Process Equipment Design
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Lecture –27
Design of Reboiler-1

Hello everyone. I welcome you all in 27th lecture of the course Process Equipment Design and here we are in 6th week of this course. In this course, we are starting a new topic and that is the reboiler. We will cover this topic in 4 next lectures. So, let us introduce the reboiler, what is the reboiler and where we use this? Being a chemical engineer you must have some idea, but let us recall that with the introduction of reboiler.

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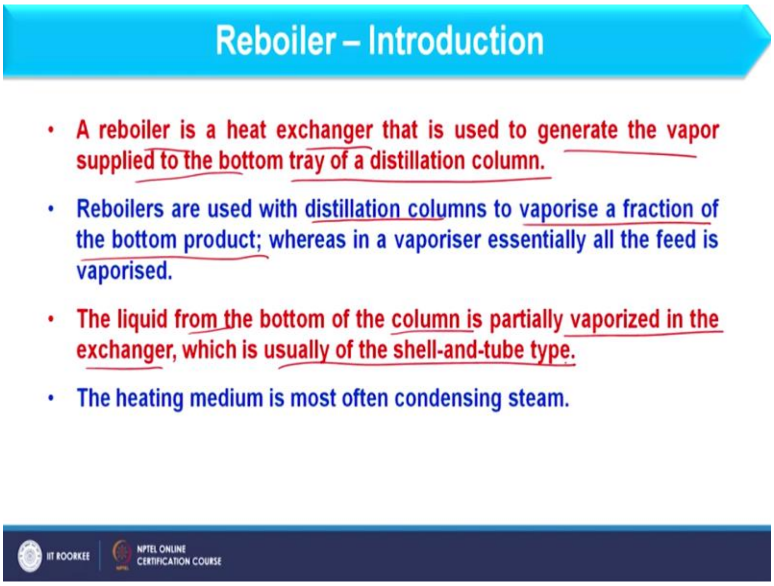

So, if you see a reboiler is a heat exchanger that is used to generate vapour supply to bottom tray of a distillation column. So, as far as reboiler is concerned this is an important unit in distillation column. As far as type of equipment is concerned this is basically the heat exchanger and it is specifically used to generate vapour from the liquid which is exiting the distillation column from the bottom.

And it enters into the reboiler where it is converted into the vapour and vapour returns back to distillation column. So, boiler are used in distillation columns to vaporize a fraction of bottom product. So as far as bottom liquid is concerned it is entering into reboiler where some section of this is converted into the vapour and that vapour liquid mixture returns back to distillation column.

Now, if I consider the reboiler as vaporizer. Reboiler basically converts liquid into vapour. However, if I convert the whole feed which is entering to the reboiler to vapour we call this as vaporizer. Otherwise as far as function is concerned, design is concerned reboilers and vaporizer both are same, but their product are slightly different both give vapour, but reboiler converts a fraction of liquid into product and vaporizer converts all feed to the vapour.

And further the liquid from the bottom of the column is partially vaporized in an exchanger which is usually of shell and tube type. So, here you see reboilers are again a shell and tube type assembly as we have found the condenser. So, here we will classify the reboiler, but those are specifically shell and tube type. As far as heating media and reboiler is concerned that is usually the steam because we have to convert the liquid into vapour.

So, liquid will take heat from a source and then it is converted into vapour. So, obviously we have to provide the heating media at higher temperature in comparison to the feed to the reboiler. So, mostly we are using a steam, but if in the plant any other stream is available which is having higher temperature then the liquid of the distillation column we can use that as heating media.

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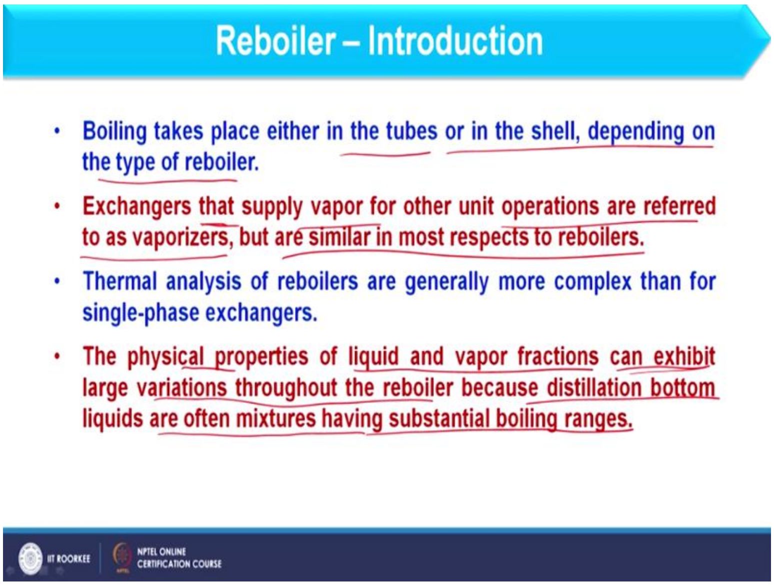

So, when I am speaking about reboiler it is basically involved boiling mechanism and because feed is continuously entering into this. Some portion of it is converted into vapour. So, vapour liquid mixture recycles back to the distillation column and again feed is entering to the reboiler. So, basically boiling process is going on, but that is going on continuously same feed may enter twice or thrice in reboiler till it will be converted into vapour.

And therefore it is called as reboiler. So, boiling takes place either in tube side or in shell side of this unit. Further, exchangers that supply vapour for other unit operations are referred as vaporizer, but are similar to most respects to reboiler. So, as far as design is concerned, operation is concerned, construction is construction both units are same, but purpose is slightly different.

Reboiler only provide vapour to distillation column, however, vaporizer provide vapour to any unit operation so that is the only difference. As far as thermal analysis of reboiler are concerned it is much more complicated in comparison to single phase exchangers and the reason is very simple that here phase change occur so we have multiphase system in reboiler which is not the case with usual shell and tube heat exchanger.

And further you can see that physical properties of liquid and vapour fractions can exhibit larger variation throughout the reboiler because distillation bottom liquids are often mixtures having substantial boiling ranges. So, if you consider the distillation column we usually consider multiple component system. So, if the components vary in vapour as well as liquid stream we should consider that while computing the physical properties.

So that may be mass-fitted. So, these are some of the points about the reboiler and now we will classify the reboiler.

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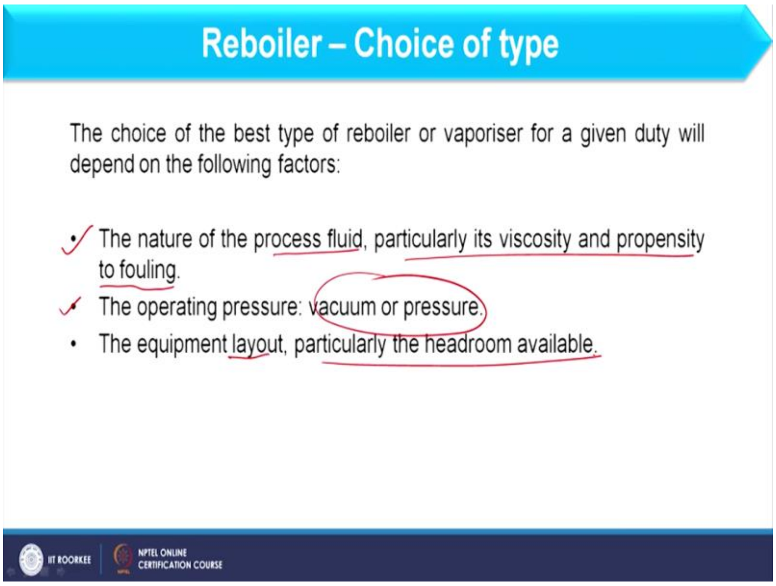

And as far as classification is concerned the choice of type of reboiler depends on different factors such as nature of the process fluid particularly its viscosity and propensity to fouling. If fouling tendency is more, if viscosity of the liquid is more we have to choose special kind of reboilers. So, this is one criteria to choose the reboiler. Second, the operating pressure whether it is at vacuum or a pressure.

And lastly we have equipment layout particularly the headroom available. So, these are some of the factors on which choice of reboiler depends and now we will see that what are the different types of reboilers available.

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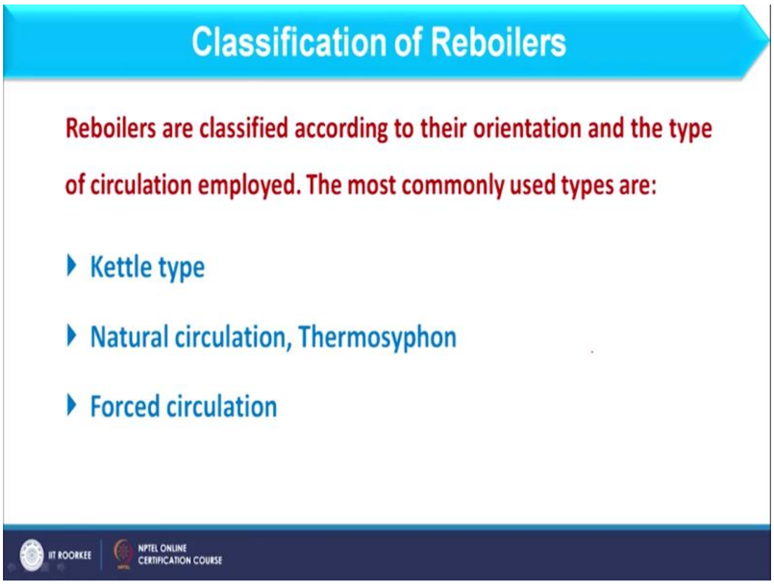

So, as far as classification of reboilers are concerned these are classified according to the orientation and the type of circulation considered. So, as we have discussed that condensers are usually placed horizontally or vertically. So, in the same line reboilers can be placed either horizontally or vertically and wherever the boiling will take place accordingly we can have the reboiler.

And along with that the type of circulation because liquid should enter into reboiler, vapour should be formed in reboiler, vapour liquid mixture should return back to the distillation column so there must be some circulation and based on this circulation we have different reboilers. So, usually we have most commonly three types of reboiler. The first one is the kettle reboiler, second is natural circulation or thermosyphon reboiler.

And thirdly we have forced circulation reboiler. So, these are main type of reboiler and we are going to discuss each type of in subsequent slide in detail.

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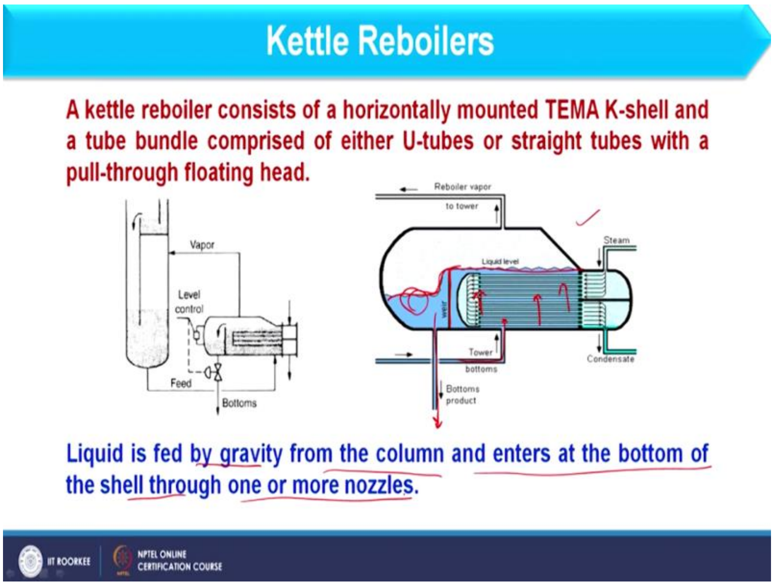

So, let us start with the kettle reboiler. Now as far as this kettle reboiler is concerned what you can understand from this? Reboiler you can understand it is used to generate the vapour, but what is the meaning of kettle? Kettle means we have some heating media and over that we keep the fluid which will be heated up. So, you all know how the kettle works. So, in the same line we consider kettle reboiler because in this whatever heating media is available.

And whatever liquid is available which is to be converted into vapour this is entirely covered the heating media and as you see in kettle the heating media is merged in fluid. So, therefore it is named as kettle reboiler. So, kettle reboiler basically consists of horizontally mounted

TEMA K-shell. Now, if you remember the nomenclature for the shell we have E, F, G type and we have another shell that we call as TEMA K-shell and K comes from the kettle.

So, kettle reboiler has special kind of shell and it is only used in kettle reboiler not in other shell and tube heat exchanger. So, along with K- shell reboilers have a tube bundle comprised of either U tube or straight tube with the pull through floating head. So, the kettle reboiler has basically the tube bundle which includes either U tube or straight tube, but that should be internal floating head type because whole bundle should be taken out from the shell.

And then it will be clean or maintenance will be done and then further it should be inserted so it is basically internal floating head type where it is placed in shell. So, as far as schematic is concerned here you can see that it is connected to the distillation column this is the distillation column and here I am having the kettle reboiler and if you see the bottom liquid of the distillation column enters to the reboiler.

And it is usually enters into shell side and if you consider the shape of the shell it is special kind of shape and therefore it is called as kettle reboiler whatever vapour is generated it recycles back to the distillation column and further we can visualize it more clearly from this schematic. Here, feed enters from the bottom and start filling this section. So, feed whatever is entering into the reboiler it is entering to shell side.

There is no option in such reboiler where feed enters to the tube side. In kettle reboiler feed always enters to the shell side and in this exchanger we have straight tube we can also use U tube over here and in this U tube side steam is basically entering which is used as a heating media and from here it exits as a condensate. So, here you can visualize that shape of shell is totally different than whatever we are using in either condenser or in normal shell and tube heat exchanger.

And the reason behind this is that when the liquid enters into this and all bundle complete bundle merged in the liquid and after that when heat transfer takes place from steam to liquid vapour formation takes place and because of the natural movement of vapour to upward vapour comes to this region and here we have the space for vapour and when vapour enters to this space it also include some liquid droplets.

So, vapour liquid separation occurs in this region and vapour whatever is generated it recycles back to the distillation column. So, in this way what we can say that the kettle reboiler generates the vapour and also separates the vapour from the liquid. So, this is the only reboiler which supply pure vapour to the distillation column. Other reboilers which we are going to discuss in subsequent slide there you can find that vapour liquid mixture both will enter to the distillation column.

So, in that case we can consider kettle reboiler as vaporizer also because it is having vapour liquid separation in the unit itself. Now, further you see here we have weir and this weir is basically type of baffle, it is basically the plate which is welded at the periphery of the shell from inside. Now, what is the purpose of this weir? The purpose of weir is that it ensures that all tubes in the tube bundle should merged in the liquid.

So, whatever feed is entering from the bottom until and unless it will not reach to this level, it will not enters in this region and from this region I can collect the bottom product. So, the purpose of weir is all tubes available in the bundle is inside the liquid and as far as design of reboilers are concerned we will discuss each and every details whatever I am sharing right now.

Like what is the tube bundle dia and what is the height of weir, number of tubes etcetera and what is the space I am providing as vapour liquid separator, what is the area of that. So, in this way we complete the design of reboiler, but that is not a simple step it includes different steps so that we will discuss later on. Now, as far as shell and tube heat exchanger and condenser are concerned there we have discussed that baffle placement is different in both type of either type it is a exchanger or it is a condenser.

So, when I am focusing on reboiler we consider baffles in these type of exchangers also. Now if you focus on this schematic what will happen? Here liquid is coming from the bottom and start rising upward through this tubes. Now, in this case movement of liquid is what? Movement of liquid is upward. Here, I am not considering this type of flow or this type of flow as we have discussed in heat exchanger as well as condensers.

So, the purpose of baffle in kettle reboiler is different because it is only used to support the tubes otherwise tube may have vibrations and which is not allowed during the operations. So, baffles are specifically used here as support plate and in this type of reboiler baffles do not have any cut, whatever plate I am considering as baffle it is basically circular plate and which is entering or which is inserted to all tubes because here movement of liquid is not decided by the baffle because movement of liquid is simply upward.

So, whatever would be the cut it does not matter at all. So, usually no cut is provided in the baffles which I am using in kettle reboiler. So, here you should consider some different construction as well as operation. Now as far as movement of liquid is concerned from bottom of the distillation to reboiler it is only because of gravity. So, liquid is fed by gravity from column and enters at the bottom of the shell through one or more nozzle.

So, in this way circulation takes place in reboiler, but feed is liquid and product is vapour it is not the vapour liquid mixture and product of the distillation column we collect from reboiler not the distillation column. If you remember the condenser the product of distillation column from top it is collected from condenser not the distillation column directly.

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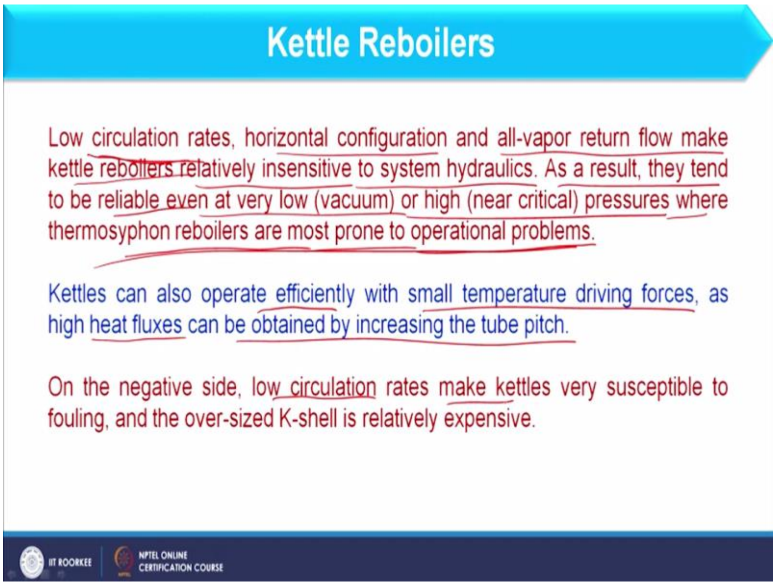

So, these are some points about the kettle reboiler. Let us have more discussion about this. So, it has low circulation rates, horizontal configuration and all vapour return flow may kettle reboiler relatively insensitive to system hydraulics. So, whatever would be the pressure vapour generates and vapour returns back to the distillation column because natural movement of vapour is upward direction only.

So, we do not have to provide any unit or any assembly to circulate the liquid as well as vapour it happens automatically. So, as a result they tend to be reliable even at very low vacuum or high pressures where thermosyphon reboilers are most prone to operational problem. So, here we consider feed and we provide vapour and we also maintain the circulation because it is not very sensitive towards the hydraulics.

And further you can see that kettle can be operated effectively or efficiently with small temperature driving forces as high heat flux can be obtained by increasing the tube pitch. So, in this reboiler tube pitch is not always 1.25 into d 0 as we have always discussed in previous equipment. So, here we have variation in tube pitch. Now, it has one negative aspect also that because of low rate of circulation what will happen it has more residence time.

So, liquid will be available for longer time in this kettle reboiler and because of that scale formation in kettle reboiler are significant in comparison to other reboilers and at the same time we are providing TEMA K-shell. So, if you consider the diameter of the kettle it is much more than the usual diameter of the shell we consider in other type of reboiler, condenser and normal heat exchangers so it is more expensive.

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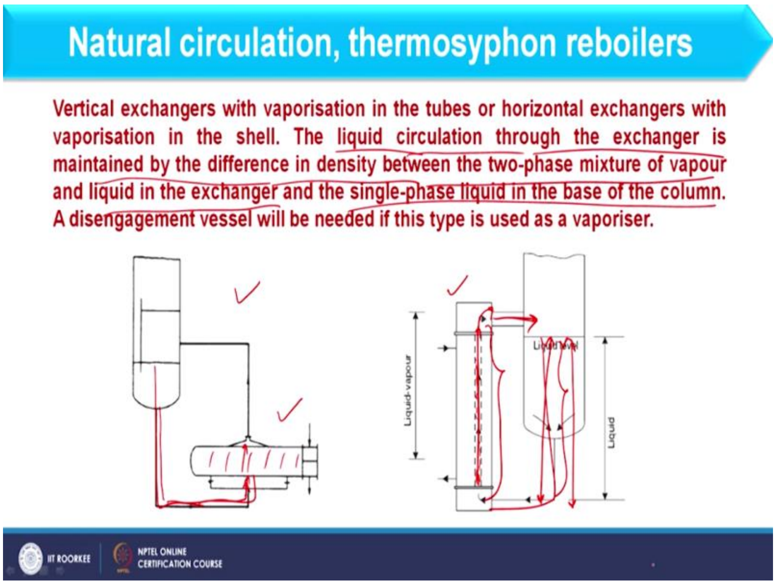

So, these are some of the negative points about the kettle reboiler and now we should focus on natural circulation or thermosyphon reboilers. So, you see here I am having the schematic of thermosyphon when it is placed horizontally and here we have the schematic when the reboiler is placed vertically. So, what will happen bottom liquid of distillation column it enters to the reboiler and it enters to the shell side of the reboiler.

If I am considering the horizontal reboiler boiling will take place at shell side and if I am considering vertical reboiler boiling is always taking place in tube side. So, we have only two combination if horizontally placed shell side will be the boiling space and if vertically placed tube side will be the boiling space and the reason is very simple because here we have to circulate the liquid automatically.

We are not providing any assembly to circulate the liquid. So, it means when the liquid is entering into the reboiler and exiting from the reboiler it has least hurdle. So, if feed enters to the horizontal reboiler thermosyphon reboiler when it is entering to the tube side it has to travel long distance and when I am considering shell side feed comes from the bottom, converts into the vapour and vapour liquid movement will be taking place upward direction.

So, horizontal shell side, vertical tube side that is the only combination we have. So, as far as natural circulation is concerned the liquid circulation through the exchanger is maintained by difference in density between two phase mixture of vapour and liquid in the reboiler and the single phase liquid in the base of the column. So, if I am considering this section or if I am considering this section we have only single phase that is the liquid.

However, inside the reboiler either it is this or this we consider two phase flow. So, natural circulation means so how we make the natural circulation. If I consider this schematic whatever pressure drop available to us it is available from this to this height. So, this we call as the pressure drop available to us and when liquid enters into this it starts converting into the vapour and vapour liquid mixture moves up and then it is entering into the distillation column.

So, in this way vapour continuously form and moves upwards because of the density difference. So, that vapour also include certain amount of liquid which also moves upward because from the bottom continuous feed is entering. Now how this circulation is maintained when I am computing pressure drop in this zone that pressure drop should be less than the pressure drop which is available in this region.

Then only the liquid which is available in distillation column is able to push or is able to enter into the reboiler. So, in this way circulation is maintained in thermosyphon reboiler and as it is circulating continuously it has less residence time and therefore it does not have much fouling problem because more circulation gives more velocity which will reduce scale formation.

But here one disadvantage is there that it does not have any vapour liquid separation unit that separation occurs in a distillation column itself and if I have to use this as a vaporizer I have to provide a vapour liquid separator above this and now we will discuss forced circulation reboiler and it is forced circulation we provide an assembly which circulate the liquid and vapour within the reboiler and distillation column. So, it is not done automatically.

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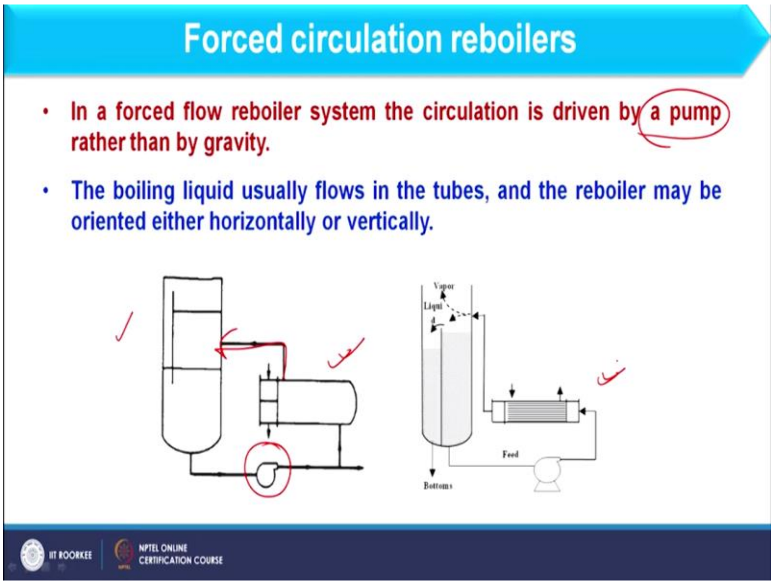

And that assembly is basically called as pump. So, you see here I am having the schematic of it. So, this is basically the reboiler and here I am providing the pump. So vapour liquid mixture again enters into the distillation column in the similar line we can consider feed to the tube side in this schematic. So, in this way we basically consider both side boiling either in shell side or in tube side because pump is used.

So, whatever difficulty in flowing occur that will be taken care by pump. So, this is about forced circulation reboiler.

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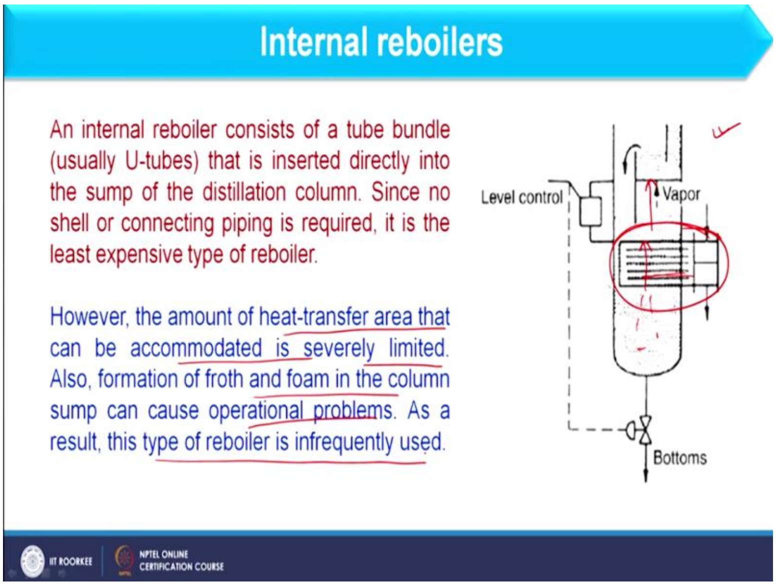

We have another type of reboiler which we consider as internal reboilers. So, internal reboiler if you see in this schematic here we have this reboiler and this reboiler complete bundle and the complete bundle of the tubes enters to the distillation column or it is fixed in the distillation column and here we have the liquid which is converted into vapour and move directly to upward direction.

So, in this case I am not providing any shell only bundle is there which is inserted in distillation column. So, as far as this type of reboilers are concerned it does not have much heat duty because bundle is inserted into the distillation column and what it shows? It shows that length of the reboiler is fixed and that will depend on the diameter of the column. So, the amount of heat transfer area that can be accommodated is severely limited.

And formation of froth and foam in the column can cause operational problem and therefore this type of reboilers are infrequently used. So, that is about the internal reboiler.

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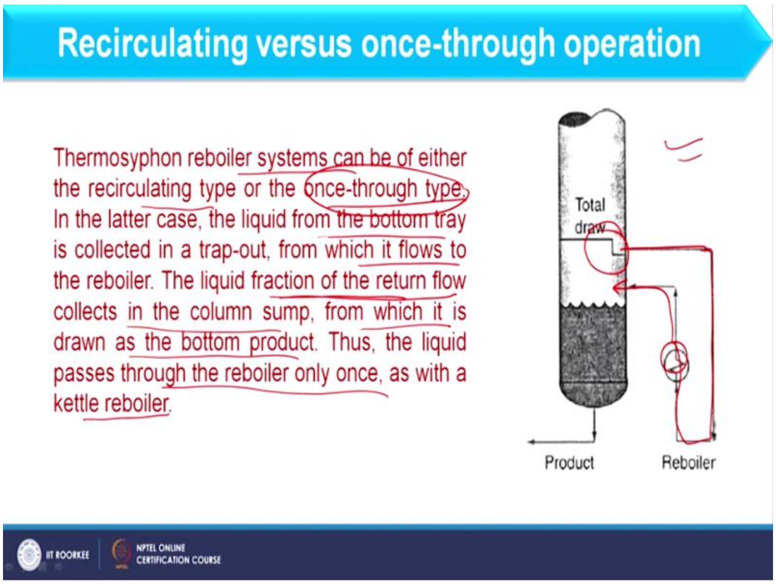

Now we have some points about recirculating versus once through operation. One through operation you understand liquid is converted into vapour and whatever liquid is remained that exits as a product. So, if you see this schematic here we take the liquid from this side and it is completely converted into vapour and then vapour enters from here. So, the thermosyphon reboiler system can be either recirculating type or once through type.

In the latter case that is once through type liquid from the bottom tray is collected in a trap out from which it flows through to the reboiler. So, it is basically this assembly. The liquid fraction of the return flow collects in the column sump from which it is drawn as a bottom product. Thus, the liquid passes through the reboiler only once as with the kettle reboiler. So, in this way once through operation is done and how recirculating operation is done that we have already discussed in thermosyphon reboiler.

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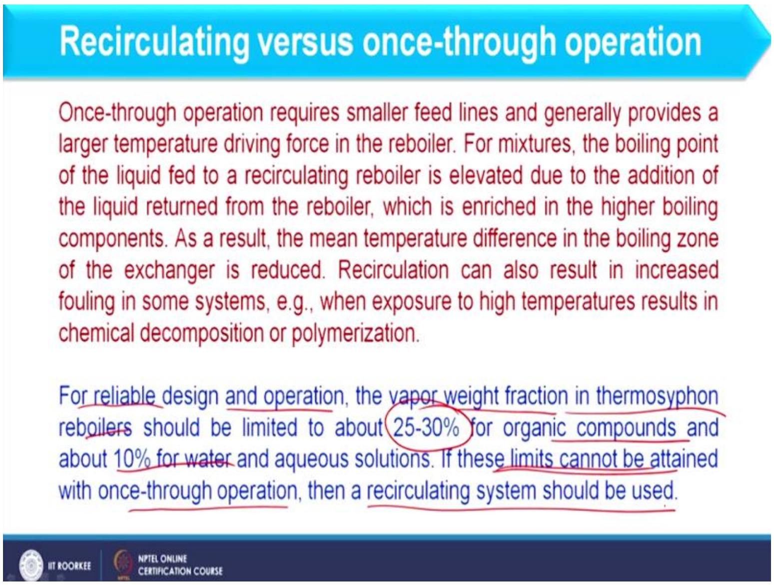

So, here I am having one important point about the reboiler that for reliable design and operation the vapour weight fraction in thermosyphon reboiler should be limited to 25% to 30% for organic compounds and 10% of water or aqueous solution and if these limits cannot be obtained with once through operation then a recirculating system should be used. So, in recirculating system what will happen only fraction of the liquid is converted into vapour and that is around 25% to 30% for organic compound.

And this point we will consider in designing of thermosyphon reboiler I will speak about that at that time and now we will discuss some fundamentals about the heat transfer in reboiler. As we already have seen that reboilers basically includes boiling operation either shell side or tube side.

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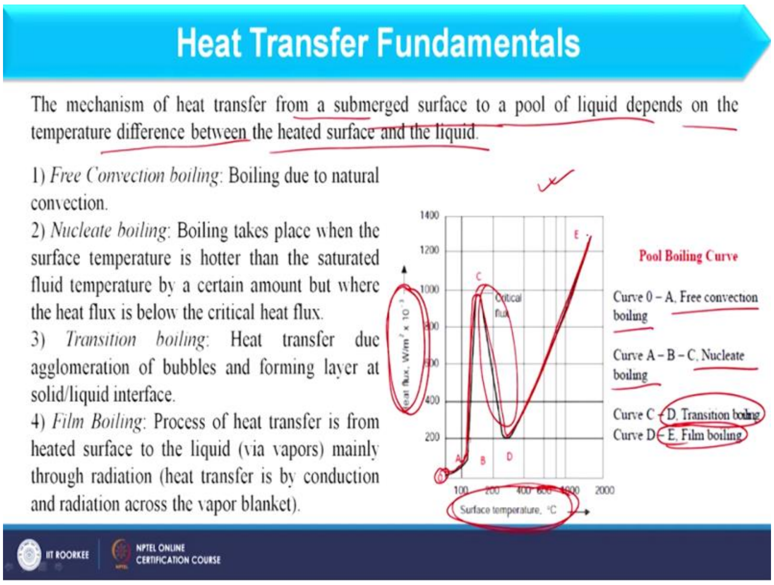

So, the mechanism of heat transfer from submerged surface to a pool of liquid depends on temperature difference between the heated surface and the liquid. So, when I consider the boiling mechanism I should also focus on the boiling curve and here we have the boiling curve for an example purpose. If you see the boiling curve varies from here and then it starts reaching to a critical point and then drops down and then finally increases.

So, if you see here I am having the heat flux on y axis and surface temperature is available on x axis. So, if you see here I am having different regimes if I consider 0 to A it is basically free convection boiling. So, at this time the heat is transferred to the liquid and liquid droplets takes the heat and recirculate in the pool. So, in this way free convection boiling is taking place.

And further if we move beyond A so A to B and then to C we consider that as a nucleate boiling because bubbles starts forming over here and after that what will happen? After that from C to D we have transition boiling. So, here basically what happens when bubbles are formed those bubbles basically covers the boiling surface. So, these bubbles join and make a film at the bottom of the pan or at the bottom of the container from which I am taking the heat.

So, when this bubbles join and make the blanket heat transfer is not taking place from bottom to the liquid because between that we have the vapour blanket. In that condition heat transfer reduces drastically and after sometime when film will be there film of bubbles will be there the heat will start reaching to the bulk of liquid through radiation and in that case we call it film boiling as we can see from D to E. So, all these points we have to consider while designing reboilers.

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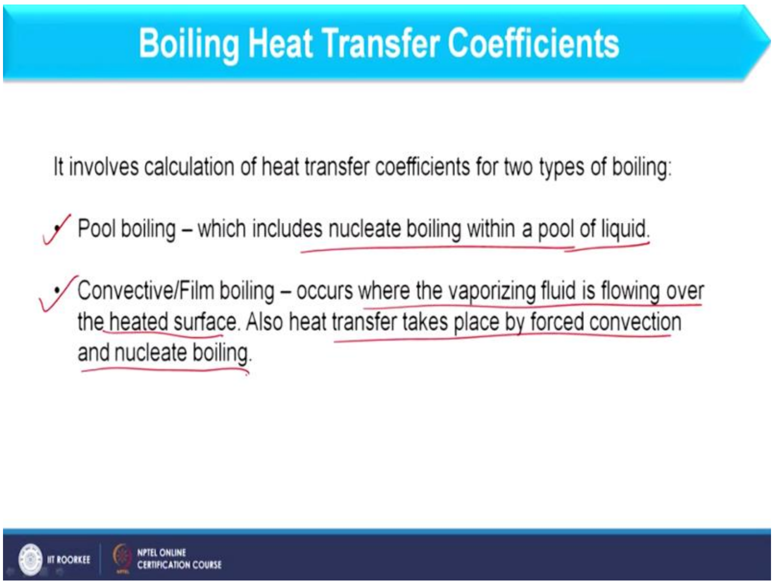

So, as far as type of boiling is concerned we usually have pool boiling which includes nucleate boiling within the pool of the liquid because bundle is completely merged in the liquid if I speak about the kettle reboiler. So, in that case nucleate boiling will occur in a pool of liquid. Next, I am having convective boiling or film boiling. It occurs when the vaporizing feed is flowing over the heating surface.

So, when the fluid is available over the heating surface it takes the heat and then molecules of the liquid will start moving in a bulk in a circular motion. So, that basically we call as the convective heat transfer and also heat transfer takes place by forced circulation and nucleate boiling in such cases.

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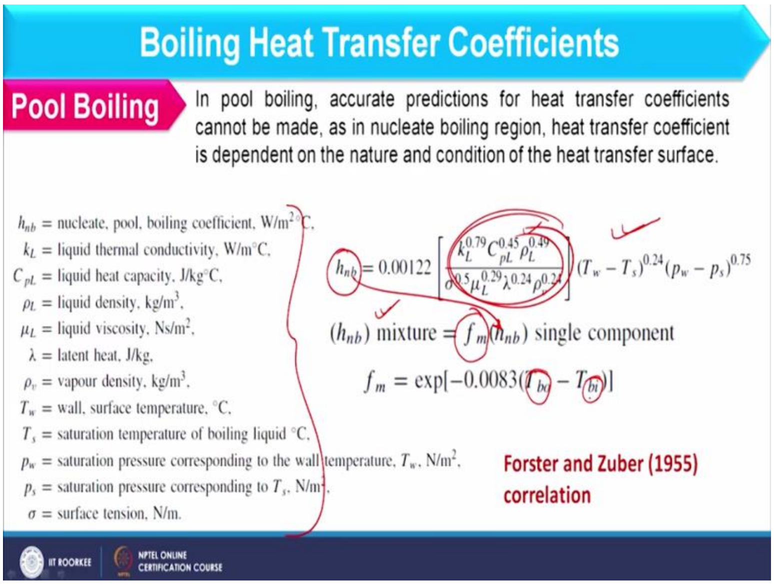

So, as far as pool boiling is concerned we have a specific heat transfer coefficient expression which is shown over here and here we have basically h nb which we call as the nucleate boiling and all parameters are defined over here and if I have to use this equation for the mixture we consider one factor and that is basically f m and h nb which is this for single component because I am having too many properties of a single compound.

So, this f m is equal to exponential bracket minus 0.0083 T bo – T bi it means boiling point outlet and boiling point inlet. So, based on these temperatures we can find out heat transfer coefficient in pool boiling.

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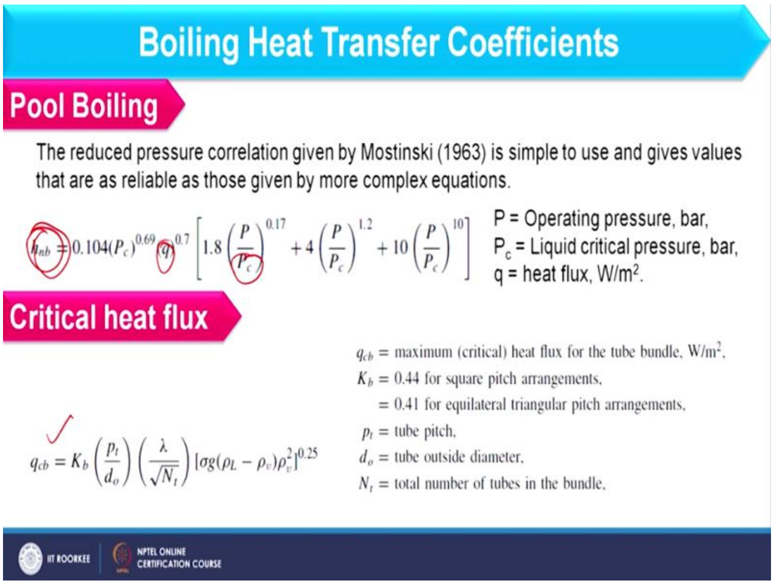

Similarly, in pool boiling we can have another correlation which is based on critical pressure. So, if you know the critical pressure, if you know the heat flux you can find out pool boiling heat transfer coefficient using this expression and next I am having the critical heat flux as we have already discussed in boiling curve that beyond critical heat flux or beyond the critical point heat transfer reduces significantly.

So, we have to ensure that in the reboiler critical heat flux should not be maintained or the boiling should take place well below than the critical heat flux. So that check is also required which is a part of design and you can use this expression to calculate critical heat flux for kettle reboiler where different parameters are explained over here.

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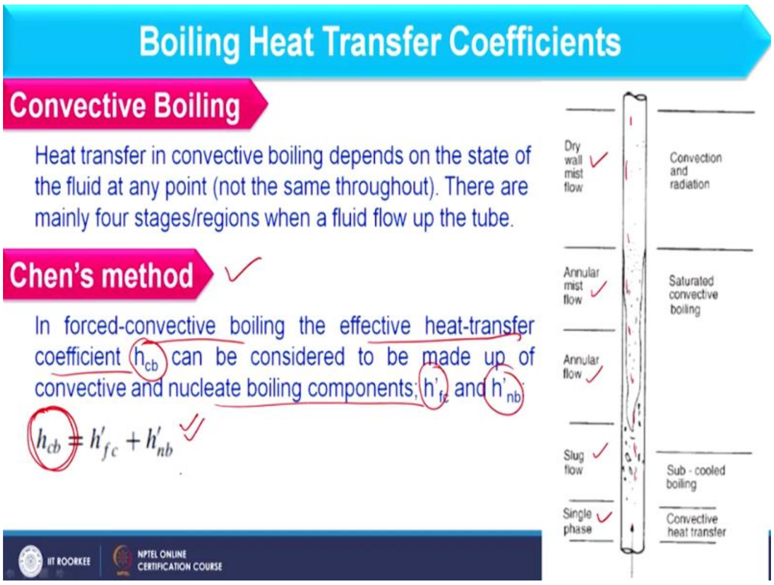

And now we have the convective boiling. When convective boiling is taking place we have different regions and these regions are single phase, slug flow, annular flow, annular mist flow and dry wall mist flow. So, as the vapour formation increases accordingly we have different regions and to account this we basically consider Chen's method and in forced convective boiling the effective heat transfer coefficient h cb can be considered to be made up of convective as well as nucleate boiling component h dash fc and h dash nb.

So, this is basically convective boiling heat transfer coefficient which is based on h fc as well as h nb with prime and what are the expression of these terms that we will discuss in subsequent lectures and I am just stopping this lecture. We will start design in next lecture. So that is all for now. Thank you.