Fundamentals of Food Process Engineering
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Lecture – 35
Freezing and Freeze Drying (Contd.)

Hello everyone, welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. We were discussing about Freezing and Freeze Drying in this chapter, that we are you know discussing since last of your classes. So, today we will continue with that.

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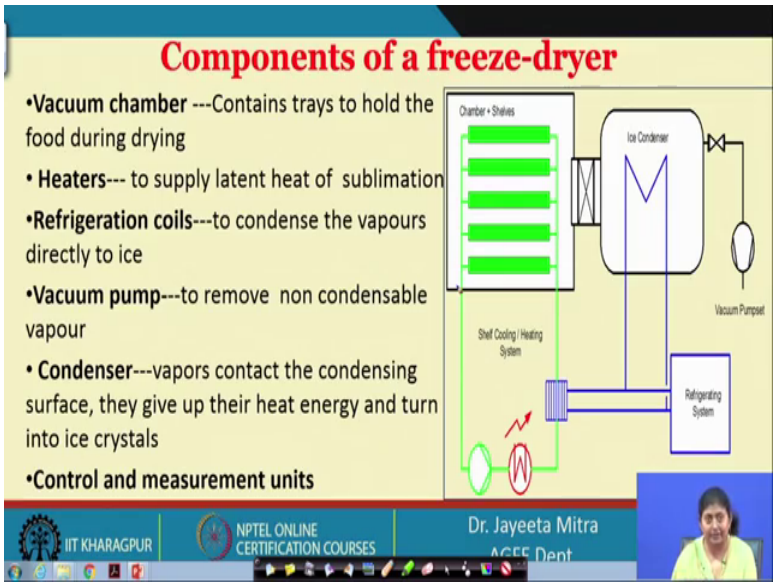

Last class we have discussed the freeze drying principle and we have calculated the freezing time based on the heat transfer through the unidirectional case we have assumed and also the mass transfer. And then we have related them to find out the temperature profile of the surface and the freezing front. In terms of the freezing front and also we have seen the governing principle behind this.

Now, what are the components of a freeze dryer, if we want to you know design them then what will be the components? That we can discuss now. So, in a freeze dryer we need to have all such arrangements, first there should be there should be a chamber where we can maintain the vacuum in a proper way without minimal leakage ok. So, they will be a chick chamber they will be a vacuum chamber that contains or whole the

trays for food for keeping the food during drying. Then there will be heaters to supply the latent heat of sublimation, there should be refrigeration coil to the condenser to condense the vapor. So, it needs to cool the condenser.

So, that the vapors can be converted to ice and also it need is it needs to lower the temperature of the product to you know freezing point because we need to first freeze the material ok. So, therefore, we need it and vacuum pump is needed to remove the non condensable vapor. So, first we need to use the, we need to remove the non condensable gases from the chamber. Later on when the sublimation will occur then, the vacuum pump will operate all those vapor to take it out from the chamber and then it will come to the condenser first it will it will condense they will take out. And vacuum pump will be continuously on to maintain the lower pressure level inside the chamber.

The condenser is actually used for the condensation of the ice crystal. They give up there, the vapors contact the condensing surface and they give up their heat energy and turn into ice crystal. Finally, we need also the control and measurement unit because there is so many points that we need to maintain. First is the temperature of the sublimation front so the temperature control should be proper and for that we need to maintain the source temperature from where the heat is coming. So, whether that is a convective source or a radioactive source; so, the source temperature we need to control. We also need to control the level of vacuum inside and the rate of heat transfer to the material.

So, here we can see that this is the shells and the chamber, but not only always this particular kind of geometry is required because some time we use the liquid material enough freeze drying also which eventually you know the slurry material which will become in a state of glassy condition. We need sometime the oils also so different configuration of freeze dryers are available based on the requirement that whether we are going to dry the direct fruits and vegetable or muscle food or some liquid sample, the medicine essential components bioactive components like that.

So, based on that the configuration may change; so this is the most basic one which is used for the frozen food or vegetables etcetera ok. So, this is a kind of a system where this is the chamber there is a ice condenser and here is a refrigeration system which is continuously used to cool the shelf also because first we need to freeze them and also the

you know condense the in the in the condenser to condense the vapor to the ice. And there is a vacuum pump attached to it to maintain the reduce pressure level in the chamber.

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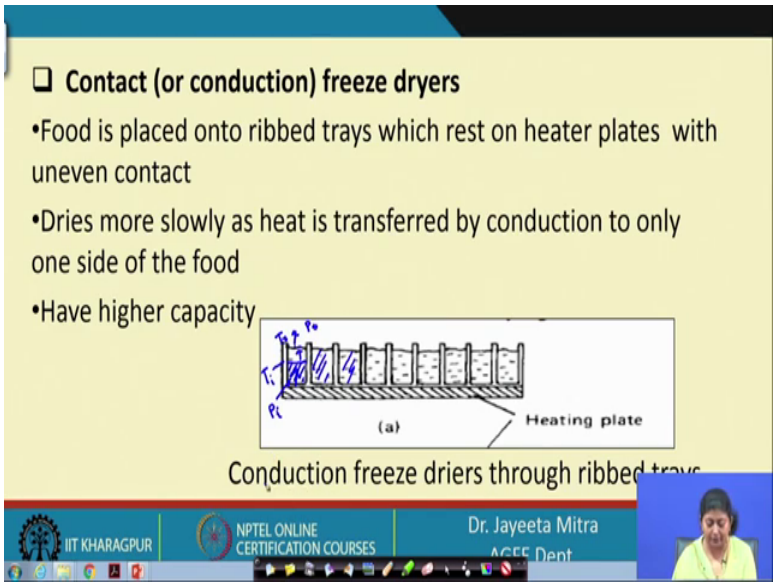

Now, contact so there are different types of freeze dryer. So, we will see some of them here, one is the contact or conduction freeze dryer where the food is placed on to ripped trace which rest on heated plates with uneven contact and dries more slowly as heat is transferred by conduction to only one side of the food ok. So, this is kind of a system it is a high capacity system where the heating plates are given like this food is kept on that. And there is a ripped trays, so we can we can see that since the thickness is more and we know that the time required is having a direct addition with z square that is the thickness square. So, as this dry layer thickness will increase so eventually the time taken will be also increased.

So, in this kind of a system heating plate is at the bottom. So, what will happen that heat transfer I mean when the frozen when the material will first frozen, then the whole thing will frozen first and then the heat is going to transfer from the bottom to the to the material, and the mass transfer will be from the top ok. So, eventually the upper layer will be getting dried ok. So, the upper layer will be getting dried so the moisture will be transferred through that.

And we know we have developed the equation of mass transfer with the relation with the sublimation front T i. And the temperature of the shelf which is here T o, partial pressure here will be the pressure of P 0 because it is kept under vacuum and here the temperature will be the pressure will be P i ok. And the permeability through the dry layer that is capital pi all such parameter we can calculate.

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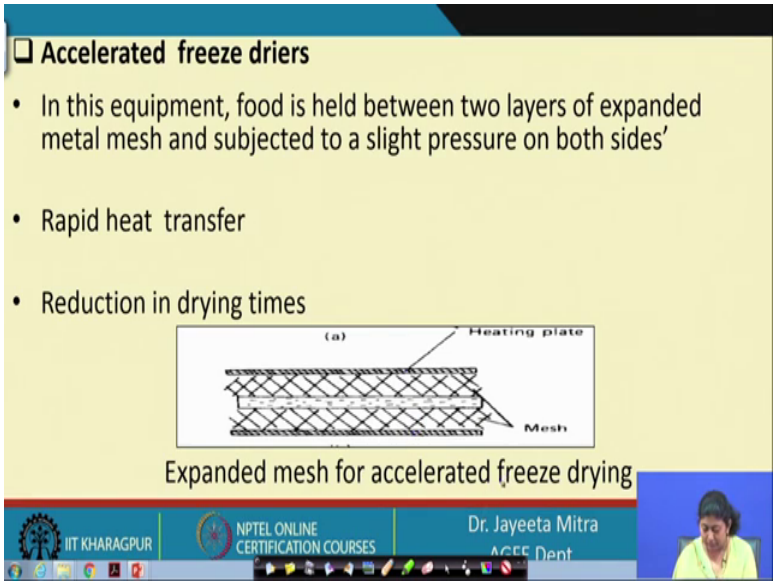

Now, we will see another system which is accelerated freeze dryer. So, what is the mechanism here in this equipment food is held between two layers of expanded metal mesh and subjected to a slight pressure on both side. So, rapid heat transfer causes from in this case and reduction in the drying time ok. So, if these two are heating plate this top and bottom are the heating plate and there is a mesh so; obviously, from both the side heat transfer will take place and the drying will be faster compared to the single side drying. And since these are these are the mesh so; obviously, we can we can accept that here the radioactive source of heat will be given to the material and the and eventually the material will be dried from both the side.

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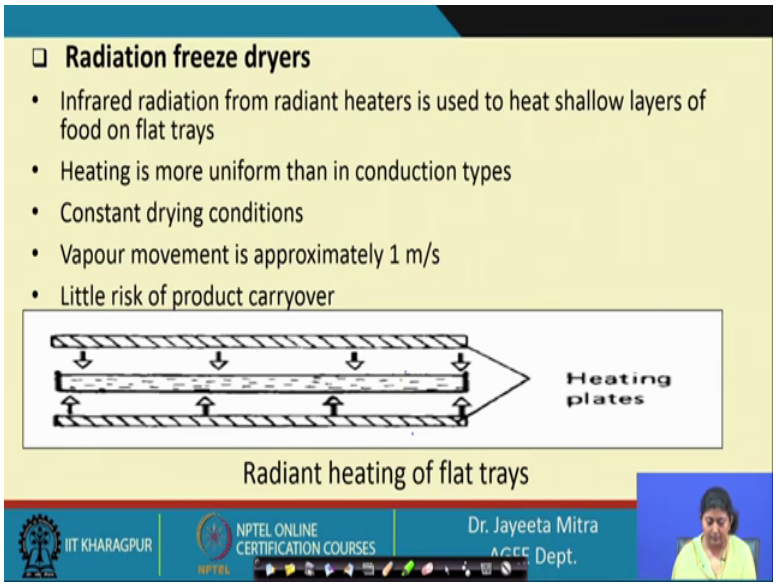

Now, next will be radiation freeze dryers. Here also we are we are keeping the infrared radiation from the radiant heaters that those radiations is coming and that is used to heat shallow layers of the food on the flat trays. So, we need to keep we need to design the system in such a way because infrared need to penetrate and based on the penetration property we can decide the thickness of the food materials. So, since here the, we cannot get very high penetration that is why, we are taking a thin layer.

So, heating is more in uniform more uniform than in the conduction type system. So, constant drying condition should be prevailing vapor movement is approximately 1 meter per second and little risk of product carry over ok.

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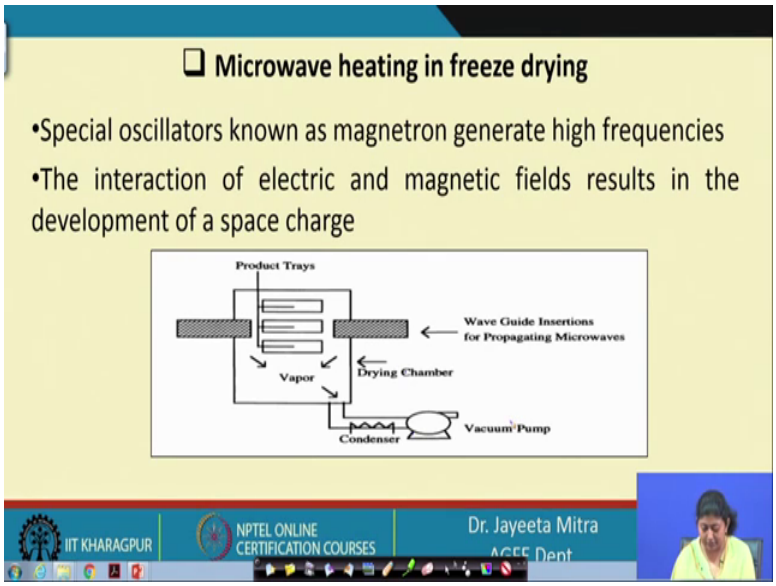

Next is microwave heating in freeze drying. So, microwave heating which is a volumetric heating; obviously, the heat generation will be very fast. Special oscillators known as magnetron generate high frequency of electromagnetic radiation. And the interaction of electric and magnetic field results in the development of space charges ok. So, products are kept on the trays these are the magnetron and here the volumetric heat generation will be there on the product trays vapor will come out. That is going to the condenser and that will form ice crystal and constantly this vacuum level or pressure level is maintained by using this vacuum pump. So, this is a drying chamber so this is how microwave heating is used in the freeze drying.

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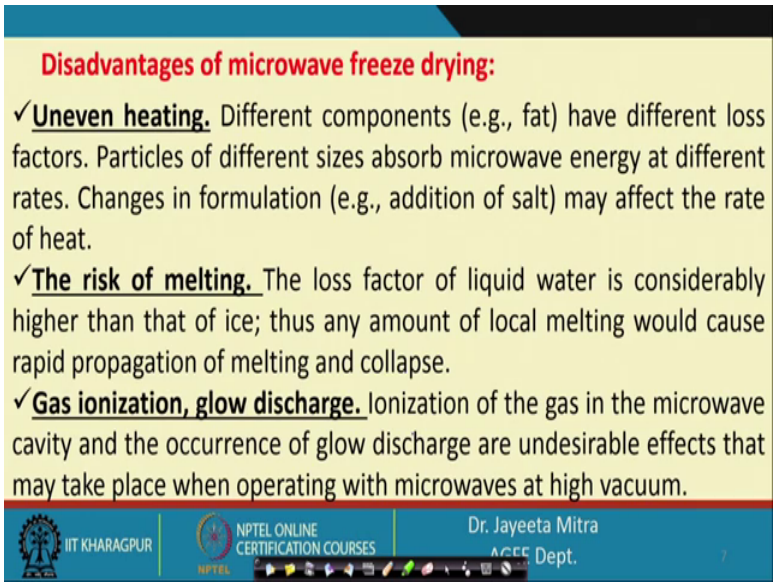

Now, there are certain disadvantages of microwave freeze drying. First is uneven heating because we know that microwave radiation when being absorbed by the you know the material in the in the food which is a dielectric material. So, because of the dipole rotation and ionic polarization the heating happens in the microwave. And there are some hot pockets will generate in case of the microwave, now all the food cannot be uniformly heated.

So, that is a drawback in normal microwave operation as well. So, that will prefilled here and that can cause the uneven you know drying also because of this uneven heating. So, different component as for example, fat have different loss factor, dielectric loss factor we know that dielectric loss factor and dielectric constant. Dielectric constant determines that how much will be the absorption of microwave radiation and dielectric loss factor signifies that what will be the dissipation of the energy in terms of heat ok.

So, because all the components in the food is not of same dielectric property that is one point and also if we consider the moisture distribution that is not also similar in all the situation and also the radiation is not also uniform. We also use the turn table inside a microwave, but then also there not be similar distribution of heat. So, these changes in the formulation and addition of salt may affect the rate of heat. So, there are many parameters that can cause the uneven heating in case of the microwave freeze drying. So,

this is property of the microwave not for freeze, but since we are heating by that so it will happen.

And there is a risk of melting because the loss factor of the liquid water is considerably higher than the than that of the ice ok. So, thus any amount of local melting would cause action rapid propagation of melting and collapse. Last one is gas ionization and blue discharge. So, ionization of the gas in the microwave cavity and the occurrence of glow discharge; are undesirable effects that may take place when operating with the microwave inside vacuum.

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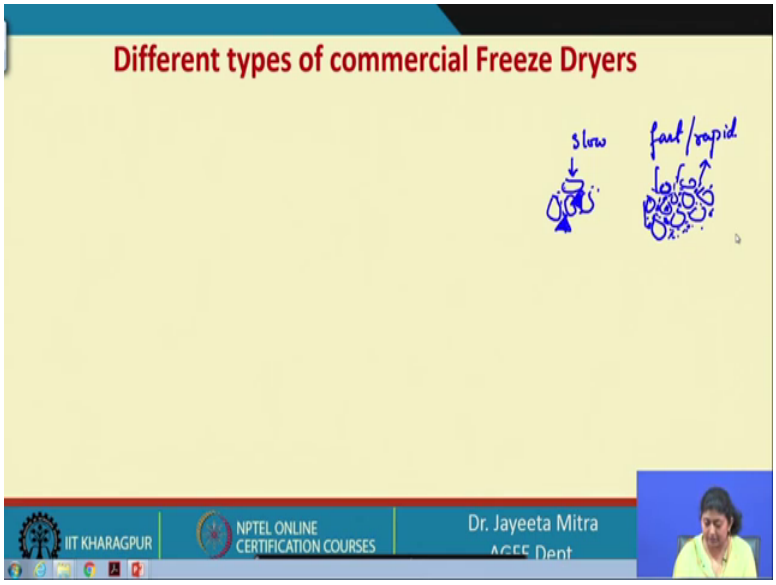

Now, different types of commercial freeze dryer. So, before going to the different commercial freeze dryer I should I would like to inform all of you one quality parameter of freeze drying that I mention that I will tell that in the freeze drying section because in the freezing section we have learn that slow freezing and fast freezing phenomena ok. So, we have already learned the slow freezing and fast or rapid freezing right.

Now, in that case one thing is that in case of freezing you are not removing the moisture. So, one damage it may cause because of the large crystal development the cell disruption was happened ok. So, in the in the cell structure there is a intracellular fluid and there is large number of ice crystal will be there which may break the structure. But in case of rapid freezing we have seen that the small you know if that if this is the distributed cell

structure and this is the you know liquid so very small ice crystal will form that does not damage the you know structure of the cell biological cell material.

But the advantage of rapid freezing; if we do that in case of freeze drying as well. Because here also first we are freezing by keeping the product in low temperature ambiance, then we are doing the sublimation. So, during sublimation if the uniform ice crystal formation is there that will directly sublime to the ambient; where the where the vacuum level is maintained and very well perforation or porous structure will form ok.

So, because of that as I have mentioned that in freeze drying the density of the product will be even lower than the umm you know original case and in other drying method it is very high. So, this is because of these phenomena that because of large porous structure the texture of the material does not damage and that will be intact. And when we want to though it we can again you know regain the structure of the material. So, very good porous structure we can observe in case of the freeze drying. And that is how it is very important there is no shrinkage and the equality looks like the original as it was in the fresh condition.

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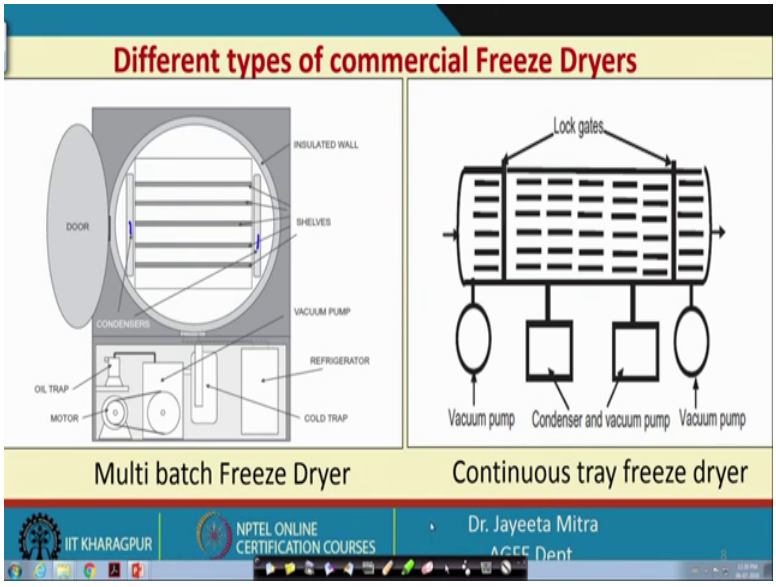

So, different types of commercial freeze dryer, multi batch freeze dryer; the first one which is the multi batch freeze dryer. So, here we have insulated wall so that as we have assume that all the heat to be supplied to the frozen layer will be use for sublimation of ice to vapor, but not for any other heat leakage or removal these are the shelves ok. There

is a condenser in these two sides. So, as and when the vapors will come out then that will come to the condenser first and will form the ice crystal.

There is the vacuum pump, oil trap, there is a motor, and there is a refrigerator. It has two purpose first to lower down the temperature of the shells to maintain the to bring the material to the frozen point freezing point. And another is the you know to make the condenser temperature low enough so that the vapor can be converted to ice there. And there is a continuous tray freeze dryer. So, continuous tray freeze dryer; there is a vacuum pump, condenser, and again two more vacuum pump is there. So, there are two lock gates; from where we can we can discharge and load the material ok. Where this in the first case is a batch system so one batch by batch we can upload and download by this one front door only whereas in this case we can continuously send it to this first and second lock gate and then can product can be taken out.

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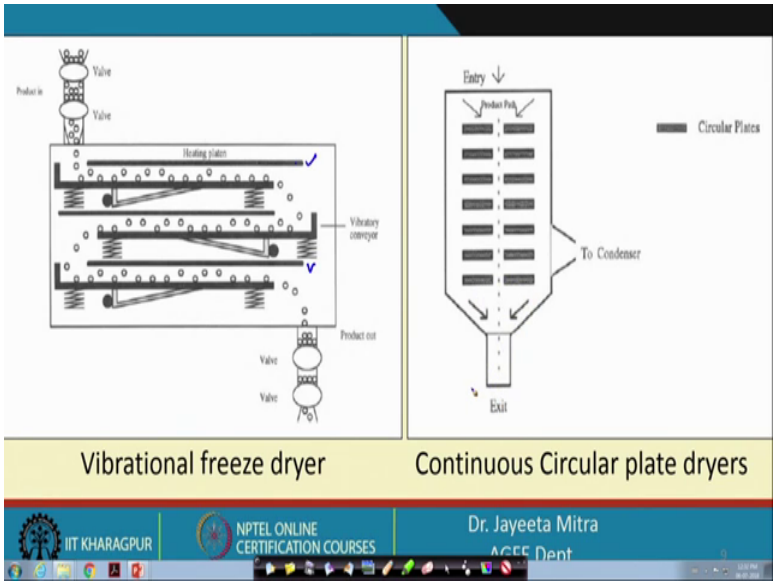

Vibrational freeze dryer so in that what we do is the product is coming in from one control hopper system. That we can design the florid as we want, we can design we can fit of all that how much the flow rate should be allowed. And then the product is coming on a tray which is you know hinge with the spring. Because the, we want to cause that vibration and the product is out from the bottom. Again it is controlled by a valve there is a vibratory conveyor system given vibratory conveyor. So, which is it is conveying at the same time it is vibrating just because it want to expose all the surface to the to the chill

temperature and also the ambient where the where the partial pressure is very low for water and in the inside it is very high.

So, all the surface should be exposed to the experimental condition of the low vacuum and heating what we are providing that is why this kind of vibratory arrangement has been made ok. And the heating plates are there. So, here we have two heating plates one this and one at the bottom, then there is continuous circular plates dryer. So, here also the entry of the circulation entry of the plates from the top is a product path how it is move coming down at the bottom. There is a condenser and also from the exit this vapor will be taken out.

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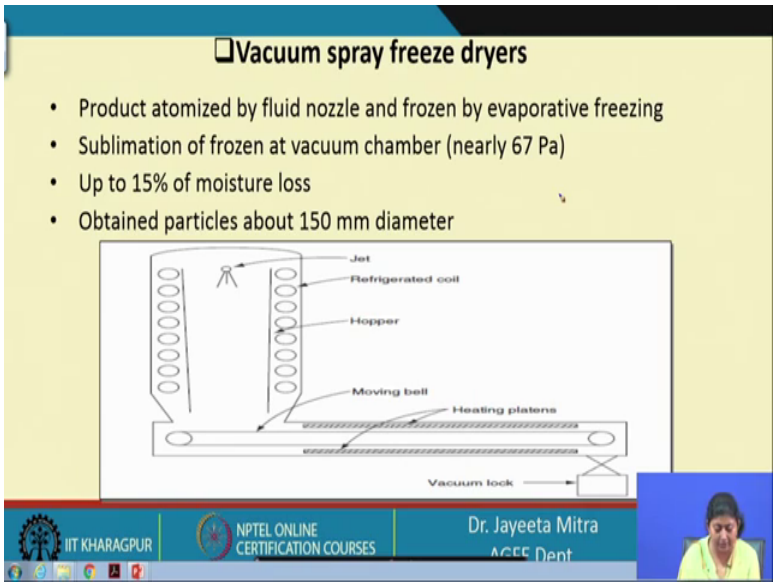

Vacuum spray dryer, vacuum spray freeze dryer so here what happened that the product atomized by fluid nozzle and frozen by evaporative freezing ok; sublimation of frozen sublimation of frozen front at vacuum chamber nearly 67 Pascal pressure. So, we can see that very low vacuum very low pressure we are maintaining, that is very high vacuum inside the chamber and like normal spray drying where the concentrated liquid is atomized through a nozzle here also the product is atomized by a fluid nozzle and frozen by evaporative freezing. That means it is exposed to reduce vacuum reduce pressure level and lower temperature so that it will be evaporate.

And sublimation as I have mentioned very low pressure is maintained up to 15 percent of moisture loss can takes place in this mechanism and obtained particles of about 150 mm

diameter. So, this is the jet through which the spray is coming into the chamber. There is a refrigeration coil which will lower the temperature of this of the chamber condition. There is a hopper and there is a moving there is a moving bell and the heating plate also there ok. So, when these particles are coming on this bell it is continuously moving so it is coming to the heating plates. And then this heating plates of providing heat of sublimation and finally, we are getting the dried product freeze dried product.

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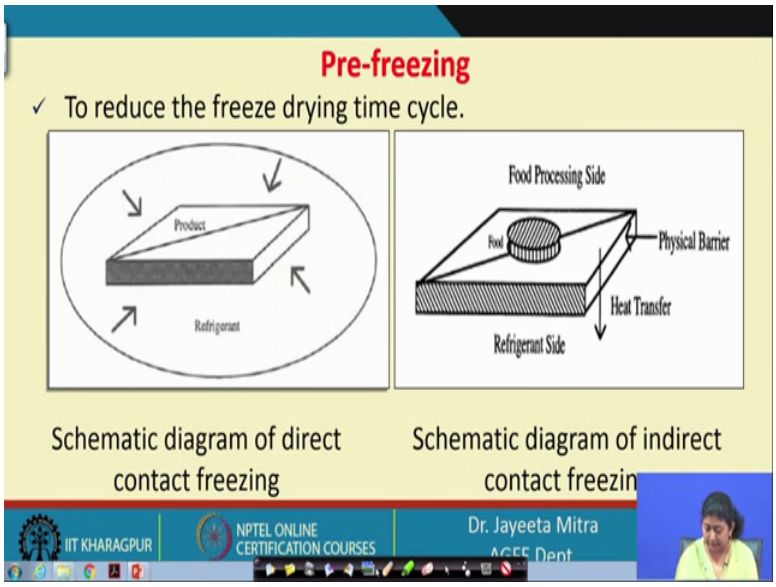

So, freeze drying related process if we some of them first one is pre freezing that is to reduce the freeze drying time cycle. So, here what we can do the schematic diagram of the direct contact freezing. So, direct and indirect both can be tried in the direct contact freezing the product is directly exposed to the refrigerant and in the indirect contact freezing the food is exposed to or it is you know kept on a material which is being cooled by the refrigeration.

So, direct contact with the refrigeration does not takes place there is a physical barrier a plate or something will be there which is causing the heat transfer. So, either conductive heat transfers through that metal or something that will happen. But pre freezing can be done in case of immersion freezing where we directly expose the material to the refrigerant.

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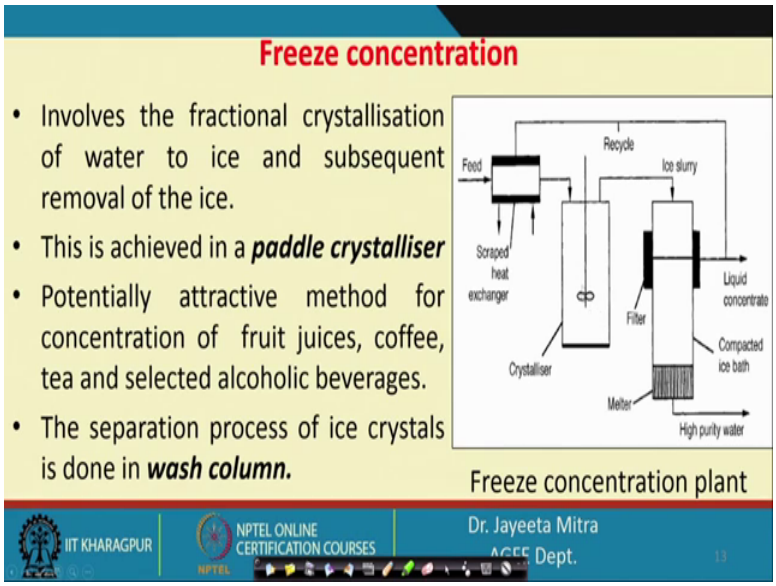

Now, another important concept is freeze concentration. So, freeze concentration. What is this? The, it involves the fractional crystallization of water to ice and subsequent removal of ice. So, here the all water available or all the moisture available in the food is not converted to ice completely it is part by part as the crystallization as the ice crystal formation will be there the ice is being removed. So, eventually gradual concentration is being done ok. So, involve the fractional crystallization of water to ice and subsequent removal of the ice. This is achieved in a paddle crystallizer here that we are using. Potentially attractive method for concentration of fruit juices, coffee, tea and selected alcoholic beverages. And the separation process of the ice crystal is done in wash column.

So, what happened that in this particular figure this particular figure where we can see that there is a crystallizer which is a paddle crystallizer we are constantly rotating it ok. So, so that the, you know better heat transfer can takes place. So, we are constantly rotating this there is a field which is a scraped heat exchanger is there. And then it is coming to this section from where the ice slurry whatever has been there that has been taken. Because eventually we are taking out all the ice crystal formed and then there is a there is a filter attach and there is a melter also. So, high purity water will be taken away from that melting section. And there is a compacted ice bath where this ice slurry is deposited. And this the liquid concentrate which is which is going out that can be

recycled if needed ok. If you want further concentration we can take out that after removal of the of the ice crystal.

So, this is potentially attractive for the fruit juice because if you want to make the concentrated juice so the moisture we need to remove. And however, if in certain cases where we cannot take out the moisture you know completely or in the pure form. If some dissolved nutrients are going away with that so in that case we cannot perform that function. For example for the milk concentration there will be a problem if we use this one because some milk solid will be lost in that case. But in fruit juices or coffee, tea this kind of beverages it is used because in that case we can most of the water can be take out by this method. And in since it is a freeze concentration so I mean without heating we are doing concentration. So, the quality of the product heat sensitive compounds for example, on the polyphenols in the tea and antioxidants of the fruit juices those will be properly preserved.

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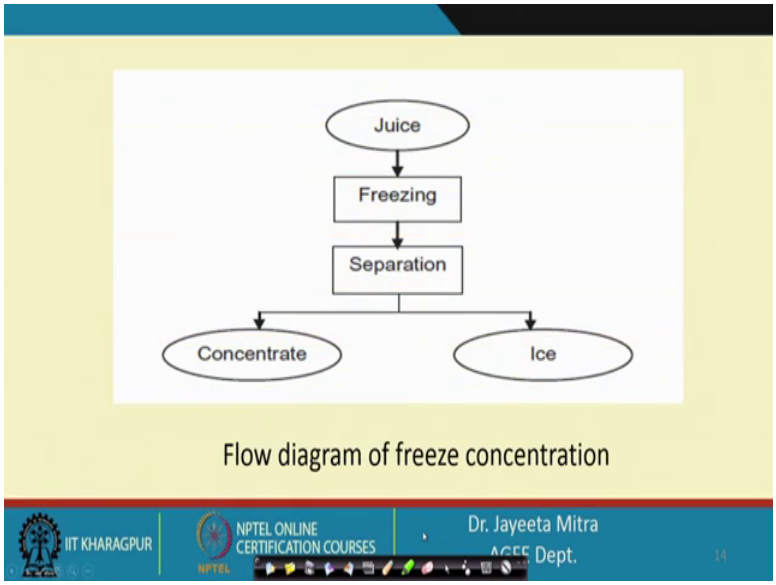

So, in the juice we freeze it first and then the separation of those two phases concentrated juice and the ice. This is the flow diagram how freeze concentration is being done.

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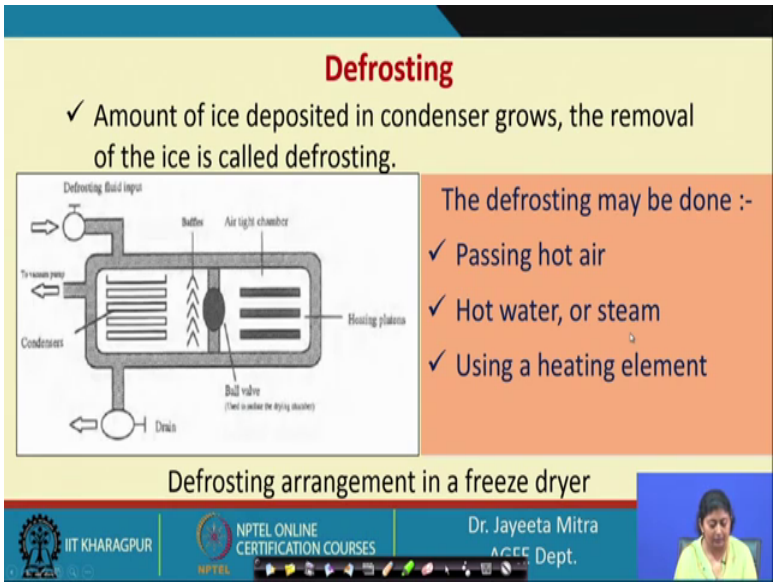

Now defrosting which is amount of the ice deposited in the condenser grows and the removal of the ice is called the Defrosting. So, this is needed as we have mentioned that pre freezing which is one part of the freeze drying where we freeze all the moisture of the food either by direct contact with the refrigerant or by the indirect contact. Similarly, defrosting is also very important because if the ice deposition is very much high in the condenser it will not work further unless we defrost it properly. So, the defrosting may be done by passing hot air over the condenser, hot water or steam or using a heating element.

So, defrosting fluid the defrosting fluid is input in this section and there is a line to the vacuum pump there is a condenser. Condenser coils there are baffles and air tight chamber is there, where the heating plates are kept. There is a ball valve which is regulating this transfer of transfer of air from this to this and there is a drain valve also.

So, when we when we want to defrost it we circulate that hot stream of water and all the you know ice will be melt and that can be taken away. So, we will stop here and we are almost finished the topic of freeze drying. And then in the next class we will continue with the new topic.

Thank you.