Fundamentals of Food Process Engineering
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Lecture - 17
Evaporation and Concentration (Contd.)

Hello everyone, welcome once again to the online NPTEL certification course on Fundamentals of Food Process Engineering. We will continue today with the topic Evaporation and Concentration.

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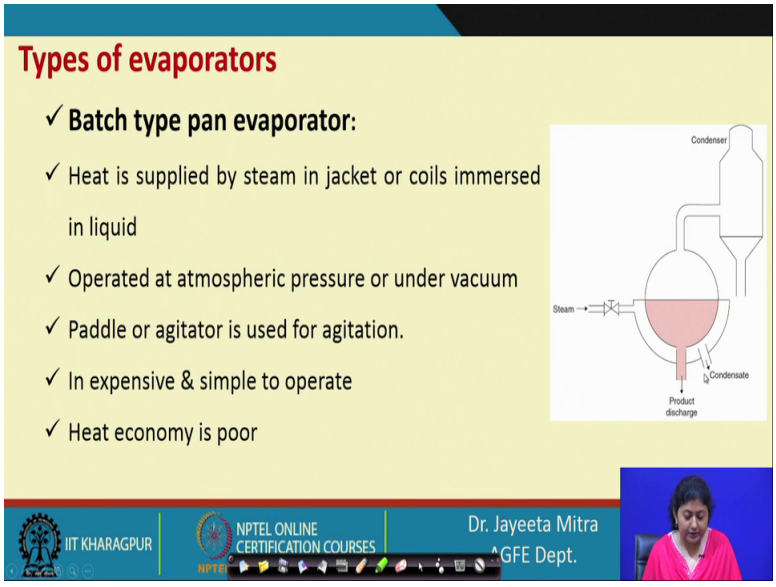

So, first we will discuss today types of evaporators. So, evaporators as we know that it is a one kind of unit operation by which we remove water from the boiling liquid and thereby the dilute feed will become concentrated product. So, first we will see the batch type pan evaporator.

So, this is how it looks like there is a pan which is put on a jacketed pan, where steam is entered steam is entered and there is a valve which controls the flow of steam into the jacket. And here it is being condensed and the liquid product dilute liquid that is kept here and it is being heated and evaporated. The vapor goes out of this section to the condenser and the concentrated product is discharged from the bottom ok. So it may also be some kind of mechanism where instead of this jacket certain coils are immersed. It

may be the design may be such that the coils are immersed in this where this coils are carrying the steam which is causing the heat transfer across the surface.

So, heat is supplied by steam in a jacket or coils that is immersed in a liquid, this batch type pan evaporators are operated at atmospheric pressure or under vacuum for heat sensitive material. And paddle or agitator is used for agitation, because as evaporation continues the liquid will become more thick and viscous. So, heat transfer across the surface will be lowered, so to increase the heat transfer agitation is being provided. This is an inexpensive and simple methods to operate and heat economy is very poor, because a steam that we are using here is condensed. And this vapor that is leaving it is it is going out and we normally in this kind of a system we normally cannot reutilize that steam, so the heat economy is poor here.

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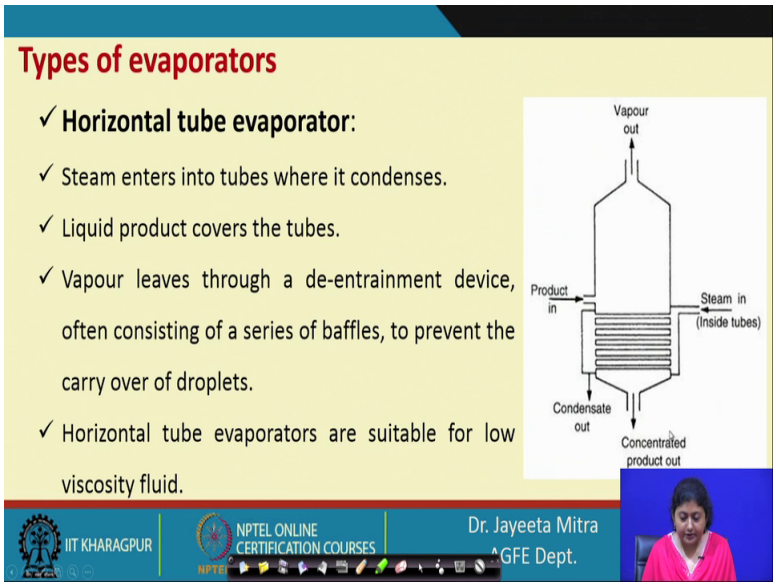

Next we will discuss the horizontal tube evaporator. So, in case of horizontal tube evaporator, see these are the horizontal tubes through which the steam is coming into the evaporation chamber and it is being condensed by coming in contact with the lower temperature surface and the condensate moves out from the other side. The product is in into the evaporating chamber and this is being splash over this tube or maybe this is this tubes are submerged into the product and by that this bundle of tubes are providing the heat transfer ok.

And the vapor will leaves out from this section concentrated product will be collected at the bottom. So liquid product covers all the tubes and vapor leaves through de-entrainment devices. So, sometime here certain kind of de-entrainment devices are placed to reduce the entrainment losses and often consisting of a series of baffles also given there has a de-entrainment device. These systems are suitable for low viscosity product.

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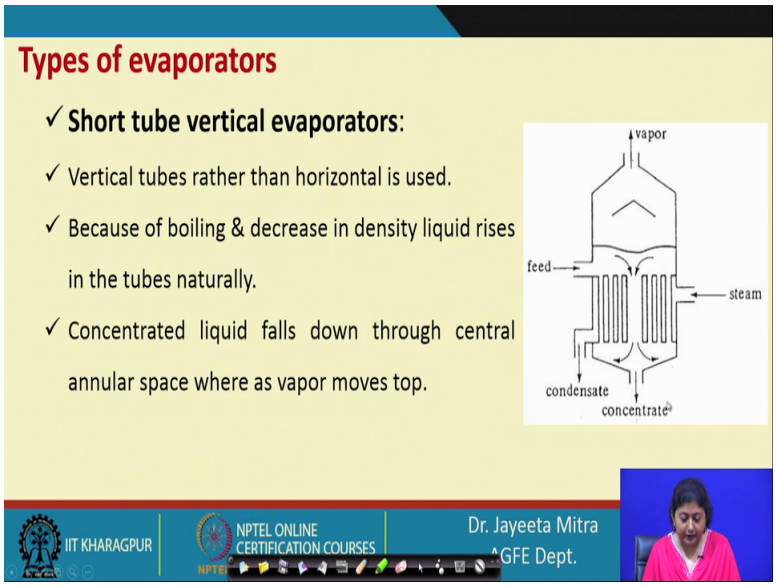

Now, then we will discuss the short tube vertical evaporators. In case of short tube vertical evaporators the steam is again coming into the tubes, but here this tubes are vertical bundles and in between there is a place in which the feed is entering from one side and falling in between the gap of those tubes through which the steam is passing. And then again by natural circulation this is being heated and circulation is continue continuously happening unless the concentrate is taken out from the bottom and the vapor is taken out from the top, steam which is condensed and collected from the other side.

So, because of boiling and decrease in density liquid rises in the bubbles naturally ok. Concentrated liquids fall down through the central annual space, where as the vapors moves from the top. So concentrated liquid which will you know eventually become concentrated because of evaporation that will fall down and from the bottom and will be collected from the bottom opening.

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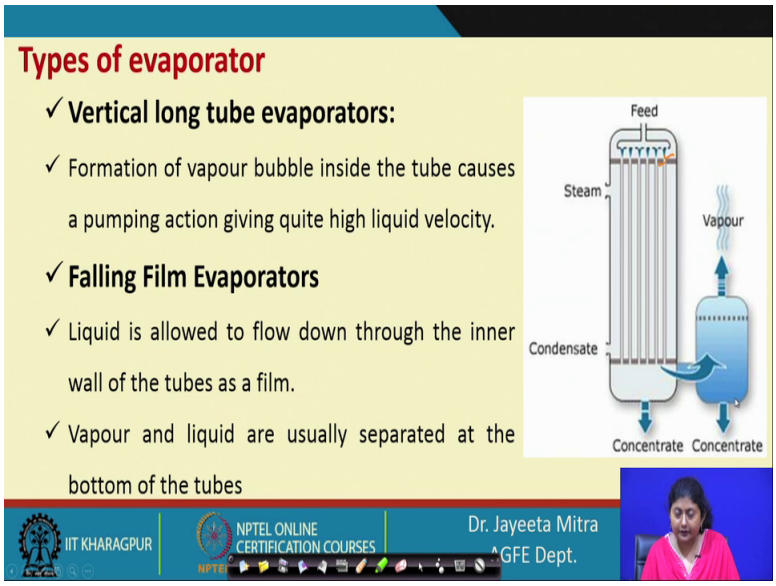

Next is vertical long tube evaporator. So formation of vapor bubble inside the tube causes pumping action giving quite high liquid velocity. So, feed here enters from top and through this vertical tubes to all this vertical tubes the feed is coming down ok, so these are the vertical long tubes.

Now, formation of the vapor bubble inside the tube causes a pumping action giving quite high liquid velocity. So all the bubbles at will form here in the liquid because the gas will try to escape out, so that will cause the increase in the velocity. And eventually that is goes to the vapor separator, where vapor come out from the top and the concentrated product will come out from the bottom steam is entered circulating the tubes and condensed and taken out from the bottom.

So, falling film evaporator where liquid is allowed to flow down through the inner wall of the tubes as a film ok. Vapor and liquid are usually separated at the bottom of the tubes as we have seen in this diagram.

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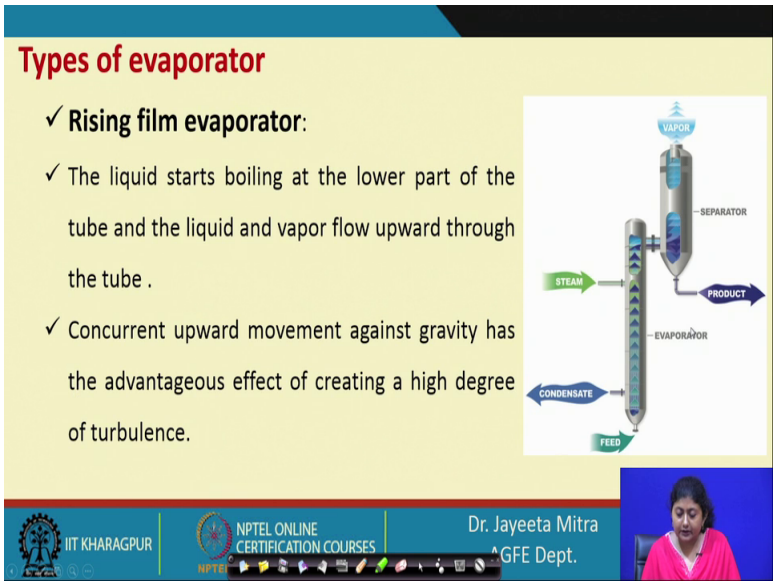

So, another kind of evaporator that is called rising film evaporator, in that what happened that the liquid starts boiling at the lower part of the tube and the liquid and vapor flow upward through the tube. So, what happened that feed which is entering from the bottom and the liquid boiling at the lower part of the tube and the liquid and vapor flow upwards through the tube. So, this feed which is enters here and steam which enters from the you know little top section and then it is coming down it is being condensing and this feed is heated up gradually and starts boiling and that boiling liquid will moves up and going to the separator.

In the separator the vapors are being separated from the top and the product is being collected, where as the condensate of the steam is getting collected from the side section of the lower part of evaporator. Concurrent upward movement against gravity has the advantages effect of creating a high degree of turbulence ok. So concurrent upward movement against gravitation this feed has to move so, this has an advantages effect of creating a higher degree of turbulence. Because we need to do it to overcome the you know gravitational effects and that is why the heat transfer increases.

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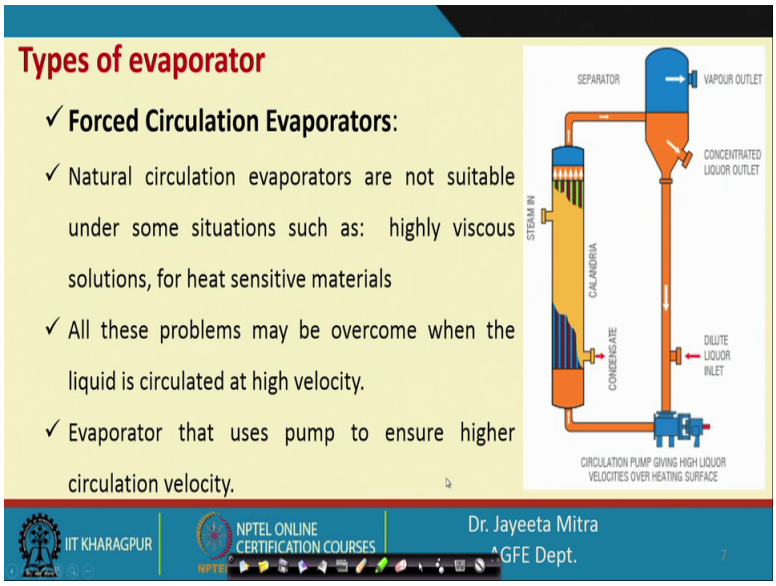

Next is the forced circulation evaporator. So natural circulation evaporators are not suitable for you know highly viscous material or for the heat sensitive material, because in heat sensitive material sometime it may happen that you know we are using higher temperature for the dilute sample. But, lower temperature for the you know concentrated sample and that time we need to throw the material against pressure. That means, from the lower to higher pressure so all such cases the force circulation is needed.

Here there is a circulation pump giving high liquid velocity over the heating surface, this is a calandria and here steam in and here the condensate is moving and this is the separator where vapor outlet and concentrated liquor outlet is shown. Now, the problem of high viscous solution and for heat sensitive material can be efficiently handled by when the liquid is circulated at high velocity, evaporator that use pump to ensure high circulation velocity that comes under the force circulation evaporator.

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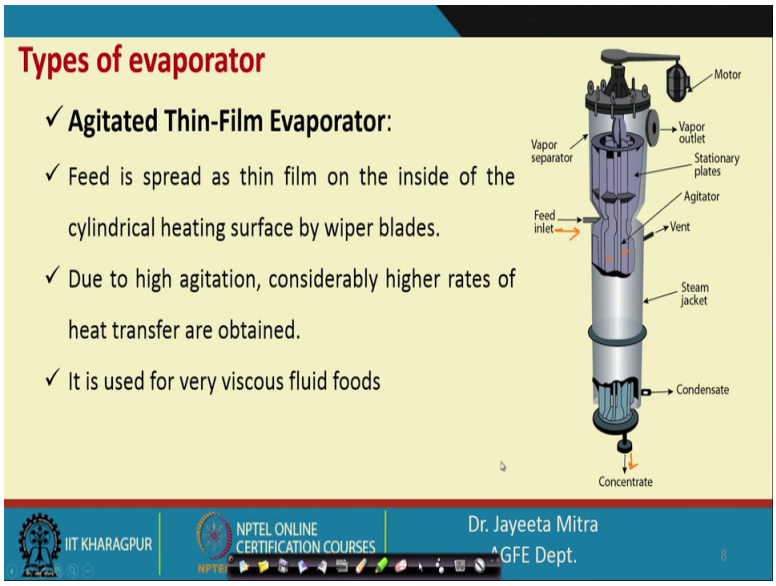

Another is the agitated thin film evaporator. So feed is spread as thin film on the inside of the cylindrical heating surface by wiper blades. And due to high agitation considerably higher rate of heat transfer are obtained here, so here is the inlet of feed the feed inlet and the concentrate is taken from the bottom. Now as the feed is coming with a thin film and there is a agitated thin film agitated is provided, there is a vent these are the agitators.

These are the agitators, there is a vapor outlet vapor separator is there which cause the you know differentiation between the vapor and concentrated liquid and then separate them move them into two different direction. And there is some motor there is a steam jacket also to cause the better heat transfer, this kind of system where agitated thin film evaporator used for very high viscous fluid food.

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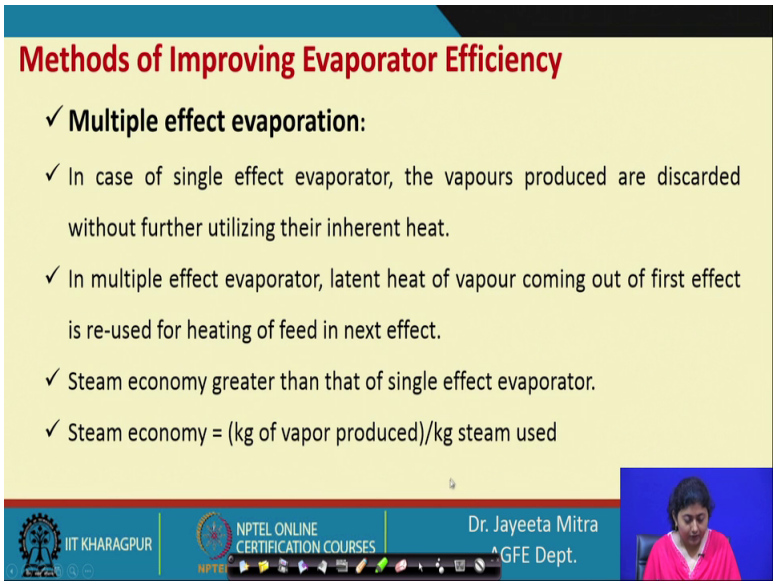

Now, methods of improving evaporator efficiency, so evaporator efficiency improvement if you want to think of we the first thing is how much the utilization of steam can be enhanced or for the same material of the steam how much higher amount of the moisture or water can be evaporated right. So, multiple effect evaporation is a solution to that problem. In case of single effect evaporator the vapors produced are discarded without further utilization of their inherent heat.

So in multiple effect evaporator the latent heat of vapor, because whatever steam we are using to concentrate the liquid and so the steam is being condensed and the liquid is evaporated. So the vapor is again generated in each single effect, so if that vapor can be used so an efficient system can be generated.

So, keeping that in mind in multiple effect evaporator, latent heat of vapor coming out of the first effect is reused for heating of the feed in the next effect right. Steam economy is greater than that for single effect evaporator, steam economy is actually kg of vapor produced per kg of steam used. So, for the single effect evaporator this steam economy is very low where this is significantly high for the multiple effect evaporator.

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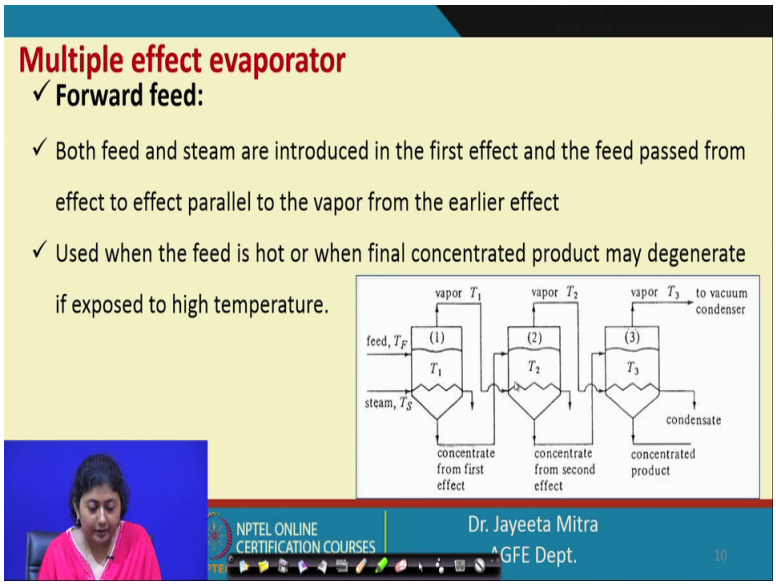

So, the first one we will discuss is the forward feed evaporator, what happens in this case of forward feed? See feed is first enters into the first effect this is a triple effect evaporator, triple effect evaporator and the arrangement is in forward feed. So, feed is entering into the first effect at temperature T f and inside the evaporator where the feed is entering the temperature, the saturation temperature of boiling water is T 1 and the corresponding pressure let us say P 1 is maintained inside the first effect or first evaporator chamber. Steam is coming at T s temperature that is saturation temperature of steam and it is being condensed via this heat exchange surface.

So we are getting condensate from here, now in case of forward feed the concentrate that we are getting that is most so this concentrate from the first effect that we are getting that is going to the second effect where the temperature is T 2 and corresponding pressure let us say P 2 is mentioned maintained ok. So the feed is moving forward and then again it is being concentrated in the second effect by the vapor that is being generated in the first effect. So, this vapor that is generated at T 1 temperature is sent to the second effect as the steam or the heating media or evaporating media.

Now, the temperature of the boiling liquid does not change we know, so at P 1 pressure T 1 temperature the vapor will move out at T 1 temperature and at T 1 temperature only it enters into the second effect ok. However, in the second effect the temperature will be a bit low corresponding to the pressure P 2 and the vapor that leaves the effect T 2 will be

at a vapor will be at a at a temperature T 2. And this vapor which is coming out coming out at T 2 temperature will again enter into the third effect here we have designed 3, we can design for more as well based on the cost of development and the economy that we are getting.

So, it is again entered into the third effect, it gets condensed and finally, we are getting the condensate here. So, for the same steam let us say 1 kg steam that we have used here that is used to evaporate water from this affect this is going to going as a vapor and this again utilized for evaporation in the next effect. Again some amount of vapor and this is finally, used for the third. So, for the same 1 kg steam that we have used we are getting the feed, concentrated product. So, the product is coming out from the second effect after concentrating to some extent and again enter into the third effect; And the vapor which is coming out of the third effect goes to the vacuum condenser to separate the vapor from any other you know material that has been taken away with the vapor, such as any volatile or any liquid droplets if it at all going to with the vapor.

So, in a nutshell we can say that both feed and steam are introduced in the first effect and the feed passed from effect to effect parallel to the vapor from the earlier effect. And this is used when the feed is hot or when final concentration of the product may be degenerated if it is exposed to high temperature, because eventually we are you know having a low temperature. Because the temperature at which it is developing the vapor it has to come into contact with a lower temperature to condensed and the lower temperature will be maintained eventually by lowering the pressure. So, pressure also is reduced from the first effect to the last effect and so is the temperature.

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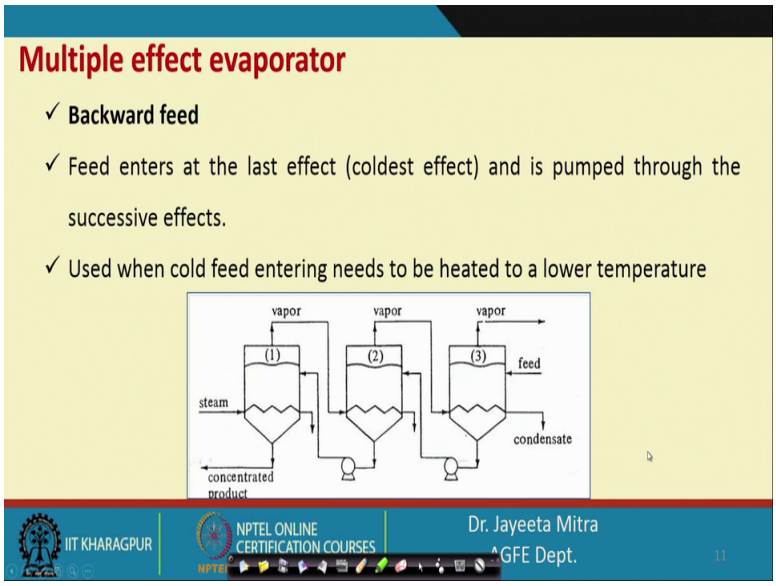

Next is the backward feed, so what is the mechanism of the backward feed here though steam is entering from the first effect and the steam is condensing the vapor which is which has to be generated if it causes vaporization of this material ok. So, that vapor will again goes to the second effect and the vapor coming out from the second effect goes to the third one. Whereas, feed is entered from the last effect and at you know at lower temperature and pressure it is being concentrated to some extent and then this concentrated feed is you know coming out of the bottom has to move to the next effect. Now, the next effect is maintained at higher temperature and pressure and this is continuously so for the first effect as well.

Now, in the forward feed case we did not utilize the pump because the concentrated feed has to go from the higher pressure to the lower pressure. So, automatically it can go there, but since here we want to move the concentrated feed from the lower pressure section to a higher pressure section so, we need to have a pump a positive displacement pump that is taking this feed to the next effect. So, the feed is entering from the last to the second to the first like that and as per requirement we can change the number of effect that we have added in series.

However the steam which is being used in the first and utilizing the concentrated feed of the second evaporator, second effect and producing the vapor that vapor goes to the second effect and vapor also produced from the second effect which is goes to the last

one. So the high heat is available to the final product that is being concentrated and that needs higher heat transfer and if it is not such a product that can you know damage in exposing to high heat treatment, so in that case we can use this one.

So, feed here enters at the last effect or the coldest effect and pumped through the successive effects and this is used when cold feed entering needs to be heated to a lower temperature.

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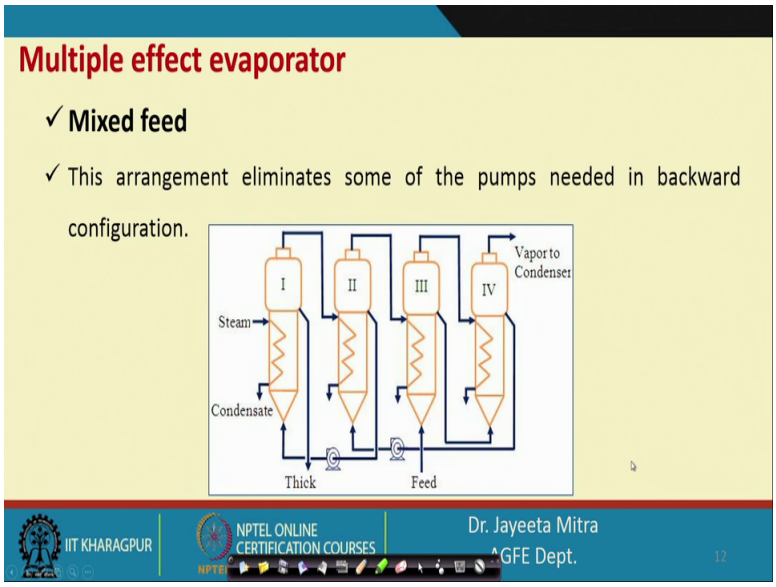

There is also a mixed feed system where feed is getting introduced in a you know an intermediate effect and then from that intermediate effect to after you know partial evaporation. Evaporation happens corresponding to the pressure and temperature inside this then that concentrated feed goes to the last effect. And from the last effect it is eventually going to the second one, that is which is placed before the effect where the feed has entered. And this is being done by the pump because again from the lower to higher pressure, we are increasing we are sending the feed and again from the concentrated feed of second to the first it is going by pump.

So, to pump we have utilized instead of three pump that needs to be use there if we have gone to fully the backward or backward method of multiple effect evaporator. So by utilizing this kind of mixed feed we can eliminate the use of some pumps requirement of the pumps, where as steam is normally utilized normally used in the first effect first. And then it moves onto the second one then evaporation evaporated vapor from the second is

moving to the third one and so on finally, from the last effect vapors are collected and sent to the condenser for separation ok.

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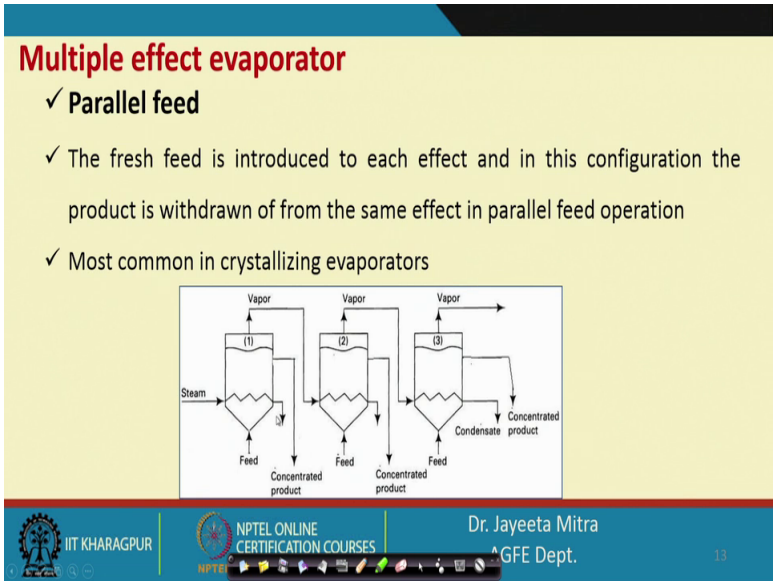

Now, multiple effect evaporator. So, another is called the parallel feed so what we have seen that so far that once we are entering feed whether it is forward or backward and once we are entering steam the rest of the thing is happening continuously. The evaporation of the first effect causing the vapor and that moves to the second one and eventually goes to the next one. Similarly, the concentrated feed of one effect either forward direction or backward direction goes to the successive effects.

But in parallel feed what we do that feed is individually entered into all the effects and the concentrated product is coming out from all the effects. Only steam is utilized from you know every effects, steam from the first effect causing vapor and that vapor is utilized in the next effect. The vapor of the next effect is utilized in the third one and so on.

So, the fresh feed is introduced in each effect and the in this configuration the product is withdrawn of from the same effect in parallel feed operation. So, this is the most common in crystallizing the evaporators ok. So, when we want to crystallize we want to remove the you know evaporation, we want to evaporate the water and finally, we are getting the crystallizing material crystallized material.

So, we will stop here; in the next class we see the, we will see the design of evaporators.