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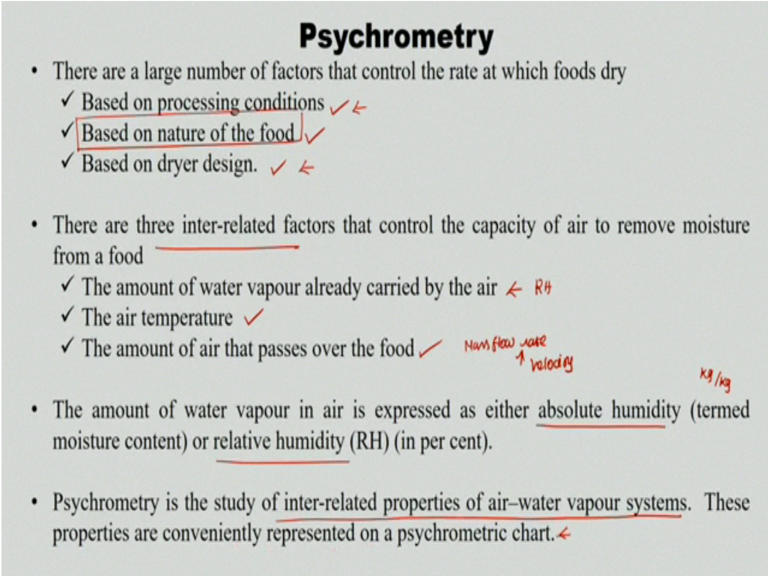

And before going into the main classification of dryers or the various dryers used in the industry, we also should know little bit about psychrometry. I am not going into detail, but because the drying conditions right. In the first slide itself, we have told the drying conditions used is very much important to maintain the nutritional value of the food as well as the food quality right.

So for that the drying conditions to be chosen. The three parameters important for drying conditions is relative humidity of the air and temperature of the air, as well as the velocity of that. When we talk about relative humidity, so we also should know basics about air, water vapour mixture and what is called moisture content? What is called relative humidity, dry bulb temperatures, wet bulb temperature?

So we are going to spend a minimum time. So, if you have further interest, please refer any of the mass transfer book and I also give the references at the end of the slide for further reading about the psychrometry.

There are large number of factors that control the rate at which food dry. One is processing condition, nature of the food and dryer design right. So the nature of the food we are by now know, like low acid food, high acid food and which type of thermal operations to be applied. So based on nature of the food we are okay with. But based on the processing condition, this is what we supposed to give certain attention.

And based on the dryer design because already designed and we are not going to discuss anything deep about dryer design, except drying time how to choose. There are three interrelated factors that control the capacity of air to remove moisture from a food. So this is where I told, one is amount of water vapour already carried by the air. So this we can get to know from the relative humidity.

And air temperature and amount of air that passes over the food. So we can call it as a mass flow rate or if you fix the drying surface area then it may be a velocity as well right. So the velocity and air temperature as well as the relative humidity. So the moment I talk about the relative humidity which is nothing but amount of water vapour in air expressed as expressed as either absolute humidity which termed as a moisture content or relative humidity which is measured in percentage. So this will be given by kg upon kg. Kg of water vapour per kg of air.

And psychrometry is the study of interrelated properties of air-water vapour system and these properties are conveniently represented as a psychrometric chart. Okay, so that you are going to see.

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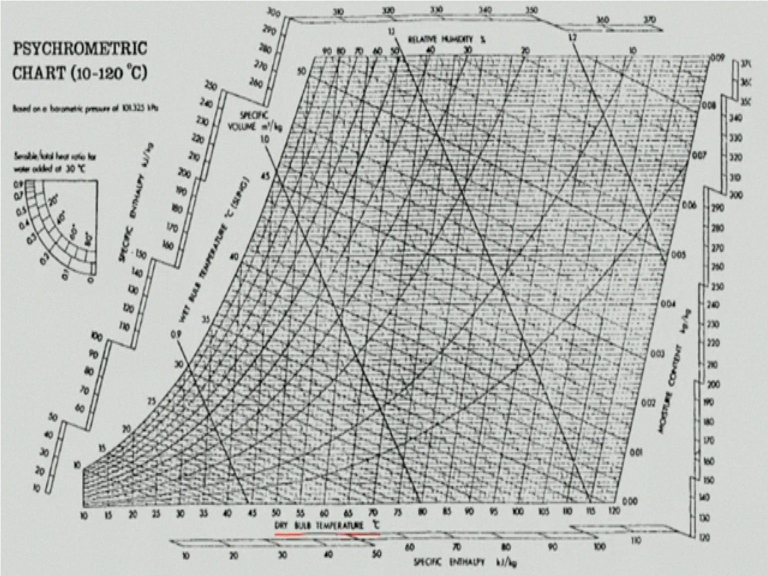

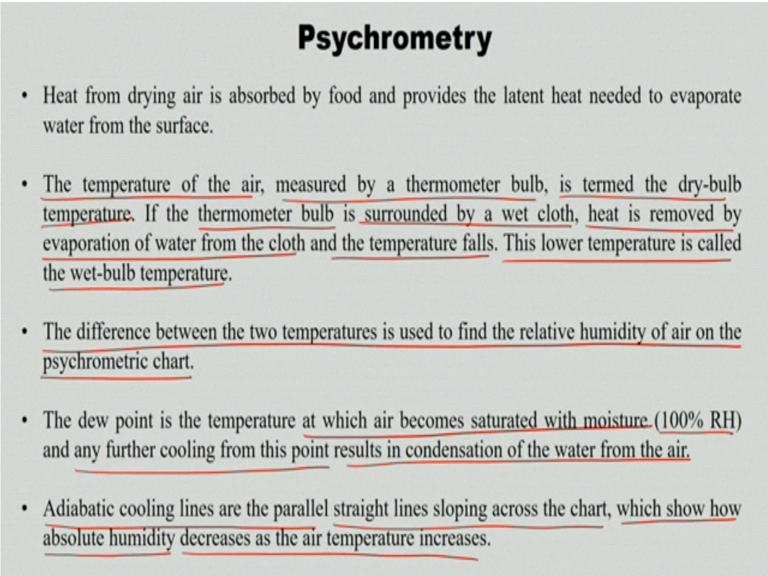

This is the psychrometric chart. So, if you see here in x-axis what you see is the dry bulk temperature right. So what is dry bulb temperature? The temperature of the air, measured by thermometer bulb, is termed as the dry bulb temperature. So what we normally measure at labs. So that is nothing but a dry bulk temperature, which is in degrees centigrade.

And in the slanting y-axis it is given as a wet bulb temperature right. So what is wet bulb temperature? If the thermometer bulb is surrounded by a wet cloth, heat is removed by evaporation of water from the cloth and the temperature falls. So this lower temperature is called wet bulb temperature. Here in the thermometer we wind the wet cloth in the thermometer bulb, so the heat is used to remove the water from the wet cloth by evaporation.

So, the temperature measured is lower than the dry bulb temperature. So that is here mentioned as a wet bulb temperature.

Then the difference between the two temperature is used to find the relative humidity, relative humidity on the psychrometric chart. For example, if I fix my dry bulb temperature as 55 and my wet bulb temperature is 35. So the 35 line is here right and my dry bulb temperature of 55 degree line is here. So if you keep this, so this is nothing but, from this, I can calculate relative humidity, how?

So this is 30 percentage relative humidity line and this is 20 percentage relative humidity line. So what we have seen is dry bulb 55 and wet bulb 35 right. So wet bulb 35 and dry bulb 55. So I put this is a 0.1 here. Okay, so this is a 20 percentage relative humidity line, this is 30 percentage relative humidity line. So, if you go from here it is around maybe I can say the 28 percentage okay. So from dry bulb and wet bulb I can fix the or I can get a know the relative humidity.

Okay, the dew point is the temperature at which air becomes saturated with moisture right. The dew point is the temperature at which the air becomes saturated with the moisture. That means 100 percentage relative humidity and any further cooling from this point results in condensation of the water from the air. So we have seen here the air, water vapour system right, so once the dew point is reached right. So there it is a 100 percentage relative humidity. After that, in water vapour will not stay with the air as the water vapour then it starts condensing as a water.

And adiabatic cooling lines are the parallel straight sloping across the chart, which shows how absolute humidity decreases as the air temperature increases. So for example, we have taken here example as a dry bulb temperature of 55 and wet bulb temperature of 35. So I got 28 percentage relative humidity. So for example if I increase or decrease the temperature. For example, from 55 to I will go to 45 okay. So 45 if you see in the wet bulb temperature. So what you get is this point right, 0.2. Okay.

So in the 0.2 if you see. So if you come here in the straight line, maybe around this and this right. So the 0.2 comes somewhere here and 0.1 comes somewhere here right. So, if you see the difference right, the 0.1 is that 55 degree dry bulb temperature and wet bulb temperature of 35 and I am just reducing my dry bulb temperature from 55 to 45. So that gives me the 0.2 so if you extend that line. So what you get is between 0.03 and 0.02 right. So the 0.1 is here, and 0.2 is here. So that difference between them will give me the moisture content that is what is it is told. Absolute humidity decreases, the air temperature increases.

So the 0.2 is lower temperature, so that is having higher absolute humidity which is nothing but a moisture content 0.1 is having higher temperature. So that gives me lower moisture content. So that means 2 minus 1 is nothing but amount of moisture that is removed when you increase the temperature. Okay, so that is something basic about the psychrometry so we are not going into detail, we told about the dry bulb temperature, wet bulb temperature by using dry bulb and wet bulb how to get the relative humidity.

And this one talks about the moisture content which is nothing but kg upon kg and we also have seen the adiabatic cooling lines are the parallel straight lines sloping across the chart, which show how absolute humidity decreases as the air temperature increases. So I fixed my wet bulb temperature as 35 and I increased the temperature from 45 to 55 by noting it down in the 0.2 and 0.1.

So 0.2 is lower temperature, which gives the higher moisture content and 55 is the higher temperature, which gives me lower moisture content. So when you increase the temperature, your moisture content is decreasing. So that is what it is told here, adiabatic cooling lines are the parallel straight lines sloping across the chart, which show how absolute humidity decreases as the air temperature increases.

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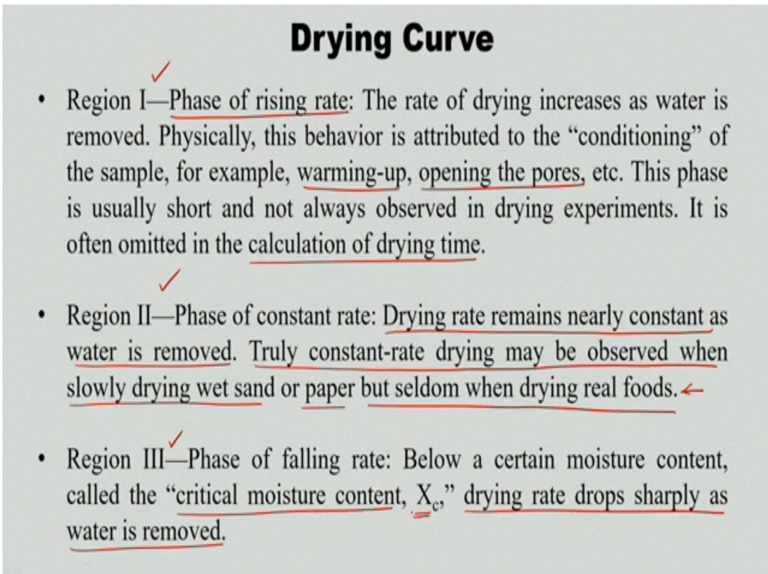

So the next one important thing what we have to know is the drying curve. So in the drying curve we have 3 regions, region 1, region 2 and region 3. The region 1, we call it as a phase of rising rate. So this is nothing but where the product is getting warmed or opening pores. So this is nothing but a phase of rising. So this normally we do not take into account for the calculation of drying time.

The second and third region are very important. The phase of constant rate, where drying rate remains nearly constant as the water is removed. And truly concentrate drying may be observed when slowly drying wet sand or paper but seldom when drying real foods. So when drying real foods this may also be avoided for the calculation because that is the very shorter time or it may not be even observed right. But here the constant rate is nothing but drying right remains nearly constant as water is removed.

The region 3 is phase of falling rate. So below is certain moisture content a called critical master content which is expressed as a Xc. The drying rate drops sharply as water is removed. So the phase of falling rate is drying rate falls with respect to X, which is nothing but a moisture content after the critical moisture content is reached.

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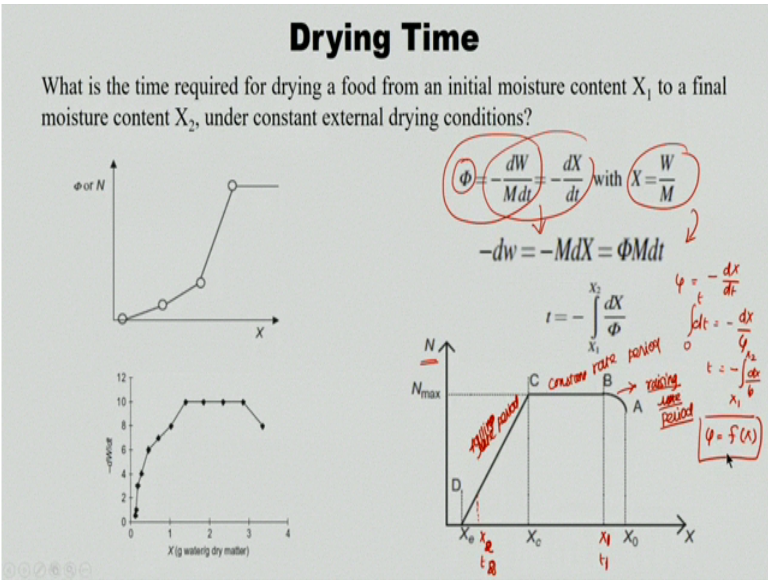

So here is your drying curve. So this phase A, B, we call it as a constant rise or phase of raising period, raising rate period. So here the product is getting warmed up or product is preparing its post to be opened. So this is a very short period, we do not normally take into account for drying calculations. So the C to B is nothing but a constant rate period, constant rate period. And the C to D is nothing but a falling rate period. Okay, so this is nothing but a Xc.

So normally our final moisture content right, from initial moisture content is nothing but here Xi. So final moisture content will be Xf. Because the equilibrium moisture content is one below which I cannot even dream of the water. So my initial final moisture content lies somewhere here. So this I will take it as TF drying time, this is the initial starting Di equal to 0. So this is what the drying curve, so here it is a moisture content which is nothing but grams of water per grams of dry matter and N is nothing but a drying rate.

So this is a moisture content, this is drying rate X versus Y and what is the time required for drying or food from an initial moisture content X1 to a final moisture content X2. So here we can also tell instead of Xf 2 and instead of Xi, X1, so T1, T2. Okay, so here the phi is nothing but a drying rate which is nothing but minus DW upon M DT right. So the W upon M is nothing but kg of water per kg of dry food material. So the W M can be written as X. So phi is nothing but minus DDT of X, where X is nothing but W upon M.

So, if you do the certain calculations here minus DW is nothing but M into DX. I am taking these two and writing. So minus DW is nothing but minus MDX. So DT, DT gets cancel. Then this can also be written as, because if you take these two right, so that can be written as phi MDT, minus DW is nothing but phi MDT. So from this, I can calculate my T. So phi is nothing but minus DX, DT. So my DT is nothing but minus DX upon phi. So T is nothing but minus X1 to X2 DX upon phi.

So this is I can do it 0 to T. So total drying time is nothing but minus X1 to X2 DX upon phi. So this phi is nothing but a drying rate which is a function of X. X is nothing but moisture content which is expressed in kg of water per kg of dry matter right. So usually I get by experimental or by modelling also we can get phi as a function of X. So this has to be further substituted in the drying time.

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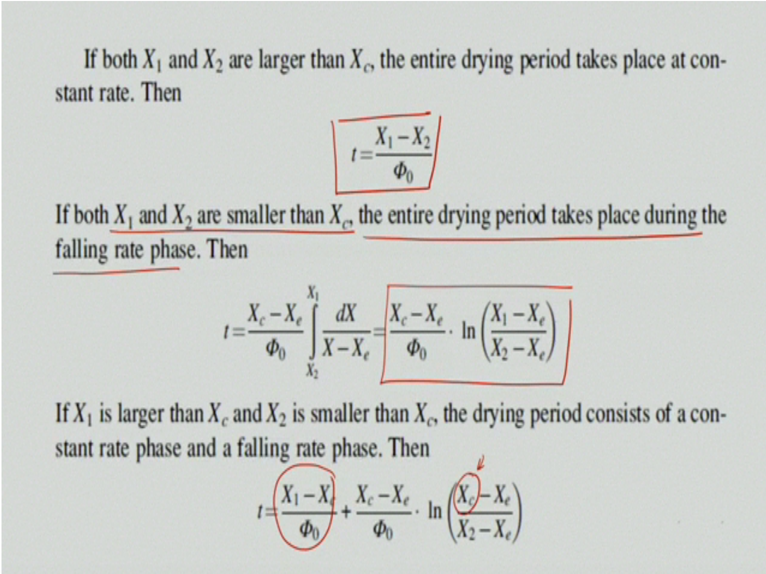

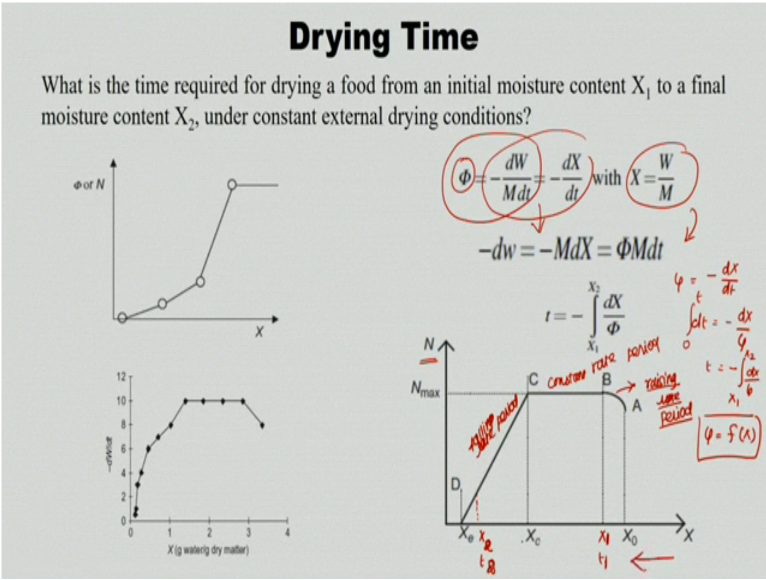

So here it is said that if both X1, X2 are larger than Xc, the entire drying period takes place at the constant rate. So if you see here, so this way you are moisture content is reducing right. So if my X1, X2, both is larger than Xc. So that means my X1, X2 comes here, so this is nothing but called constant rate period. So total drying time is in the constant rate period, which is nothing but X1 minus X2 upon phi naught, phi naught is nothing but initial drying rate.

If both X1, X2 are smaller than Xc. So that means so here it lies X1 and X2, so that means it is in the falling rate period right. So entire drying period takes place in the falling rate period. So, which is nothing but Xc minus Xe. Xc is critical moisture content, E is nothing but equilibrium moisture content. Phi naught is nothing but initial rate of drying, X2 to X1, X2, X1 is a initial final moisture content, the X upon X minus Xe. So after integration what you get is the final formula is this for drying time.

So Xc minus Xe divided by phi naught into log of X1 minus Xe divided by X2 minus Xe. So this means E is nothing but equilibrium moisture content, X1 is initial moisture content, X2 is final moisture content. Xc is nothing but a critical moisture content.

If X1 is larger than Xc, X2 is smaller than Xc. So if you see here, so X1 is larger than Xc. So that means X1 lies here and X2 is smaller than Xc the drying period consist of both the constant rate as well as falling rate. So constant rate is this formula and remember, X2 is replaced by Xc. Because the Xc is the final moisture content in the constant rate period. And your falling rate period stands with Xc minus Xc divided by phi naught into log of Xc minus Xc. Because the initial moisture content here is replaced by the Xc right, minus Xc divided by X2 minus Xc. So this is the way we calculate the drying time.

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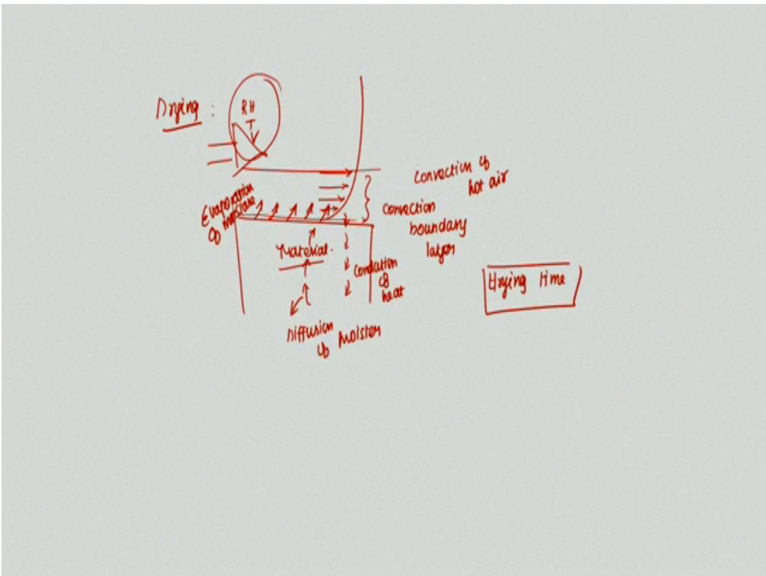

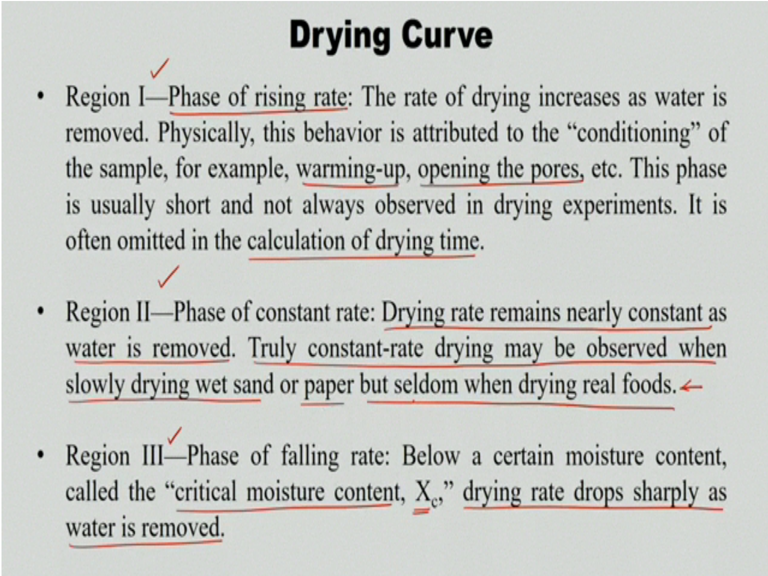

So now, we are going to see the process of drying a little bit and we are going to see what are all the different dryers used. So what happens is? So this is my food material right, so here I am sending a hot air. So with particular relative humidity and temperature and velocity right. So when the air sees the food material, so the process is nothing but a convection okay. So it forms a boundary layer, boundary layer means the velocity of the. So this is nothing but a convection boundary layer, convection boundary layer where your velocity varies from 0 to the free mainstream velocity. Okay, so this process is convection.

Then what happens the surface moisture of the food gets evaporated right. So this is nothing but a evaporation operation. So when the heat is applied on the surface of the food and it has to conduct through the food material right. If it is solid material, the heat has to conduct. So this process is nothing but a conduction. And my moisture should defuse from the internal site to surface. So this process is nothing but a diffusion of moisture, diffusion of moisture. This is conduction of heat, so convection of hot air, evaporation of moisture. So this is what overall happening in the drying processes right.

So, what we need to take care? The drying conditions and how much time I need to dry? Right, so drying time and the mechanism is convection of hot air, evaporation of moisture, conduction of heat inside the material and diffusion of moisture from inside material to the surface of the food material right. So this is where we have seen. And one particular thing here we told about why we do not take normally constant rate of drying is.

So here if you see, actually whatever the moisture content is there in the food material surface is getting evaporated right. So the same rate, the moisture also defuse from the inside material and it should come to surface of the food material right. If there is any difference between these rates, then the constant rate period may not even appear right. Because here the in the constant rate slowest step is rate of evaporation, in the falling rate period the slowest rate controlling step or rate controlling step or slowest step is diffusion of moisture from the internal side of the food material to the surface right.

If these two are matched, then the process go smoothly right. So, but in the food material, most of the time the rate at which the moisture evaporation near the surface may not be equivalent to the rate of diffusion of moisture from the internal to surface of the food material. Because of which the constant rate period may not even appear in most of the real foods. So mostly it will be done under the falling rate period okay.

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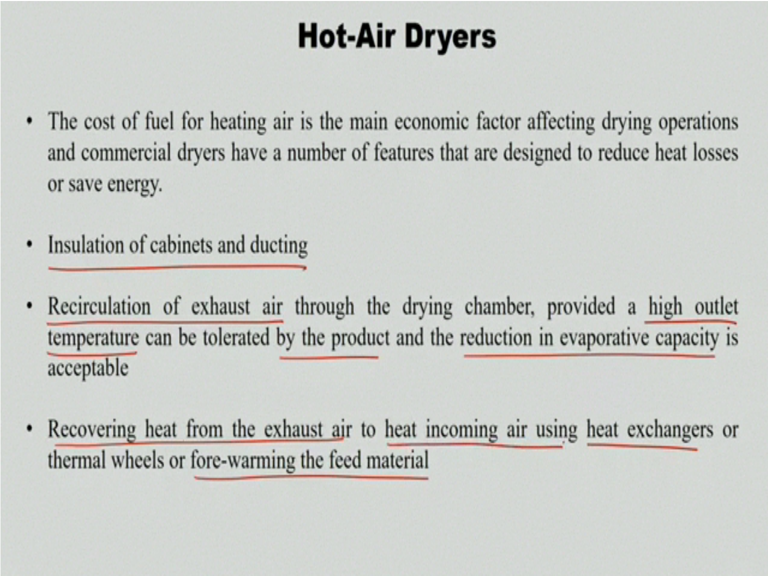

So now, we are going to see the dryers. So normally the hot air dryers this is in general. But here we are also thinking about the conventional hot air dryers, what are all the measures can be taken to improve the process as a energy conservation process? One is insulation of cabinets and ducting that should be done and recirculation of exhaust air right. So whatever the air going in exhaust that can be recirculated. So, if that we are doing that we need to also be careful about the outlet temperature can be tolerated by the product.

Because the exhaust air temperature should be tolerated by the product, it should also be acceptable for reduction in evaporating capacity. And recovery heat from the exhaust air directly, it can be recirculated or we can use some heat exchangers and that heat can be used to fore-warming the feed material or to heat the incoming air. So this way we can improve the efficiency of the hot air dryers.

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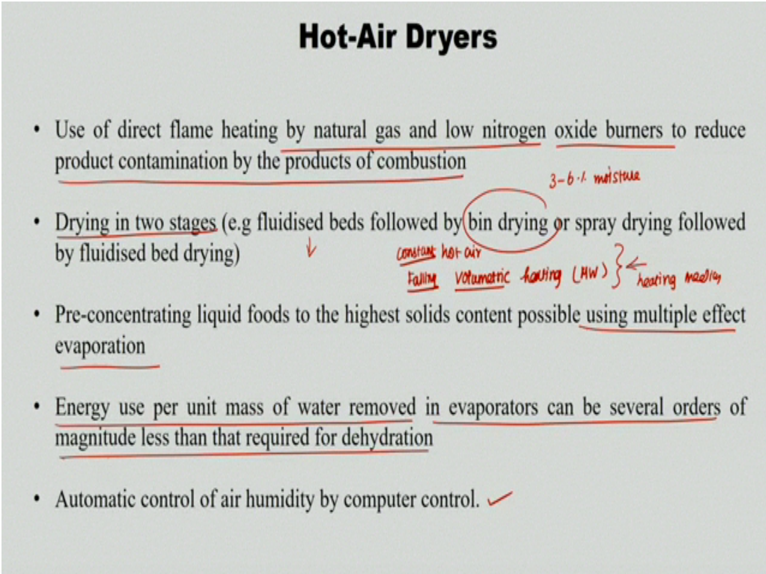

And use of direct flame heating of natural gas or low nitrogen oxide burners to reduce the product contamination by the products of combustion right. So, if we use the direct flame or nitrogen oxide burners, then product contamination can be taken care. And drying in two stages, one example we told is like the surface moisture can be removed using hot air. Because the falling rate period right, if the surface moisture which is happening in the constant rate period stop.

But the falling rate period, if the moisture should be removed we can use any volumetric heating technique. Because in the falling rate period, the moisture has to defuse from the inside material to the surface right. So in that case, we can the volumetric heating maybe microwave heating, so that the drying can be efficient right. So that is what it is told the drying in two stages, one is by using the hot air or volumetric heating in the falling rate period and hot air in the constant rate period.

And also it is based on the heating medium used and the amount of moisture removal. For example, in the bin drying you will be able to 3 to 6 percentage of the moisture. If the moisture lot, if the high amount of moisture content to be removed. So we can first put fluidised to bed dryers.

Then we can send the dried product from the fluidised bed dryers to the bin dryer to remove the final moisture content. Okay and also other combination would be spray drying, followed by fluidised bed drying. So it is based on the amount of moisture removal and this mechanism, this two-stage drying is based on the heating medium, heating medium.

Pre-concentrating liquid foods the highest solids content possible using multiple effect evaporator. So instead of removing high amount of moisture in the dryer. So it can be removed previously by or pre-concentrating by evaporation and after the drying for final moisture removal. Because the energy per unit mass of water removed in evaporators can be several orders magnitude less than the time required for dehydration. And also automatic control of air humidity by computer-control. This also improve the energy efficiency of the hot air dryers.

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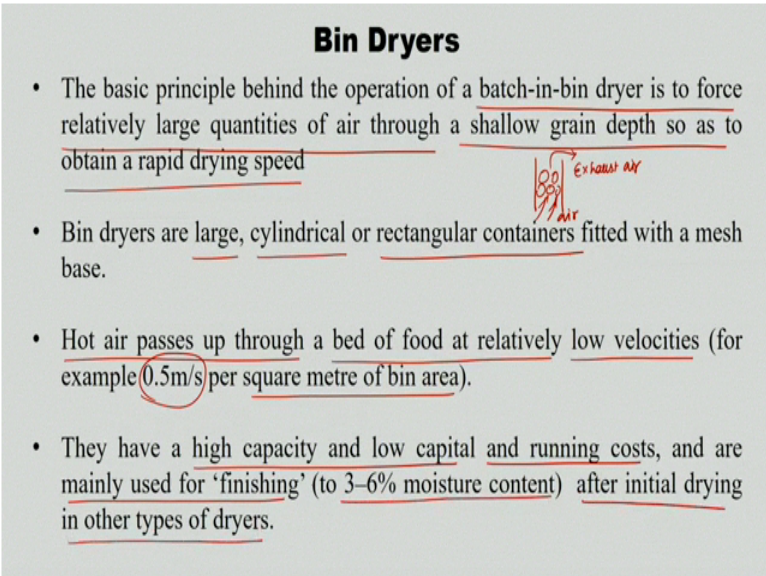

Then bin dryers as I told earlier, so this is nothing but a small storage dryers, right. So it is batch bin dryer is used to force relatively large quantities of air through the shallow grain depth, so that to obtain rapid drying speed. So that means, so it is bin so through which the air is, hot air is passed through, here you have a food material, so your exhaust air goes. So taking the moisture away. Okay, mostly storage bins right. So these are storage bins through which the hot air or normal air at particular temperature is circulated.

So here the bin dryers are large, cylindrical, rectangular containers fitted with the mesh base. And hot air passes up through a bed of food and relatively low velocities. Example 0.5 metre per second, per metre square of bin area. So, very low velocity air is passing through. They have a high capacity and low capital and running cost. Because it can be used as a storage vessel as well are mainly used for finishing to about 3 to 6 percentage moisture content. After initial drying in another type of dryers.

This is not a main dryer. So after drying it can be used for storage as well as the drying right. Because the air at particular temperature is passed through these food material. It removes about 3 to 6 percentage of moisture content.

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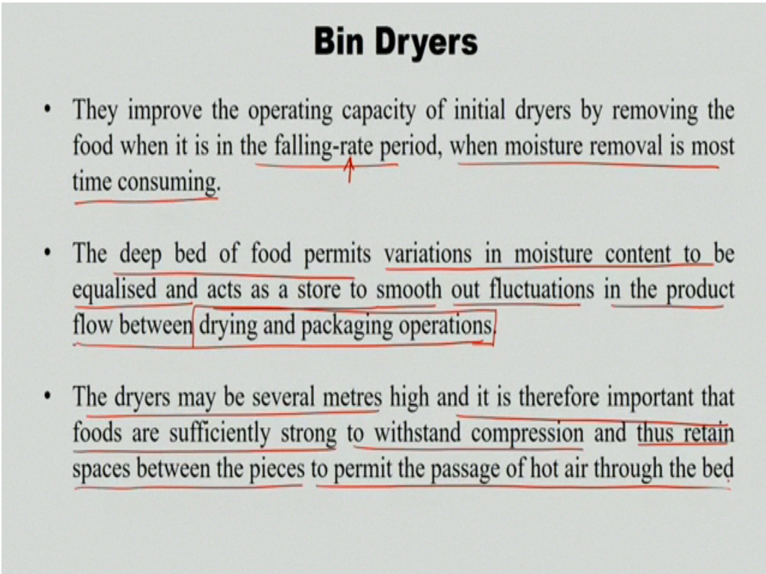

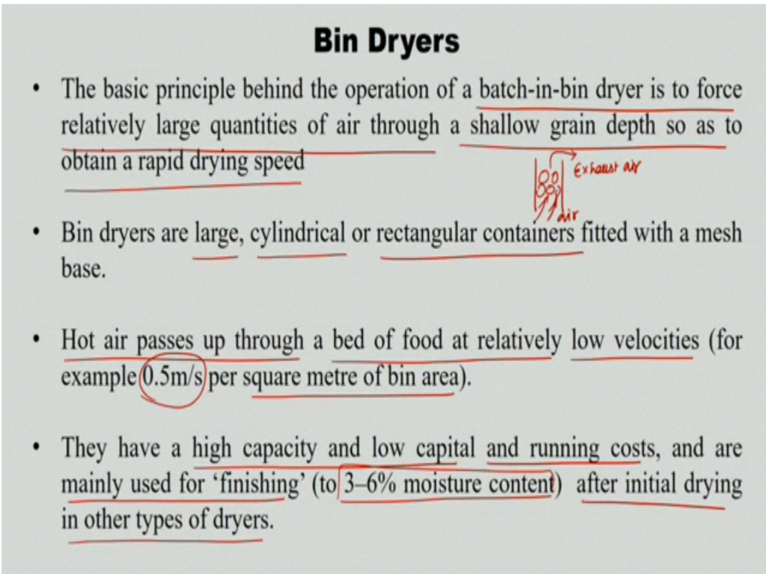

To improve the operating capacity of initial dryers by removing the food when it is falling rate period, when moisture removal is most time consuming. So they improve the operating capacity of initial dryers by removing the food when it is in the falling rate period, when moisture removal is most time consuming. So we said here it can be a final drying equipment right.

The initial drying is done by any other drying equipment, where we take this as I told earlier this is the moisture removal from the interior of the food material right. So it is a time-consuming process. So instead of doing it in initial dryer, so certain 3 to 6 percentage moisture removal can be done in bin dryer as well. While storing it we can also remove some of the moisture in the falling rate period. That means inside a food material, surface moisture can be removed from the initial dryer as well.

The deep bed of food permits variations in moisture content to be equalised, act as a store to smooth out fluctuations in the product flow between drying and packaging operations. The deep bed of food permits variations in moisture content to be equalised and acts as a store to smooth out fluctuations in the product flow between drying and packaging operations. So between drying and packaging operation, so the bin dryer is used.

So that means if there is any variations in the moisture content that will be taken care in the bin dryer. Because it acts as a intermediate storage as well as drying equipment between the drying and packaging operation. The dryers may be several meters high and it is therefore important that foods sufficiently strong to withstand the compression and thus retains spaces between the pieces to permit the passage of hot air through the bed.

So this is as I told earlier this also can be as a intermediate storage. So intermediate storage will be large storage area right. So the height of the bin dryers is very much high and the food material are stored in high quantities. So in that case, it should withstand the compression. Because when you are keeping large amount of food material in the bin dryer, so the food material should withstand the compression. As well as there should be a space between the food material for the air to pass through. Otherwise, the drying will not be done equally. Okay, so this is about bin dryers, our first dryers what we are discussing today in the food processing industries.

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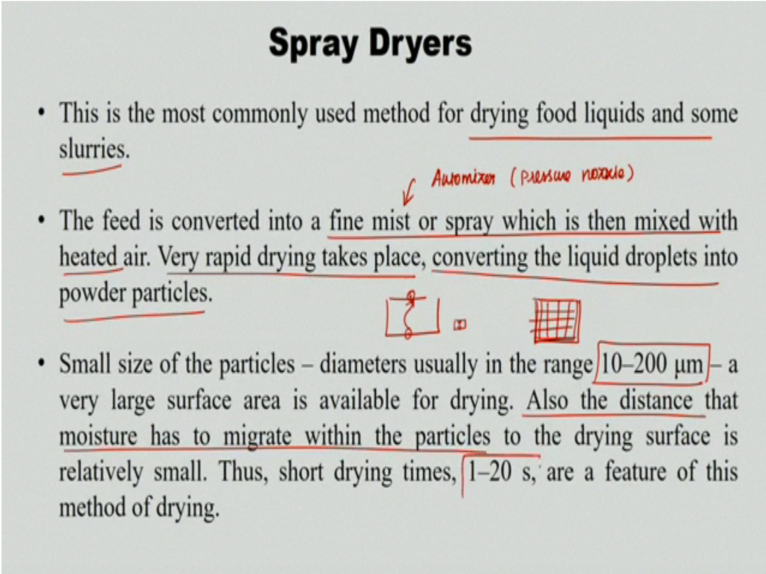

The second one is spray dryer. So the bin dryers mostly used for solid food material, but spray dryers are used for drying liquids and some of the slurries. The feed is converted into a fine mist or a spray which is then mixed with the heated air. So here we use a atomiser, atomiser or maybe pressure nozzle as well. Okay, so it is sprays right, the liquid food particle is sprayed and mixed with the hot air. Very rapid drying takes place, converting the liquid droplets into powder particles. So what you get is fine dried powder.

The small size of particles, the size of the particles used to here is 10 to 200 micrometre. So that is the way the surface area of each particle is increased because if you have a large food chunk, then you are hot air to be passed in the less surface area. But when you reduce the food chunks into the small, small particles size, so that means the 10 to 200 micrometre.

So large surface area is available for the hot air to pass through right. So in that way the drying is very quick right. Instead of drying a large particle, the small particle, the surface area is increase. So that is why the hot air is available for drying very quickly right. So also the distance that moisture has to migrate within the particle to the drying surface is also relatively small.

So think of a food material from here this point to this point, the moisture has to migrate. So if I have a very small particle, so this height also reduced in that way also you will have less drying time, which is about 1 to 20 second.

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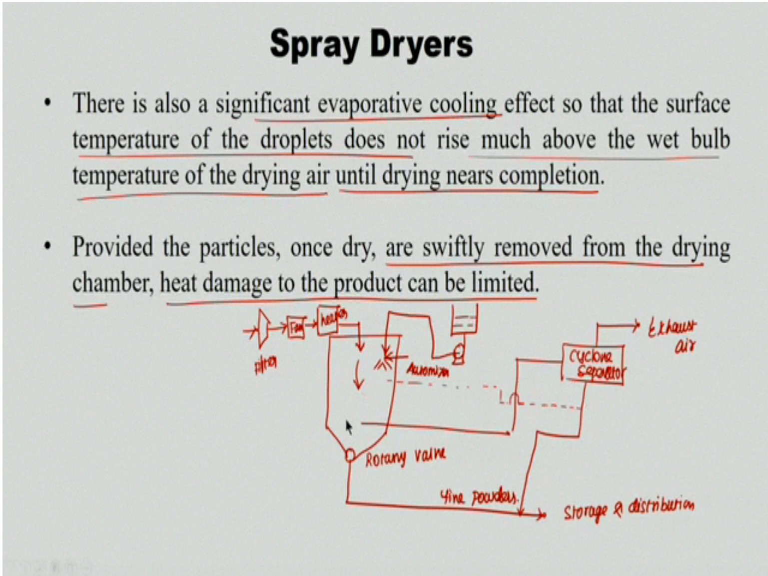

So there is also significant evaporative cooling effect, so that surface temperature of the droplets does not rise much above the wet bulb temperature of the drying air until drying nears the completion. So total drying takes place in the temperature less than the wet bulb temperature of the drying air. Because the particles are the droplets does not increase the temperature right.

Due to the evaporative cooling effect the droplets temperature does not rise, which always reminds less than the wet bulb temperature of the drying air. And provided the particles, once dry, are swiftly removed from the drying chamber, heat damaged the product can be limited. So that is also another advantageous spray dryer. One advantage is due to significant evaporative cooling effect, your droplet temperature does not rise and it always less than the wet bulb temperature of the drying air throughout the drying period.

That second advantage is the products are swiftly removed from the drying chamber, so that the heat damage to the product is very limited. So for example, this is your drying chamber. Okay, so here you get the air filtered remember, this is the food processing application. So we need to take care about the air quality as well. So then with using fan and heater your hot air is given to the drying chamber.

So from here you have a liquid product tank, so from there your liquid food particle is pumped and it is sent to the food chamber, here we use atomiser to spray the food particle. So this is mixed with the dry air, so your product is taken, maybe we can use here the rot or rotary valve. So the fine powders goes to the storage and distribution line, storage and distribution. So here it is a fine powders. Okay.

So then air is further sent to the cyclone separator, cyclone separator. Because the air also has some of the powdered product, so exhaust air leaves. So then fine powder is further feed in to the final product or sometimes what happens. It may also goes back to the, it may also go back to the drying chamber for as a recycle product.

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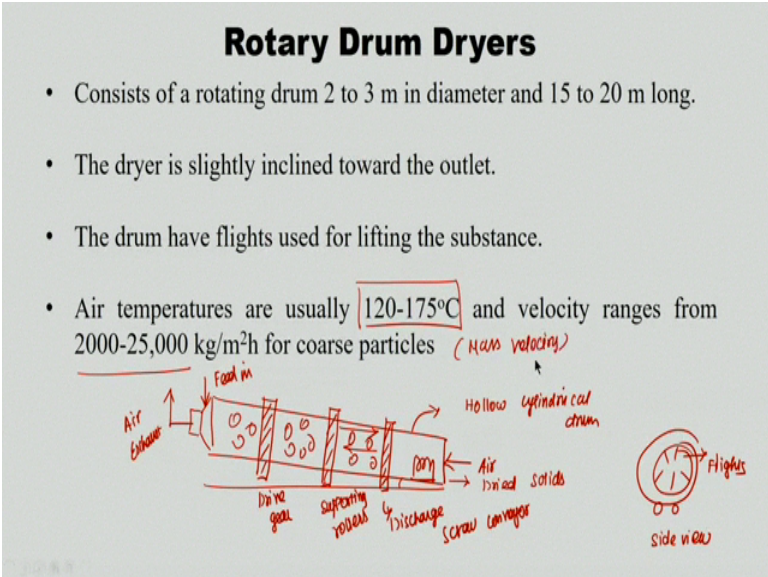

So the next one is rotary drum dryers. So, which consist of a rotating drum 2 to 3 metre in diameter and 15 to 20 metre long right. The dryer is slightly inclined towards the outlet. So it is something of this kind, this is a hollow cylindrical drum. So this is the air exhaust, this is feed in. So you have various provisions here, so here the one is drive gear, then supporting rollers, the third one is discharge screw conveyor.

So your air enters here, so here we have a heating element which heats the air and your solid is coming from the inlet in this way, solid, it is a counter current flow. Okay, so that is the way solid gets dried. So these slanting will helps for easy handling of solids from the inlet to outlet. So here you will get dried solids.

So the drum also have flights used to for lifting the substance, when the drum is rotating, so this here you have a flights. So, which helps in right, so this is in the wheel, so this is a side view. So this flights are used for lifting the substances. And the air temperature usually 120 to

175 and velocity ranges from 2000 to 25,000 kg per metre squared hour. So this is nothing but mass velocity. Okay, so this is about the rotary drum dryers.

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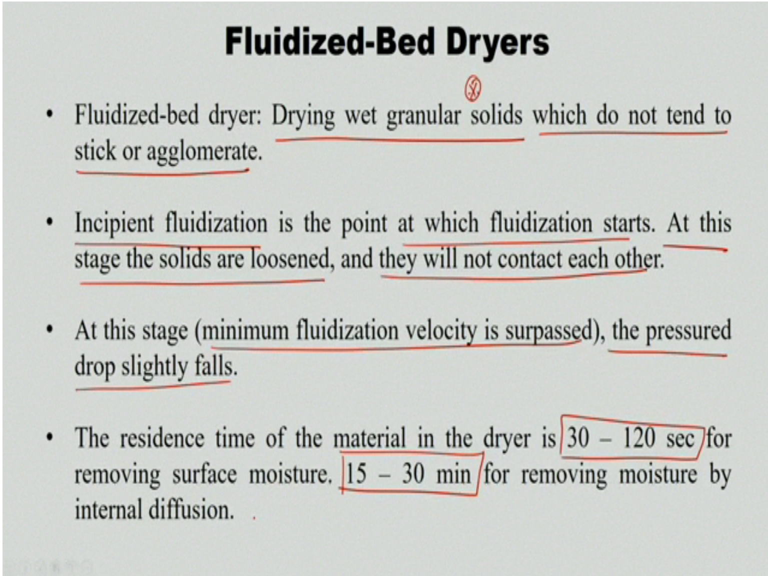

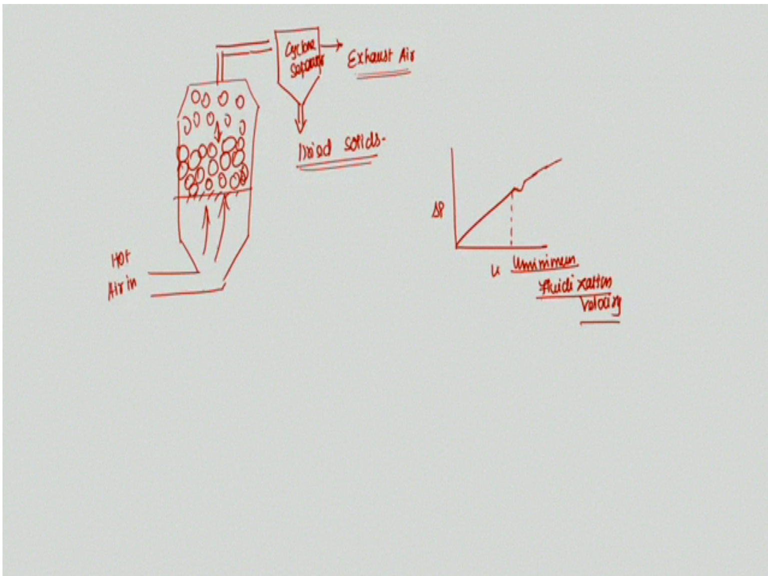

So the next one is fluidized bed dryers, so normally fluidized bed dryer will have a. So this is your air in that means hot air, so you have a perforated plates in which your food particles were kept okay, so this is your exhaust, so this is attached to the cyclone separator from which your exhaust air is coming out.

So your dried solids, you will collect here. So what happens is here if you draw a graph between velocity versus dell P. So this is linear line. So once it reaches the minimum fluidization velocity, minimum fluidization velocity. So this solid particle starts fluidizing along with the air, so this is the second condition, when your minimum fluidization velocity of the particle is reached then it starts fluidizing along with the flowing air current.

So then it goes to cyclone separator where you are air and dried solid were separated. That is the you get the dried solids. So here you will find some depth in the pressure drop due to fluidization of the food material. So then it forms the linear line right. So, and one more thing is also here you need to take care is for example here the drying wet granular solids which do not tend to stick or agglomerate. The thing you need to take care is it has to be used for wet granular solids which do not stick or agglomerate. So that kind of food solids only you can use this fluidized to bed dryer.

And incipient fluidization is the point at which the fluidization starts. At this stage the solids are loosened, and they will not contact each other. So they gets loosened and start fluidization along with the air stream. At this stage where minimum fluidization velocity is surpassed, the pressure drop slightly falls, because it starts fluidizing. And the residence time of the material in the dryer is 30 to 120 seconds for removing surface moisture. That means in constant rate period and 15 to 30 minute for removing moisture from internal diffusion. That is for falling rate period. So this is the mechanism with which your fluidize bed dryer is working.

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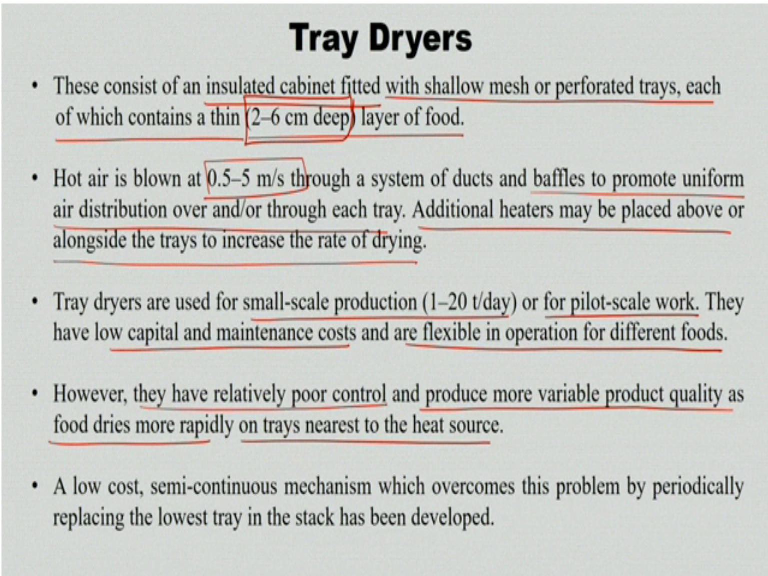

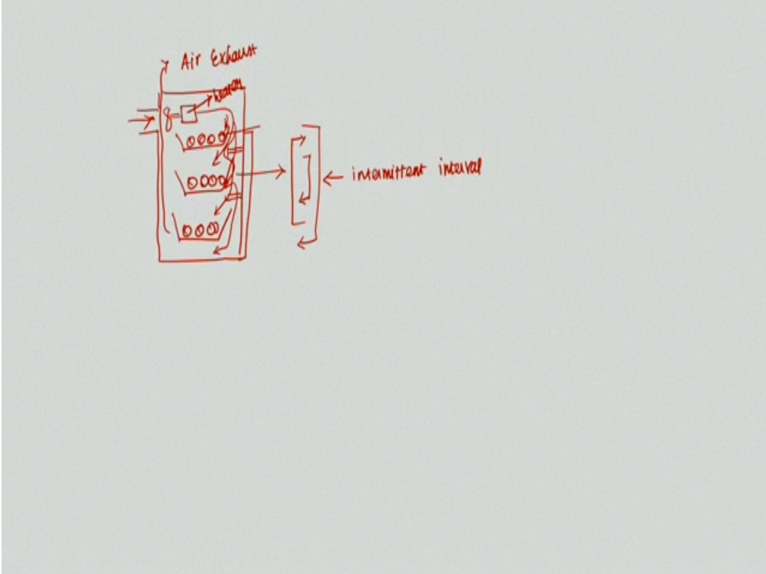

And the next one is tray dryers. So these consist of an insulated cabinet fitted with shallow mash or perforated trays, each of which contains a thin layer of food. So, which is about 2 to 6 centimetre deep right. So one cabinet is there in which a lot of trays, perforated trays in which the food material is kept. So the thickness of the food material here is 2 to 6 centimetre.

Hot air is blown with the velocity of 0.5 to 5 meter per second through a system of ducts and baffles to promote uniform air distribution over and or through each tray. So baffles will swing take care of the uniformity in the heating. Additional heaters may be placed above or alongside of the trays to increase the rate of drying okay. So in the tray dryers, you will have a cabinet, so this is your door. So you have a trays over here. Okay, so here is where your food material is kept which is of 2 to 6 centimetre deep.

So here you have a air inlet. Okay, so you have got a fan here, so from the fan it goes to heater, the heated air passed through each of the tray. So here your food materials are kept okay, so after passing through, so this air exhaust through this. So after once the drying operation is over. These trays are taken out with the dried solid okay. So what we wanted to tell here is system of ducts or baffles to promote uniform air distribution over and or through each tray.

Because here, there is no guiding rot, so if we keep baffles or guiding rots. So it will help the air passed through each tray more economically. Okay, so the dryers are used for small scale production, which is of 1 to 20 tons per day or for pilot scale work. So they have a low capital and maintenance cost under flexible in operation for different foods.

Because what I need is one cabinet and some trays and one fan and heater. So it is the capital cost is very much low and maintenance cost as well because we can take the tray out and cleaning is a very much easy.

And however, they have relatively poor control and produce more variable product quality as food dries more rapidly on the trays nearest to the heat source. So this problem is there right, so that is where here we took additional heat is may be placed above or alongside of the trays to increase the rate of drying. So here the mechanism is, here your heater stays right. So the air, which comes here will be so hot, so the tray next to the heater will get dried too quickly.

And further drying damage the food material right. And also, there may be a mechanism, these kind of heaters can be kept near each tray and the flowrate of air will take care of the temperature and the drying of the food material. So that is what here it is said, there is a poor control and which produces more variable product quality. The tray which is near to the heat source will get dry fast and the tray which is away from the heat source will take time to get it dried. And so you will get the variable product quality.

At low cost, semi-continuous mechanism which overcomes this problem by radically replacing the lowest tray in the stack has been developed. Actually, the semi-continuous mechanism means, so there is a control mechanism which keeps changing the tray first tray to last, then this one to first like this right. At intermediate time, at intermittent time, at intermittent interval. There is semi-continuous mechanism which keeps changing the tray so that way we can optimize the drying time among the trays and get the good product quality.

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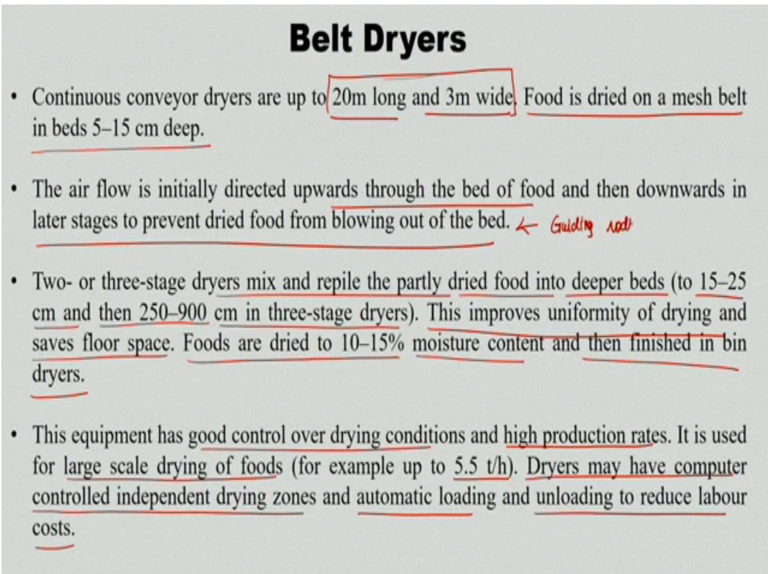

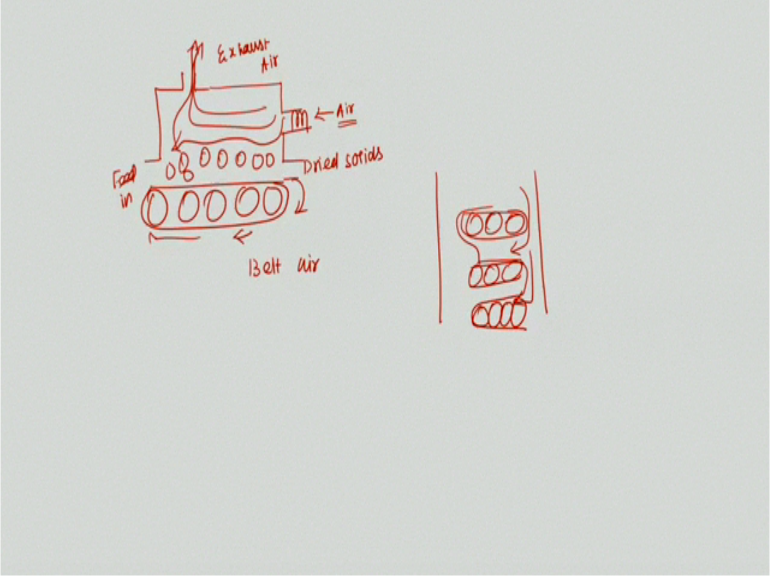

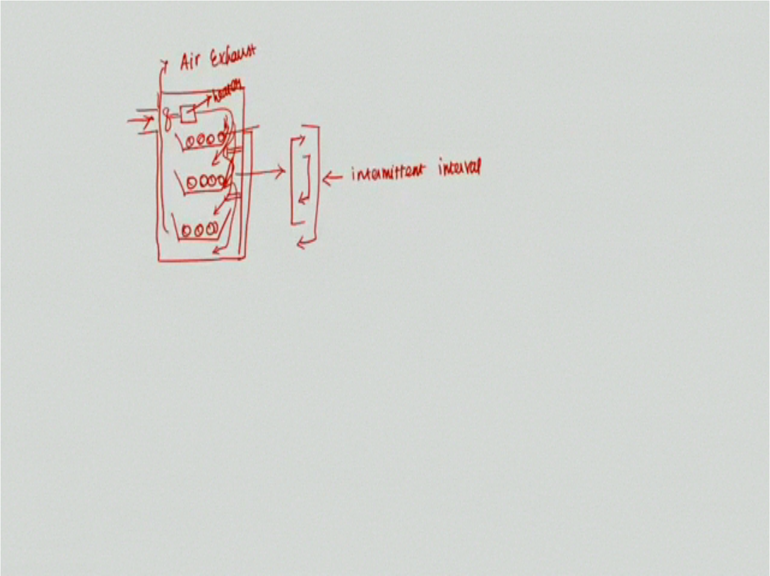

The next one is belt dryers. So these are continuous conveyor dryers are up to 20 m long and 3 m wide. Food is dried on a mesh belt in beds of 5 to 15centimetredeep. So belt dryers have the conveyor belt. Okay, so this goes like this, so your product is feed in. So your dried solids will be out from here. So here something of this kind because you need place to air to get in. So here you have a heater and air comes from the, filtered air comes from here, so this gets heated and here is your food material. So it pass through the food material and it goes out, exhaust air.

So here you have a guiding rods to guide clear along the exhaust. So this conveyor belt will be conveying the solids from the inlet to outlet. So this is simple belt dryer and there are varieties in each cabinet, there may be a for example, the total cabinet will be there. So here you have many such belts right. The feed in comes from here and goes in the second belt and comes here and goes in the second belt. So this will be done in many belts right. So that kind of design also available.

So this is another belt where solids will be coming and for the air side. So air will be passed through every belt right, what you have seen here in the tray dryers. So the same kind of mechanisms, so you can also observe in the belt dryers. So instead of trays your products will be conveyed through a belt conveyor. So that is a difference between tray dryers and belt dryers. So continuous conveyor dryers are up to 20 meter long and 3 meter wide. Food is dried on a mesh belt in beds 5 to 15 centimetre deep.

The airflow is initially directed upwards through the bed of food and then downwards in the later stages to prevent right food from blowing out of the bed. So that means the airflow as I said here, so there would be a guiding rods, which takes care of the airflow. So above and below the drying solids, the food to be dried.

And two or three stage dryers mix and repile the partly dried food into the deeper beds. So, which is of 15 to 25centimetreand then to 50 to 900centimetrein three stage dryers. So that is what I told here, so instead of one particular conveyor belt in which the food materials are passing. So we will have set of three stages or two stages based on the requirement. So this improves the uniformity of the drying and saves the floor space. And foods are dried to 10 to 15 percentage moisture content and then finished in bin dryers right.

So 10 to 15 percentage moisture content is done in belt conveyors. Then the food material is passed to the bin dryer for final moisture removal. So this equipment has good control over drying conditions and high production rates. It is used for large scale drying of foods. For example, 5.5 tons per hour belt dryers. The dryers may have a computer-controlled independent drying zones and automatic loading and unloading to reduce the labour cost right.

In the belt dryer two things we need to see, one is it can be done as a single stage or multiple stage, multiple stage handles high production rates. Moisture content of about 10 to 15 percentage is removed and the solids are further feed in to bin dryers for further moisture removal and the capacity this belt dryers handles is 5.5 tons per hour.

And also the airflow is initially directed upwards through the bed of food upwards and then downwards in later stages to prevent dried food from blowing out of the bed right. So it should not move from the conveyor belt. So that mechanism is taken care by the guiding rods.

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Table 15.3 Advantages and limitations of parallel flow, counter-current flow, centre-exhaust and cross-flow drying

Type of air flow	Advantages	Limitations
Parallel or co-current type: food→ air flow→	Rapid initial drying. Little shrinkage of food. Low bulk density. Less damage to food. No risk of spoliage	Low moisture content difficult to achieve as cool moist air passes over dry food
Counter-current type: food→ air flow←	More economical use of energy. Low final moisture content as hot air passes over dry food	Food shrinkage and possible heat damage. Risk of spoilage from warm moist air meeting wet food
Centre-exhaust type: food→ air flow→↑←	Combined benefits of parallel and counter-current driers but less than cross-flow driers	More complex and expensive than single-direction air flow
Cross-flow type: food→ air flow↑↓	Flexible control of drying conditions by separately controlled heating zones, giving uniform drying and high drying rates	More complex and expensive to buy, operate and maintain

Okay, so here the advantages and limitations of different flow configurations. So it can be done in co-current, counter current, centre exhaust and crossflow type. So, if food as well as air flow is in same parallel or co-current mode, one thing is the low moisture content difficult to achieve as cold moist air passes over the dry food. So that means, so your food is at high moisture level and your air is here from hot air is passing through right.

So hot air sees the high moisture content food right. So then, along with the length, the moisture content of the air increases right. So low moisture content in the food is difficult to achieve because the cold moist air is in contact with the food material at the later stages of the drying. So this limitation in parallel are co-current flow is taken care here because the counter current type your high moisture food in the end is seen by the hot air right. So here the low final moisture content as hot air passes over dry food right.

So the dry food sees the hot air, so that limitation in the co-current flow is taken care in the counter current flow. Otherwise the advantage of co-current flow is little shrinkage or low bulk density or little damage to food. No risk of spoilage. So this risk of spoilage in terms of heat right because the high moisture content food is seen by the hot air right. So in that case, the thermal damage can be avoided. So whatever advantages here in the co-current flow that is the disadvantage for counter current flow.

And centre exhaust type is nothing but whatever the exhaust air that is recirculated back to the dryer. So the combined benefits of parallel as well as counter current driers, but less than the crossflow driers. Because one will be in the co-current flow, other will be in the counter current flow. So here more complex and expensive than the single direction air flow.

In the crossflow type the food and air flow is perpendicular to each other. The flexible control of drying conditions by separately controlled heating zones, giving uniform drying and high drying rates in crossflow and more complex and expensive to buy and operate and maintain. That is limitations.

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Table 15.1 Characteristics of driers

Type of drier	Characteristics of the food						Drying conditions			Examples of products
	Batch or continuous	Solid/ liquid	Initial moisture content	Heat sensitive	Size of pieces	Should be mechanically strong	Drying rate	Final moisture content	Typical maximum evaporative capacity ($kg\ h^{-1}$)	
Bin	B	S	Low		Int	Yes	Slow	Low	–	Vegetables
Cabinet	B	S	Mod		Int		Mod	Mod	55–75	Fruits, vegetables
Conveyor/band	C	S	Mod		Int		Mod	Mod	1820	Breakfast cereals, fruit products, confectionery, vegetables, biscuits, nuts
Drum	C	S	Mod		Sm		Mod	Mod	410	Slurries, corn syrup, instant potato, gelatin
Foam mat	C	L	–	Yes	–		Fast	Fast	–	Fruit juices
Fluidised bed	B/C	S	Mod		Sm	Yes	Mod	Low	910	Peas, diced or sliced vegetables, grains, powders or extruded foods, fruits, desiccated coconut, herbs
Kiln	B	S	Mod		Int		Slow	Mod	–	Apple rings, slices, hops
Microwave/dielectric	B/C	S	Low		Sm		Fast	Low	–	Bakery products
Pneumatic/ring	C	S	Low	Yes	Sm	Yes	Fast	Low	15 900	Starches, gravy or soup powder, mashed potato
Radiant	C	S	Low		Sm		Fast		–	Bakery products
Rotary	B/C	S	Mod	Yes	Sm	Yes	Mod	Mod	1820–5450	Cocoa beans, nuts, pomace, cooked cereals
Spin flash	C	L	Mod	Yes	Int/Sm		Fast	Low	7800	Pastes, filter cakes, sludges, viscous liquids
Spray	C	S	–		–		Fast	Mod	15 900	Powders, instant coffee, powdered milk
Sun/solar	B	S	Mod		Int		Slow	Mod	–	Fruits, vegetables
Trough	C	S	Mod		Int		Mod	Mod	–	Peas, diced vegetables
Tunnel	C	S	Mod		Int		Mod	Mod	–	Vegetables, fruits
Vacuum band/shelf	C	L	–		–		Fast	Low	18 200	Juices, meat extracts, chocolate crumb

Key: S = Solid, L = Liquid, Mod = Moderate, Int = Intermediate to large (granules, pellets, pieces), Sm = Small (powders).
Data from Barr and Baker (1997).

So here are various types of driers were given and their mode of operation, whether it is good for solid or liquid food or how much initial moisture content, it can handle and whether that particular dryer is useful for heat sensitive materials and size of the food particle, whether it should be a small or intermediate or granules or pellets or pieces.

And whether it can be mechanically strong or not, drying rate is low, moderate or fast. And what is a final moisture content and typical maximum evaporative capacity of each dryer and their examples of the products, everything given in the one table. So this is taken from the references what I am going to give you.

So the bin dryer we have seen, cabinet we have seen, cabinet dryer, conveyor and belt dryer we have seen and rotary drum dryer we have seen and fluidized bed dryer we have discussed and after that spray dryer we have discussed. And there are a lot of dryers which are used for the food industry. So I request you to refer the material or reference material given in the lecture for further various driers applied in the food industry.

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Technique	Applications	Advantages	Limitations
Microwave and dielectric drying	High value products	Low temperature, batch or continuous operation, good quality products	Slow, expensive
Microwave augmented freeze drying	High value products	Low temperature, rapid, good quality products	Expensive
Centrifugal fluidised-bed drying	Small particles, vegetable pieces, powders	Rapid, easy to control	Loss of product integrity, noisy
Ball drying	Small particles, vegetable pieces	Low temperature, rapid, continuous operation, good quality products	Loss of product integrity, difficult to control
Ultrasonic drying	Liquids	Rapid	Requires low fat liquids
Explosive puff drying	Produces honeycomb structure in small particles	Rapid, good rehydration of products	Loss of product integrity, high levels of heat

And this is latest to technique used for drying of solids because if you see whatever the driers we have discussed. So all are based on hot air driers and I also discussed about how to increase the efficiency of the normal hot air driers, what are all the measures to be taken care? But nowadays microwave or dielectric heating drying is used.

And microwave augmented freeze drying is used. That means the microwave is used, electromagnetic sources used to dry the food product. And centrifugal fluidised bed drying. So there centrifugal forces used and ball drying, ultrasonic waves are used for drying. So their applications, advantages and limitations are given, so you may refer.

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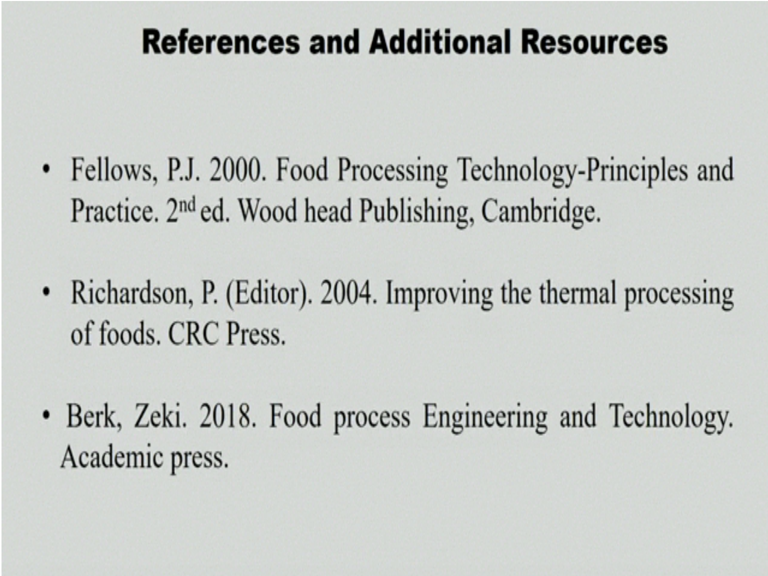

So this is the for the references and additional resources which I have used in this particular lecture. And also, this is limited lecture on various type of driers used for the food industry. So I request you to further refer these material to get to know further various types of driers used in food industry. Thank you.