Process Equipment Design
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Lecture –34
Design of Evaporator-1

Hello everyone. This is 34th lecture of the course Process Equipment Design and I welcome you all in this lecture and here we are going to start discussion on evaporator. First of all, we will discuss that what is evaporator, what are the different types of evaporator, what are its application and then we are going to discuss the design part of evaporator in detail. So, let us introduce the evaporators and as far as you know that evaporators are the units where we concentrate the feed, where the feed is concentrated by removing the solvent from this.

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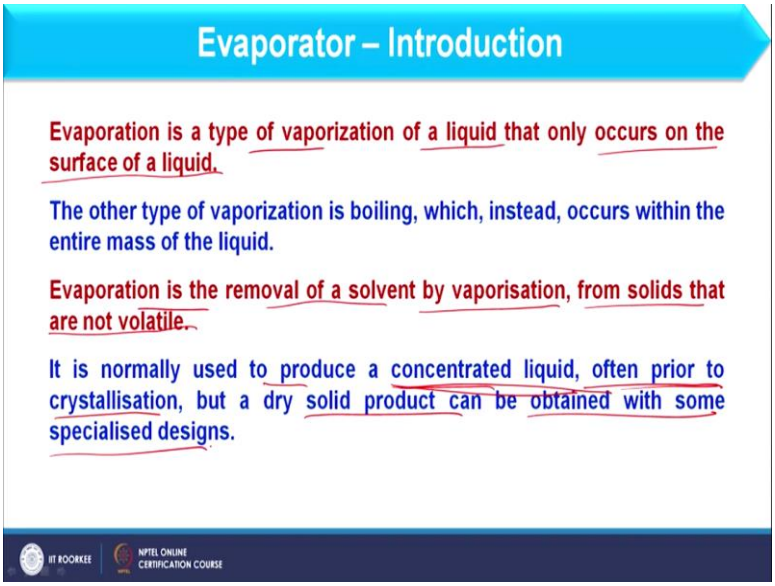

So, as far as evaporation is concerned it is a type of vaporization of liquid that only occurs on the surface of the liquid. So, that evaporation is basically the process where liquid is converted into the vapour, but only at the surface and secondly it is done at any temperature. Evaporation is carrying out at any temperature wherever the temperature difference is observed.

So, this is the process where liquid is converting into the vapour and it is similar to vapourization. So, it means that vaporization and evaporation is the same thing. No. As far as conversion from liquid to vapour is concerned it is the same. However, we can have some

operational differences such as vapourization takes place in the bulk as we understand the boiling.

So, this is the bulk phenomena and evaporation is basically the surface phenomena. Vapourization takes place only at a particular temperature where liquid reaches to its boiling point. However, evaporation can be carried out at any temperature where temperature difference is observed. So, in evaporation removal of solvent by vapourization from solids that are not volatile.

So, in evaporation solvent is converted into the vapour and that solvent is not volatile in nature. So, if solvent will be removed from the feed obviously solute concentration will be increased in the feed and we can obtain thick feed as the outcome of the evaporation. So, it is normally used to produce concentrated liquid often prior to crystallization. So, that is the unit which is available before the crystallization.

But a dry solid product can be obtained with some specialized design. So, evaporators are usually used to obtain concentrated liquid which is before the crystallization. So, what will happen in crystallization? When the evaporation is taking place whatever solution I am having that is at the saturation condition and what will happen in crystallization. In crystallization, sudden pressure drop occurs.

And therefore whatever saturated liquid is available in evaporator when it enters into the crystallizer it is reaching to super saturation condition where precipitation of the solid occur and the crystals are formed. So, we will discuss crystallization and crystallizer design separately and here we are mainly focusing on evaporators.

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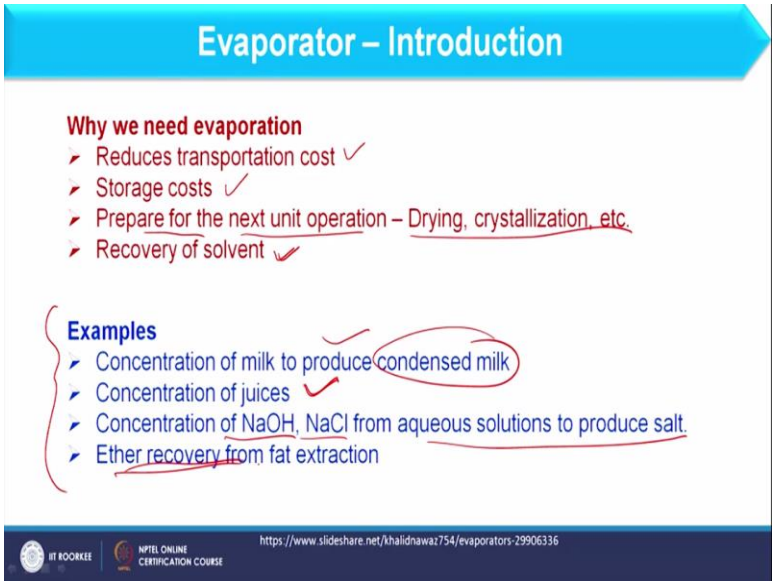

So, let us see why we need the evaporation. So, here we have some points like it reduces the transportation cost. If liquid is available and if concentration of the liquid is less. So, volume of the liquid will be very high. So, transportation of high volume liquid is costly in comparison to concentrated liquor. So, therefore we carry out evaporation before transportation of liquid is done. Now why it is so?

In many industry, instead of installing a separate effluent treatment plant they used to install a centralized effluent treatment plant in which the waste is brought from different industry. So, in that case what we have to do the evaporators are used to concentrate the waste at the plant side and then that waste is brought to the ETP that is effluent treatment plant. So, transportation cost of thick liquor is comparatively less in comparison to lean liquid.

And second option we have the storage cost because storing of thick liquor is cheaper in comparison to large volume lean liquor and evaporation is required when we need to prepare the feed for next unit operation such as drying and crystallization as we have already discussed in the previous slide. And if we need to recover the solvent, we have to carry out the evaporation.

So, evaporation is not only used to produce the thick liquor. It is also used to recover the solvent. Now, how it is recovered because when evaporation is taking place then the solvent is converted into the vapour and if that solvent is let us say water which is in most of the cases it is. So, water is converted is converted into the vapour. So, when water is converted into the vapour it is not including the impurities of the water.

So, vapour is comparatively pure water. So, when that vapour is condensed we can obtain clear water in comparison to the slurry. So, in this way we can recover the water and that water can be used for different purposes and in the similar line we can recover the solvent from the slurry and evaporation is used there. Further, as far as different applications are concerned evaporations is used to concentrate the milk to produce condensed milk.

It is used to prepare the juices where concentrate juice are obtained and it is used to concentrate sodium hydroxide, sodium chloride from aqueous solutions to produce salt. So, evaporation is very important as far as salt production is concerned and you must have heard about desalination process also. So, what happens in desalination where we convert the sea water into useful water.

So, in that case main product is vapour not the thick liquor because thick liquor contains more amount of salt and that is further used to produce the salt, but my main aim is that I can produce drinkable water or useful water from sea water and that is basically the vapour which is generated in evaporation in desalination process. So, when that vapour is condensed we use that for different purposes.

So, along with this we have other application also like ether recovery from fat extraction and if I ask you what are the industrial applications of evaporator? So, you should understand that evaporators are integral part of some of the industries such as sugar industry where sugar is prepared through crystallization. So, before crystallizer evaporators are used. In the similar line, we use evaporator in pulp and paper industry where paper is usually prepared with the wood chip.

So, wood chip when it is washed with the solution the solution contain many organic compound which is available in wood. So, clean wood is basically transported to paper manufacturing and the solution which is left which contain sufficient amount of organic. We do not throw this we usually prepare steam from this. So, to prepare the steam we basically concentrate this liquor up to certain percentage let us say around 50% or 60%.

And after that it is burned to produce steam and so the electricity. So, in this way the organic compounds available in liquor are used and in that case multiple effective evaporators are

used. So, you can have sugar industry, pulp and paper industry, you can have desalination and all these process includes evaporators. And now we will discuss some properties of the liquid which are suitable for evaporation process.

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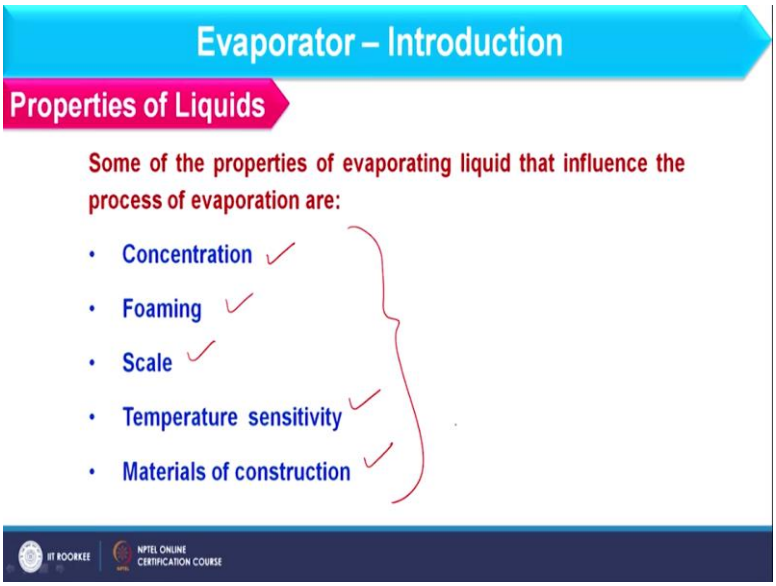

So, these properties are the concentration of the liquor, foaming tendency of the liquor and scale formation of the liquor and temperature sensitivity of the material and finally we have material of construction. So, you can see based on all these parameter we decide suitable type of evaporator for a given application. So, in that way these properties are very important and now we will focus on performance of evaporator.

Now as far as performance of evaporators are concentrated for this we have two basic criteria. First is the capacity and second is the steam economy.

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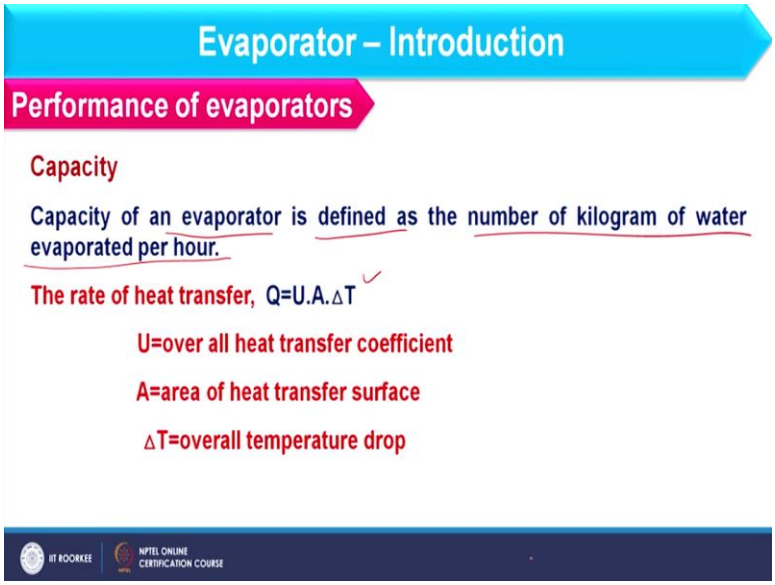

So, let us discuss capacity first. So, as far as capacity of an evaporator is concerned it is defined as the number of kg of water evaporated per hour. So, how much water is being evaporated in one hour that is basically the capacity of the evaporator and it is given by the simple equation that is Q = U A delta T and I am not going into detail of each parameter that I assume that all these parameters you know already.

And next parameter we have is the steam economy or we consider that as evaporator economy also.

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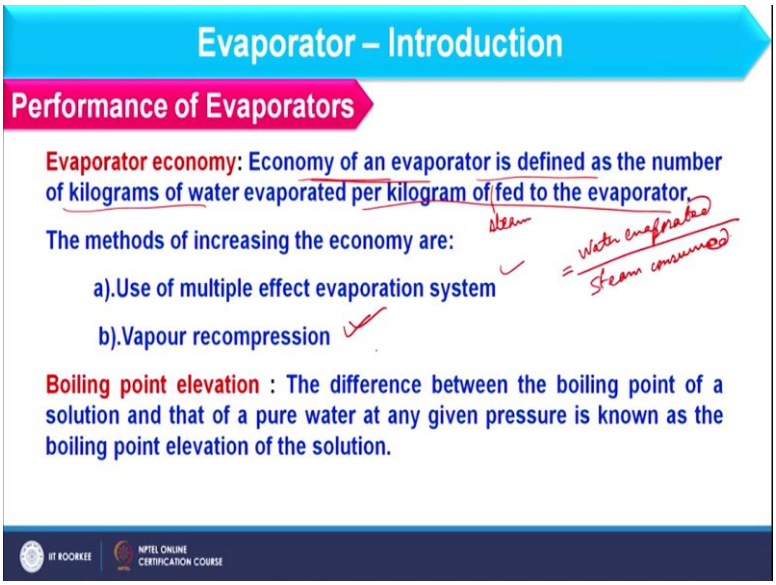

So, economy of an evaporator is defined as the number of kg of water evaporated per kg of steam fed to the evaporator. So, steam economy and evaporator economy you can define as water evaporated divided by steam consumed. So, in this way we consider steam economy as

a unit less quantity. Now as far as steam economy of one evaporator is concerned it is usually 0.8.

So, whatever steam is provided 80% of that steam is used to generate the water. So, in that way we consider steam economy as 0.8 and that is basically the thumb criteria. Now, if I ask you what are the methods to increase economy of the evaporator? The very first method in that case is use of multiple effect evaporation system. Now what is this multiple effect evaporator system?

When we carry out the evaporation process in evaporator whatever solvent is available that is converted into vapour. So, instead of condensing that vapour and get the clean product what we can do, we can use that vapour as a heating media in another evaporator because if you consider the heating media in evaporator that is basically the steam. However, if I am having the vapour it also contain sufficient amount of latent heat which can be used as a heating media.

So, vapour generated in first effect is used as a heating media in second effect and whatever vapour is generated in second effect it is used as a heating media in third effect and so on. So, in this way you can use steam once only and you can generate water in multiple effects. So, many a times you can generate the water or you can remove the solvent consuming steam only in first effect.

So, in this way multiple effect evaporators are used in fact this phenomena you must have observed in your houses also like when we cook the food let us say inside the pan food is cooked and that pan is covered with the lead and above that lead if we put some material in bowl so that material will also be heated up. So, what I am doing basically whatever vapour is generated in the pan it is heating the lead.

And that heat which is available in the lead is transferred to the bowl and so the material which is inside the bowl and if you have gone through famous temples there when bhandara are going on so how the food is cooked because what they do. They basically take very big pan at the bottom and below that fire is there and at the mouth of that pan they put another pan which contain some other material.

So, whatever vapour is generated in the bottom pan it is basically giving heat to the pan above to this and the food which is available in second pan or the upper pan it also cooked. So, in that way we consider multiple effect evaporator in our day-to-day life and we have industrial application of this also which we have already discussed. So, when I am considering that economy of the evaporator it can be increased when we use the vapour generated in first effect as heating media in second and so on.

So, this is one method only. Second method we have is the vapour recompression. So, what happens with the vapour recompression? Whatever vapour is generated in first effect it can be used as a heating media in second effect, but it cannot be used as a heating media in first effect. In the similar line whatever vapour is generated in second effect, it can be used as a heating media in third effect, but not in second effect as well as in first effect.

So to do that we have to compress the vapour. When we compress the vapour we basically increase the temperature and pressure of the vapour and so it can be used in previous effects in comparison to subsequent effects. So, vapour recompression is the option to increase economy of the system. Now when we consider economy of the evaporator usually the thumb rule is it is 0.8 into number of effects.

Let us say if I am having N number of effects in a multiple effect evaporator. So, economy of the system should be 0.8 into N and we can also consider boiling point elevation and we can also consider boiling point elevation in evaporator. So, what is this boiling point elevation? When we have the solution where some other component is present which we consider as the impurity.

So, for that solution vapour pressure reduces in comparison to pure solution. So, in that case what will happen more heat is required for the desired evaporation. So, in that case temperature of the solution increases in comparison to that of pure solvent. So, the difference of these two temperature like temperature of the mixture minus temperature of the solvent it gives the boiling point elevation. I hope it is clear to you and this point we will further discuss in subsequent lectures.

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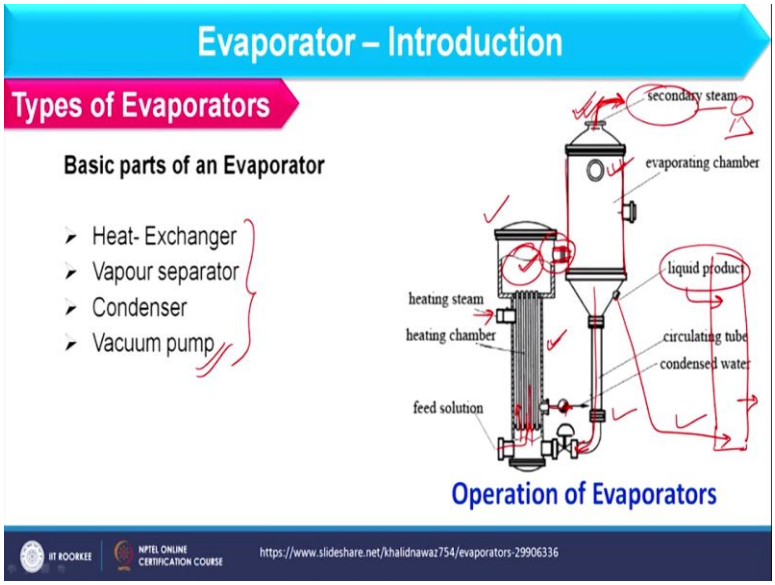

Now, we will focus on types of evaporator and for that we should first understand what are the basic parts of an evaporator and these are basically heat exchanger, vapour separator condenser and vacuum pump. So, as far as operation of evaporators are concerned here we have heat exchanger, vapour liquid separator and along with we have the recirculation pipe and whatever vapour is generated from here it enters into the condenser and whole system is attached to the vacuum pump.

So, as far as operation is concerned then what will happen here this is the heat exchanger which is basically shell and tube type heat exchanger where boiling takes place or evaporation takes place inside the tubes. In shell side, we have steam which works as a heating media. So, you can understand that feed when it is entering into this heat exchanger it is entering into the tube side.

So, what will happen when the feed enters into the tube side, vapour formation is taking place and when it exits the tube it has basically vapour liquid mixture which is available over here. So, that mixture of vapour and liquid is further separated into vapour liquid separator and that is available over here. So, if you see when feed is entering into this vapour liquid separator it is appearing from this schematic that connection is perpendicular to the shell.

This is the shell and connection is perpendicular to the shell. Now what happens exactly in such type of vapour liquid separator feed enters tangentially not perpendicularly. So, because feed is entering tangentially it get circular motion inside the evaporator and because liquid is

heavier than the vapour it is basically at the inner periphery of the vapour liquid separator and from the wall of the separator it brings down.

And whatever vapour is available it is taking out from vapour liquid separator from this side. So, whatever liquid is available that we can take as a product and what we can also do to get the desired concentration of the liquid we basically recirculate the liquid in the heat exchanger. So, that further concentration of the liquid can be obtained and for that purpose we use recirculation pipe.

So, if I ask you that what is an effect of the evaporator? Effect of an evaporator consist three different components the heat exchanger, the vapour liquid separator and recirculation pipe. So all these three combination combinedly called as effect. If I am saying second effect, so whatever vapour is generated from this side it is entering into the heat exchanger over here and it is entering to the shell side of this heat exchanger.

And whatever liquid is available over here it will be used as a feed to second heat exchanger. So, in that way we define the effects.

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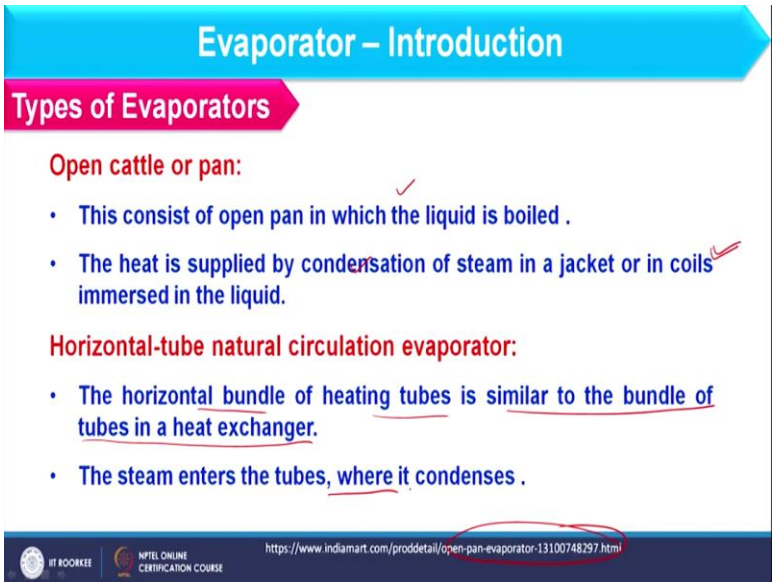

And now we will focus on different types of evaporators quickly. So, let us see that. First of all, we have open kettle or pan evaporator you all have done experiment in this in your heat transfer course. So, this consists of an open pan in which liquid is boiled. So in this type of evaporator boiling of the liquid takes place where steam is used as a heating media or we have some internal heaters also.

Heat is supplied by condensation of steam in a jacket or in coils immersed in a liquid. So, sometime we also put the coiling which is merged with the liquid and inside this coiling we have the steam and instead of providing the steam in the coil we can also provide steam in jacket. So, heating media is steam and liquid is evaporated through boiling.

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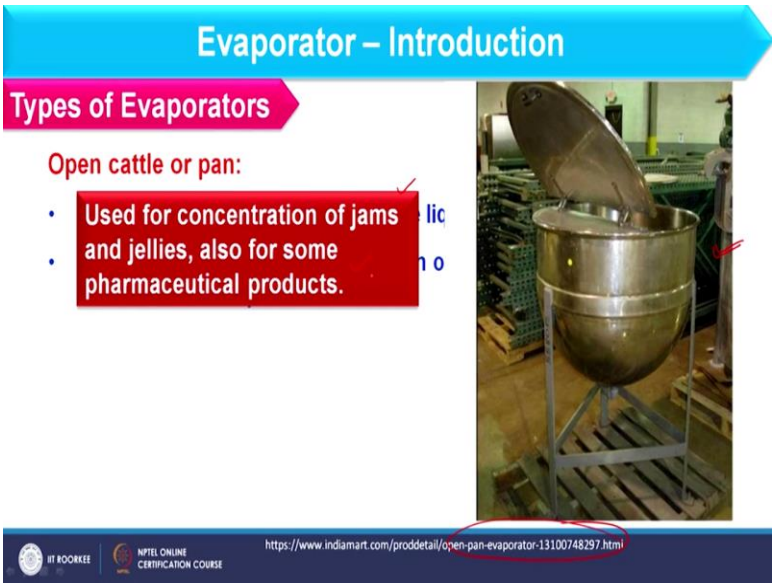

So, this is the image of an open pan evaporator you can study about this in detail in this link. So, these type of evaporators are used for concentration of jams and jellies and also for some pharmaceuticals products. So, in that way you can use open pan evaporators and next I am having horizontal tube natural circulation evaporators and in this horizontal bundle of heating tube are used which is similar to the bundle of tubes in a shell and tube heat exchanger.

The steam enters in the tube where it condenses and therefore evaporation takes place in shell side in horizontal natural circulation evaporator.

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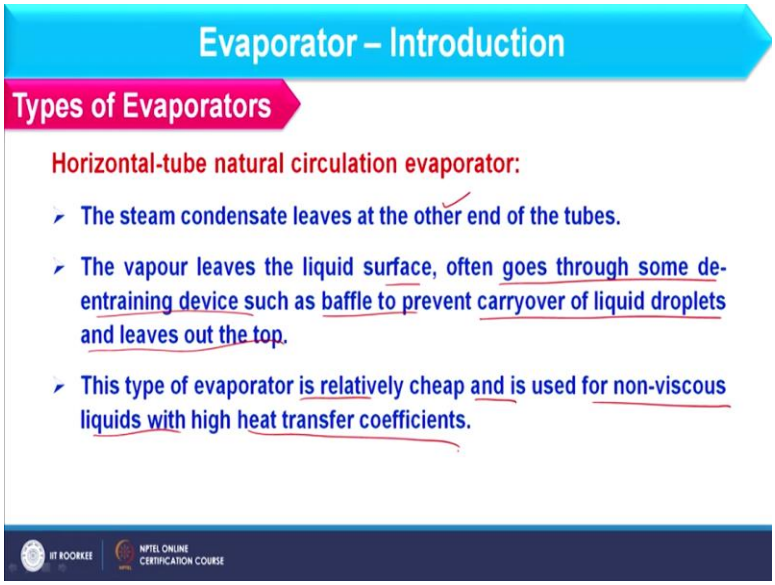

Steam condensate leaves at the other end of the tubes, vapour leaves the liquid surface often goes through some de-entrain device such as baffle to prevent carryover of the liquid droplets and leaves out from the top and this type of evaporator is relatively cheap and is used for non viscous liquid with high heat transfer coefficient. So, these are some points about the horizontal natural circulation evaporator.

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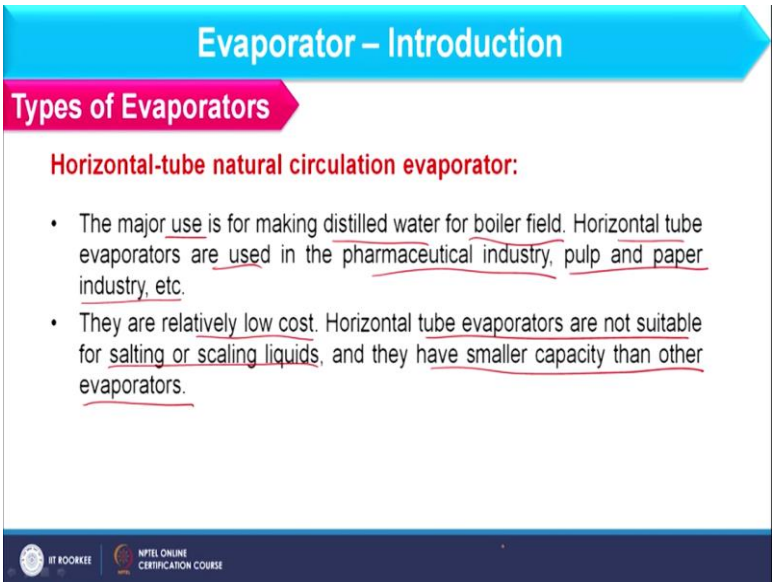

And we can further discuss this as these are mainly used in making distilled water from boiler field. Horizontal tube evaporators are used in pharmaceutical industry, pulp and paper industry etcetera and they are relatively of low cost. Horizontal tube evaporators are not suitable for salting or scaling liquid and they have smaller capacity in comparison to other evaporators.

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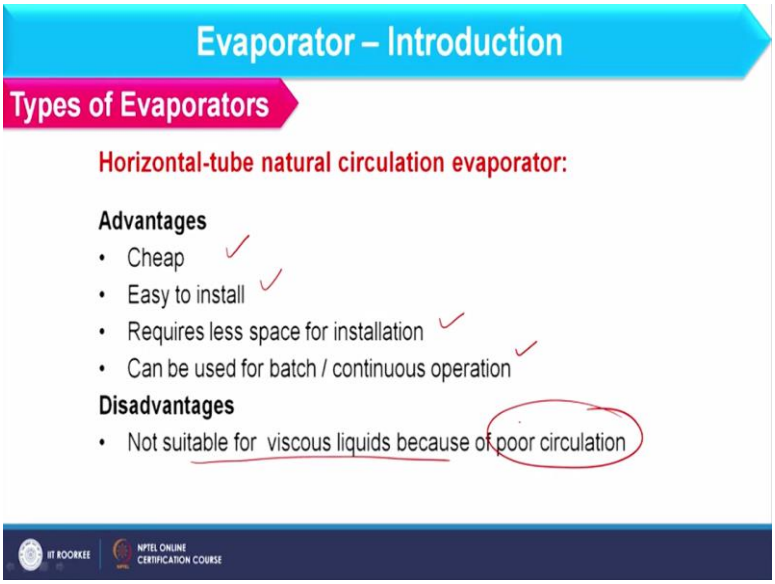

And further I am going to discuss advantages and disadvantages of horizontal natural circulation evaporator. Advantages are it is cheap, easy to install, requires less space for installation and can be used for batch and continuous operation. Disadvantage is this it is not suitable for viscous liquid because it has poor circulation condition. So, in that way we have discussed points about horizontal natural circulation evaporator. Now I am having vertical type natural circulation evaporator where I am using short tubes.

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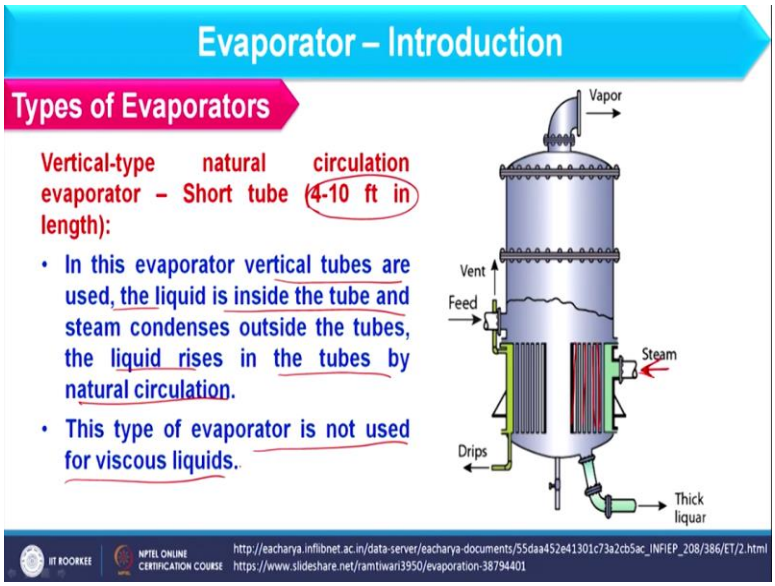

So, as far as tube length is concerned usually it is 4 to 10 feet and in this evaporator vertical tubes are used and liquid is inside the tube. So, if you see here I am having the vertical tubes and in this tube we usually have the liquid and steam is provided outside the tubes and in this type of evaporator liquid rises in the tubes by natural circulation. So, this type of evaporator is not used for viscous liquid because it is difficult for viscous liquid to move on its own.

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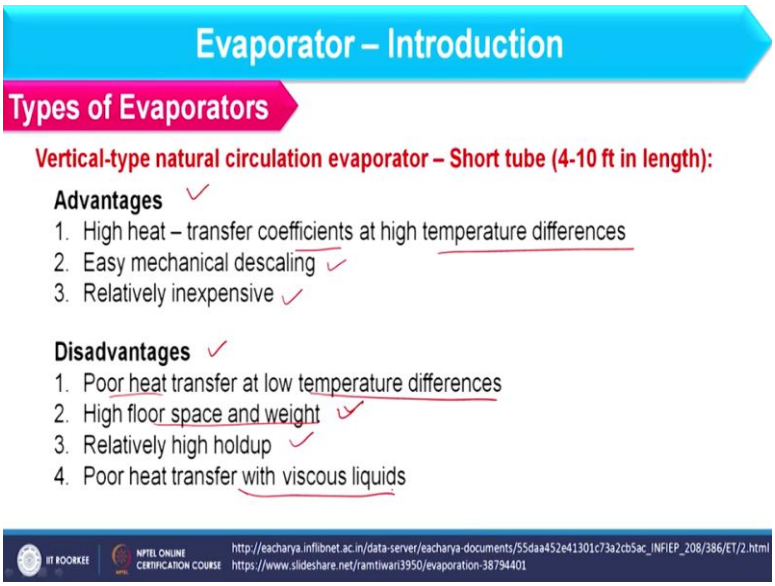

And we have some advantages and disadvantages of this type of evaporator. Let us focus on advantages first. It has high heat transfer coefficient at high temperature differences, easy mechanical descaling and relatively inexpensive because here we have vapour liquid separation as well as evaporation both are in single unit and further as far as disadvantage are concerned poor heat transfer at low temperature differences can be observed.

High floor space and weight because complete assembly is available in one unit relatively high holdup and poor heat transfer with viscous liquid. So, here we have these points about vertical natural circulation evaporator. Now, we are considering vertical natural circulation evaporator, but with the long tube.

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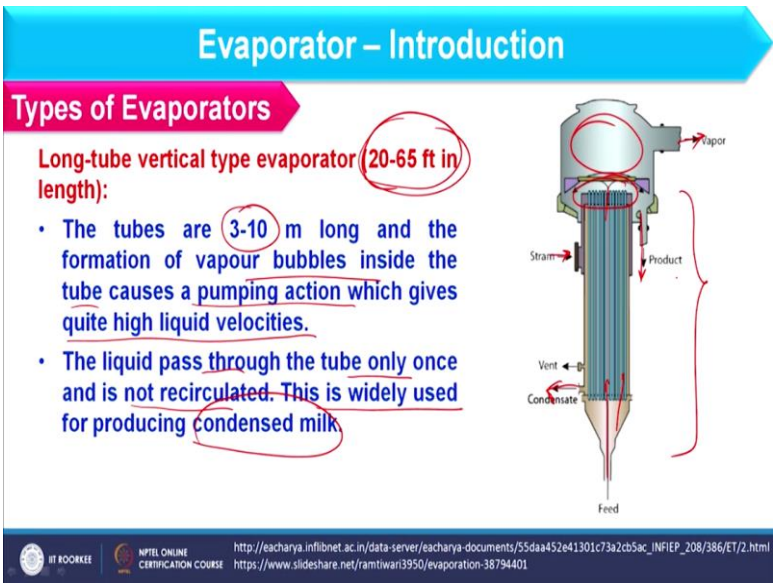

So long tube means we have tube length as 20 to 65 feet. So, usually 3 to 10 meter long tubes are used. The formation of vapour bubbles inside the tube causes a pumping effect which gives quite high liquid velocity and liquid pass through the tube only once and is not recirculated. So, these are widely used to make condensed milk. So, if you consider here we have the image of long tube vertical evaporator where feed enters to the tube side and steam is entering to the shell side.

So, inside the tube vapour formation is taking place and vapour and liquid exits from this side and then vapour liquid separation occurs over here and from here we have the liquid as products and vapour as another steam. In this way long tube vertical type evaporator are working and here it is not circulating. So, we cannot say that it is vertical tube natural circulating evaporator.

It is only the long tube vertical evaporator where tube length is usually 3 to 10 meter and now we have falling film evaporator. So, as the name says it is the falling film and evaporation takes place inside the tube. So, what happens liquid is basically entering from the top of the tube and then around the periphery of inner side of the tube liquid is available in the film so that is why it is called as falling film.

So, when it is taking heat from the steam which is available in shell side vapourization takes place and the vapour liquid mixture exits from the bottom of the tube and then it is entering into the vapour liquid separator where vapour and liquid are separating. Now, in this case as vapour liquid separator is available at the bottom of the tube where I am having vapour liquid mixture.

So, in this case recirculation is also not considered. So, whatever liquid is available that comes in contact with the steam only once and therefore this type of evaporators are mainly suitable for heat sensitive material.

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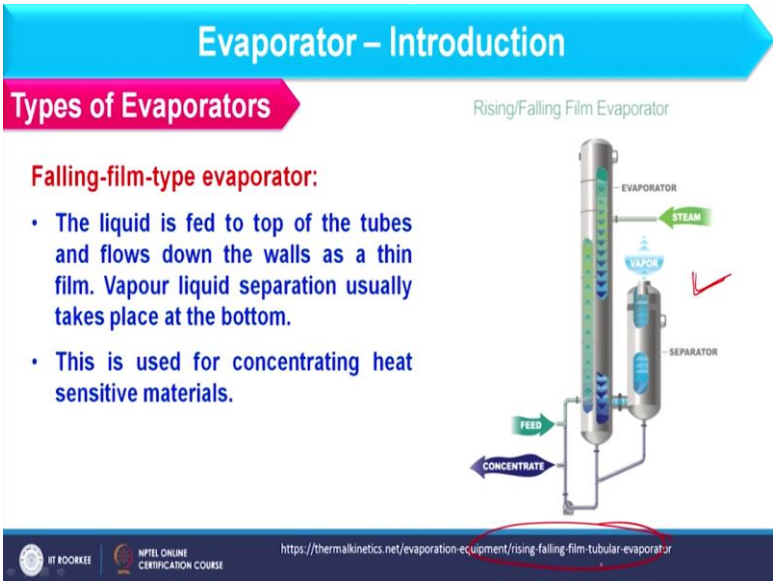

So, you can observe the operation of falling film evaporator in this and you can read about this evaporator from this link and if I ask you for better understanding of these equipment it is better to have some video which are available on YouTube. So, if you search by the name of these evaporators you can find the YouTube video where the working you can understand very effectively.

And now we have forced circulation type evaporator and if you understand this that why I am using the forced circulation because it is used for fouling tendency liquid as well as for viscous liquid which cannot recirculate on its own.

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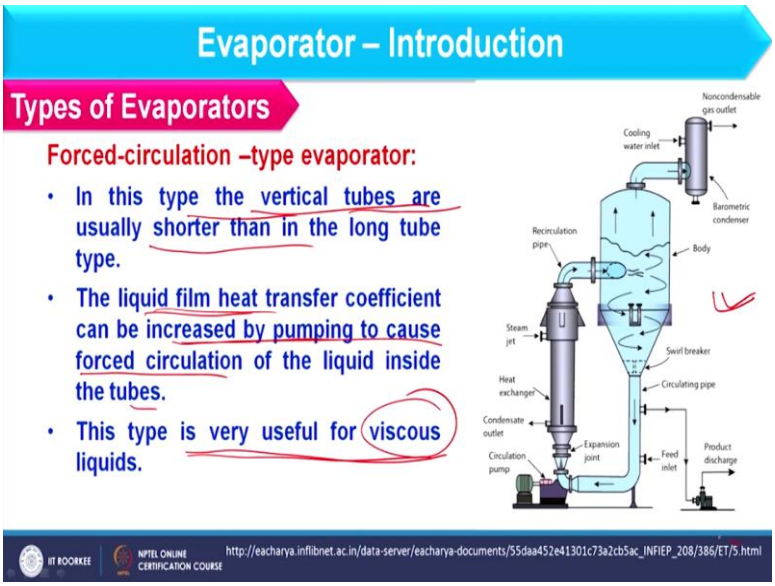

So, in this type of evaporator vertical tubes are arranged and length of these tubes are not very long. The liquid film heat transfer coefficient can be increased by pumping to cause

forced circulation of the liquid inside the tubes and this type of evaporators are used for viscous liquid and here you can observe the schematic and details you can find here.

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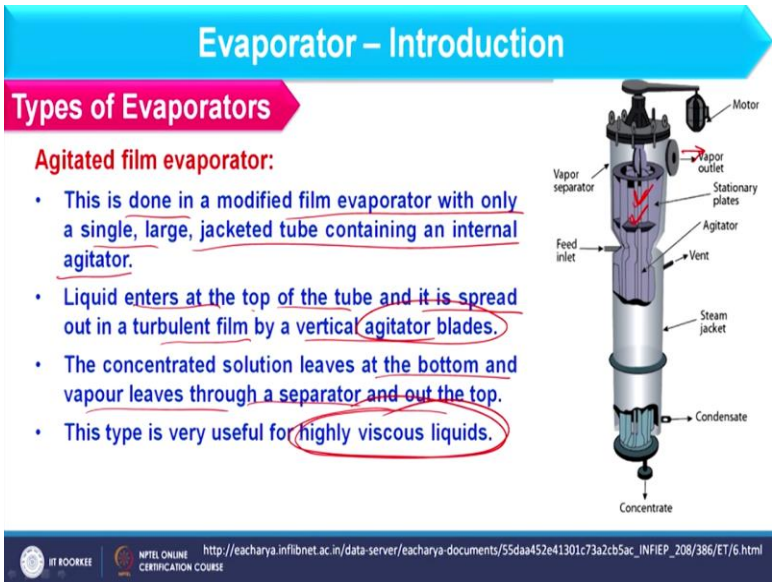

So, lastly we have agitated film evaporator where if you see inside of the shell we have only one tube of larger diameter and in this tube we have agitated assembly. So, whatever liquid is available inside the tube that agitator basically spread that liquid at the tube periphery and at the outside of the tube we have steam because of the heat transfer whatever liquid is available inside the tube it is basically converted into vapour.

So, this is done in modified film evaporator with only a single large jacketed tube containing an internal agitator that point we have already discussed and liquid enters in this at the top of the tube and it is spread out by a turbulent film with the help of agitator blades. The concentrated solution leaves at the bottom and vapour leaves the separator from above side as it is shown in this figure.

So, this type of evaporators are very useful for heavily viscous liquid. So, you see here we have discussed the evaporator, we have seen its applications and different types of evaporators. So that is all for now. Thank you.