Process Equipment Design
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Lecture –30
Design of Reboiler-4

Hello everyone. I welcome you all in 30th lecture of the course Process Equipment Design and here we are going to discuss design of reboilers and this is the last lecture of 6th week also. So in this particular lecture, we will start design of vertical thermosyphon reboiler.

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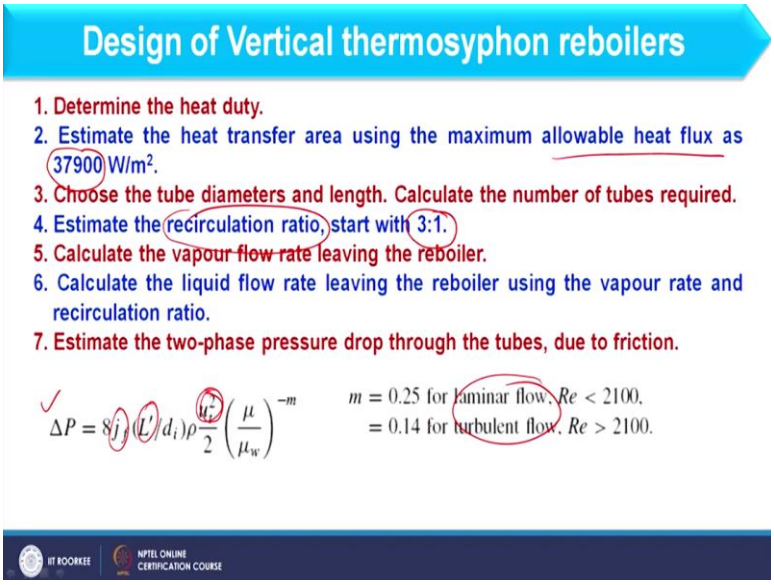

So, let us focus on the steps one by one. The first step is we have to define the heat duty or we have to compute the heat duty and how we can compute this because I already know that how much vapour I need to generate. So, that vapour flow rate into lambda will give me the heat duty and this is the simple calculation. So, once I am having the heat duty what we can consider next?

If you remember the last lecture we have discussed maximum possible heat flux available in vertical thermosyphon reboiler and its value comes as 37,900. So, we will start with maximum allowable heat flux so that this heat flux should never be exceed during the design because whole design will depend on this value only. So, once you know the heat duty, once you know the heat flux you can find out heat transfer area of reboiler.

So, in this way area you can calculate without considering U factor because here I am having another factor which is more important and once that factor will be maintained we can compute heat transfer coefficient. So, in second step you can find heat transfer area and after that we have to decide tube dimension that is the diameter of the tube and length of the tube and we will calculate the number of tubes required.

So, in vertical thermosyphon reboiler we consider only 1-1 pass, 1 shell pass and 1 tube pass. So, whatever number of tubes you obtain just consider next value to this because number of tube should never be in decimal. So, whether it is even or odd it is immaterial because we provide only one pass in tube side and after that we have to assume very important parameter and that is recirculation ratio.

And to start this calculation we should consider recirculation ratio as 3 is to 1. Now what is this recirculation ratio? This is basically the ratio of liquid and vapour available when it is returning back to the distillation column. Let us say if I am maintaining 3 is to 1 recirculation ratio. So, in this 1 is vapour and 3 is for liquid. So, let us say 4 kg per second feed is entering from distillation column bottom to reboiler.

So in which one kg per second vapour will be there and 3 kg per second liquid will be there. When the mixture of vapour and liquid exits reboilers and enters to the distillation column. So, here we are assuming this ratio and through the calculation we will try to maintain this recirculation ratio. Once this recirculation ratio will be maintained then only we will proceed for heat transfer coefficient calculations.

Now, once I am having the recirculation ratio I can find out vapour flow rate which is leaving the reboiler. So, whatever vapour flow is there in the reboiler that you have to calculate and you know a priori that how much vapour is to be generated. So, now you have vapour flow rate as well as recirculation ratio. So considering this you can find out liquid flow rate which is leaving the reboiler.

And addition of liquid flow rate plus vapour rate will give the total feed to the reboiler. So, in that way you can find out vapour rate, liquid flow rate as well as the feed rate to the reboiler. Now once you have that recirculation ratio and vapour and liquid flow rate you have to maintain two phase pressure drop throughout the tube and as we have discussed in kettle reboiler design that the pressure drop generate in the reboiler because of two phenomena.

First is due to friction and second is due to static head. Here friction generated due to vapour we are not considering that as we have considered in kettle reboiler because here mixture moves not the vapour only. So, first of all we will focus on pressure drop in the tube due to friction. So, let us see the empirical correlation for that. So, here I am having the empirical correlation for pressure drop due to friction where I should find out j f value and L dash this is basically the total length and u t is basically tube side velocity.

And m value will depend on the flow that is either laminar or turbulent. So, you can choose m value accordingly. Now the point is how you should consider this? We can consider this at two different points at the entry point and at the exit point, why? Because when the fluid is entering into the reboiler it is pure liquid and when it is exiting the reboiler it is a mixture of vapour and liquid.

So, when I am computing the pressure drop I should calculate mass flow rate per unit area that we represent as capital G. So, that is same when feed is entering and when the mixture is leaving the reboiler, but where we will find the change? We will find the change considering u t parameter that is the velocity in tube side because when it is entering the feed is pure liquid and density of the liquid should be considered.

However, when it is exiting we should consider density of the mixture not the liquid or not the vapour. In this way, we can find change in velocity and so we can find the Reynolds number and we can see j f factor and we can find out pressure drop. So, this pressure drop due to friction you have to calculate at entry level and at exit level. So, this pressure drop due to friction you have to find out at entry and exit of the tubes.

And you should consider average of these two value as pressure drop due to friction in tube side and secondly we should consider pressure drop due to static head because liquid will always available in tube side and why we have considered the friction because that liquid vapour mixture moves throughout the length.

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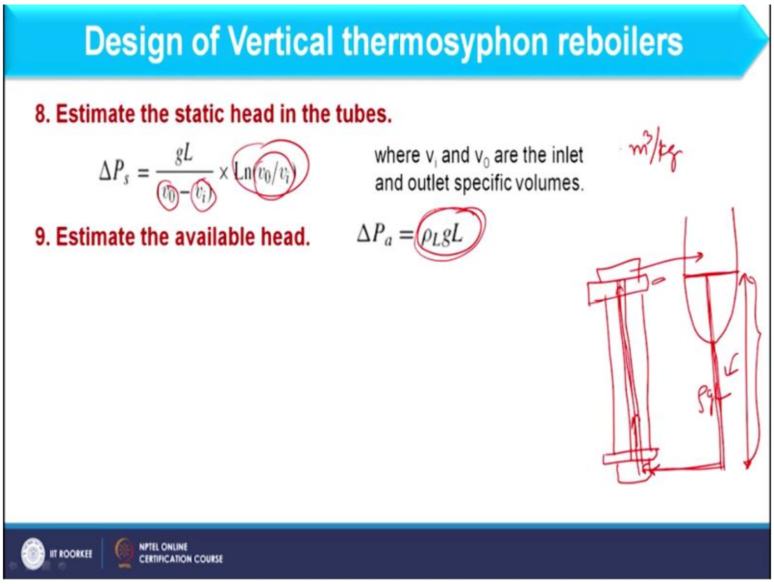

So, as far as static head is concerned we have the expression like rho g L, but here we are considering this differently because I am having different condition of feed at inlet as well as at exit condition. So, here we should consider specific volume instead of densities. So, you see here I am having specific volume at outlet and here I am having specific volume at inlet and this is nothing, but meter cube per kg.

So, that is just reverse of the densities and here I am having L n v 0 / v i because this specific volume of the feed is continuously changing from inlet to outlet therefore we have consider L n value of this ratio, but if you consider this particular expression this is nothing, but rho g h. So, total pressure drop in tube side will be what that is due to friction which we have seen in the last slide.

And that is due to static head addition of these two will give total pressure drop in tube side. So, that pressure drop we should compare with the pressure drop which is available. So, to understand that we should consider vertical thermosyphon reboiler like this and here I am having the distillation column this is the liquid level and it is returning back from this side. Now, what will happen?

If I consider the inlet pipe and upper tube sheet will be equal to at the same level where liquid is available in distillation column. So, this distance is nothing but the length of tube. Now what we have computed? We have computed pressure drop in this tube and this pressure drop which is available in this tube should be compared with the pressure drop available here and that is nothing, but rho g L.

So, what will happen whatever pressure drop is available over here it should be larger in value in comparison to pressure drop in this tube then only it will be able to push this liquid upward and circulation can be maintained. I hope it is clear to you so now we have to find out available head and available head where in the distillation column. So, if I know the length of the tube we can simply find out pressure drop in distillation column side and that will be rho L g L.

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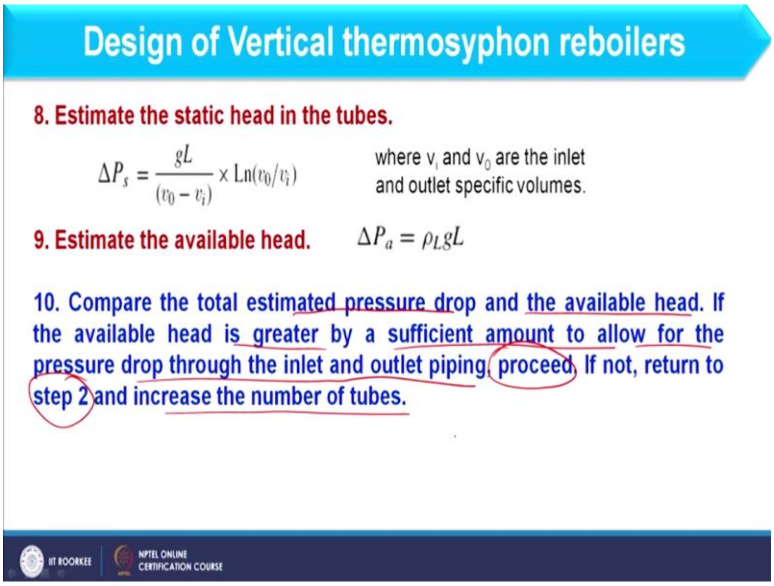

So, now we compare total estimated pressure drop and the available head. If available head is greater by a sufficient amount to allow for the pressure drop through the inlet and outlet piping we accept the design and proceed further if not we have to return to second step and increase the number of tubes. So, how I should increase the number of tube? In second step we have consider maximum heat flux.

Now, we will reduce heat flux from the maximum value and after reducing the heat flux when we will calculate the area, area becomes larger than that is available with maximum flux. So, if we fix the dimension of the tube we can find increased number of tubes and whatever feed is entering into the tube previously now it is entering to more number of tubes. So, it will reduce the velocity and so the frictional loss.

However, if you want to change available head you cannot do anything because density of the fluid is constant g is constant and length is also constant. Whatever you can change is only the frictional head and that can be affected by number of tubes. So, in this way first of all you have to maintain the recirculation ratio and then we should proceed for the calculation of heat transfer coefficient.

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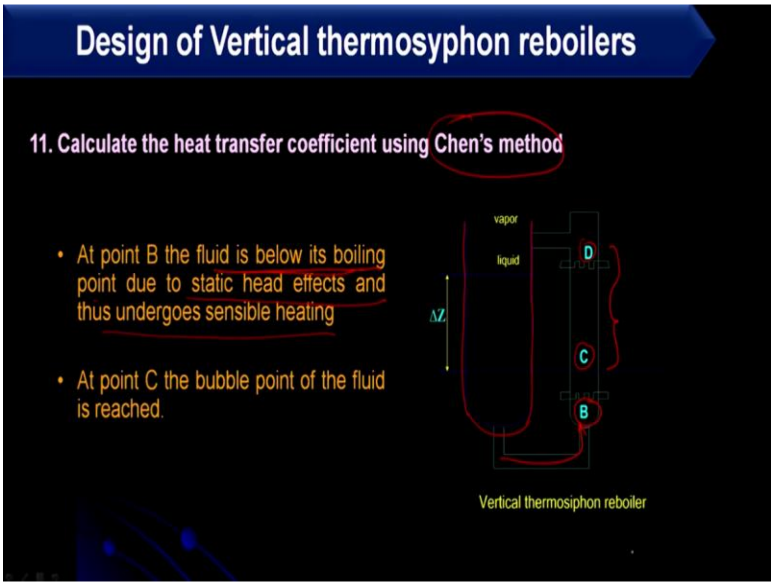

So, as far as heat transfer coefficient is concerned we find that through Chen's method. So, here I am having this vertical thermosyphon reboiler and I am having different points here like B, C and D. So, what will happen at point B? At point B fluid is below its boiling point due to static head effects and thus undergoes sensible heating. So, usually fluid enters to reboiler at boiling point, but because of some losses over here it may reach below boiling point.

So, first of all sensible heat should be supplied and if I am providing the sensible heat we should consider convective heat transfer. So, further at point C what will happen? Fluid will reach to its boiling point and after that vapour formation will start.

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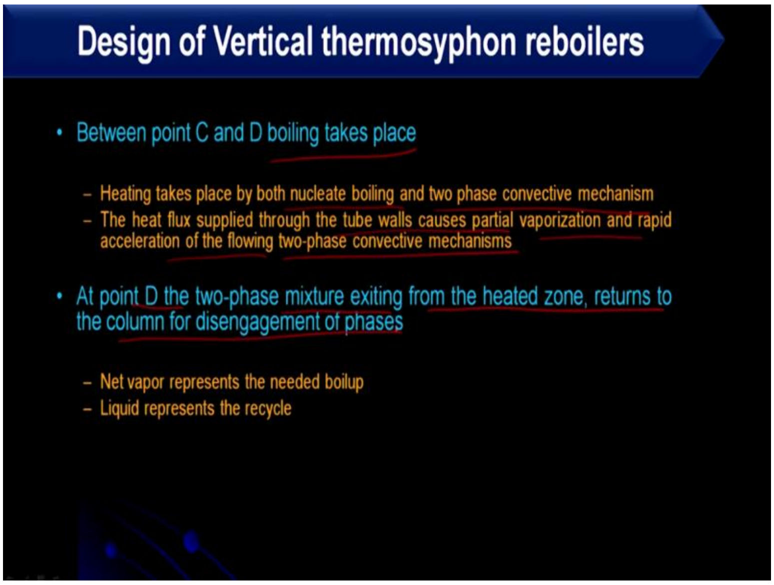

Further, if I consider the flow pattern between C and D here boiling will takes place. So, heating takes place by both nucleate boiling and two phase convective mechanism. Heat flux supplied through tube walls causes partial vaporization and rapid acceleration of the flowing two phase convective mechanism. So, as far as boiling is concerned we should consider nucleate boiling as well as convective boiling.

But that will occur at upper section or when we consider at the exit of the reboiler. At entry of the reboiler, pure convective heat transfer will be there and further at point D two phase mixture will be available which exits it and returns to the column for disengagement of vapour liquid. So, in this way we can understand the heat transfer mechanism in vertical thermosyphon reboiler.

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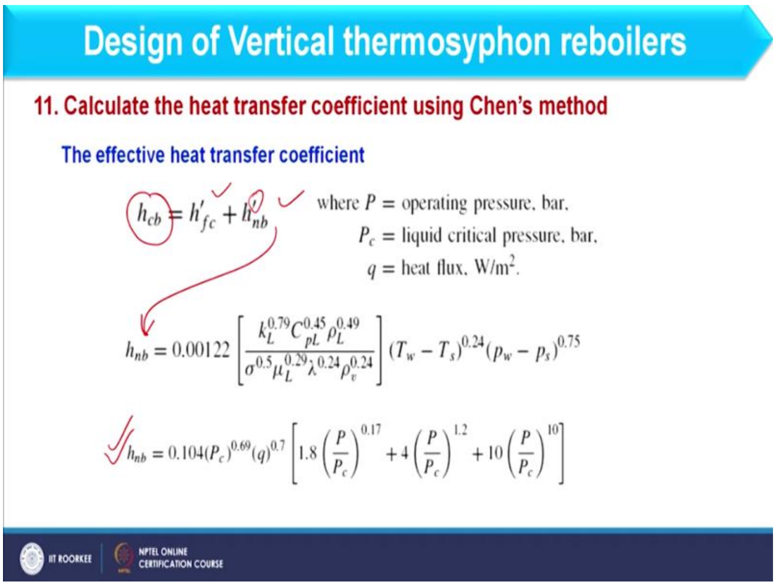

So, let us start the calculation of heat transfer coefficient using Chen's method. So, effective heat transfer coefficient should be what? Effective heat transfer coefficient at exit of the tube should be equal to h fc dash and h nb dash. So, h nb dash nucleate boiling coefficient you can find either by this equation or by this equation and here you see this is h nb we have to consider h nb prime.

So, how this prime will be considered that we will see. So, let us start the calculation of heat transfer coefficient.

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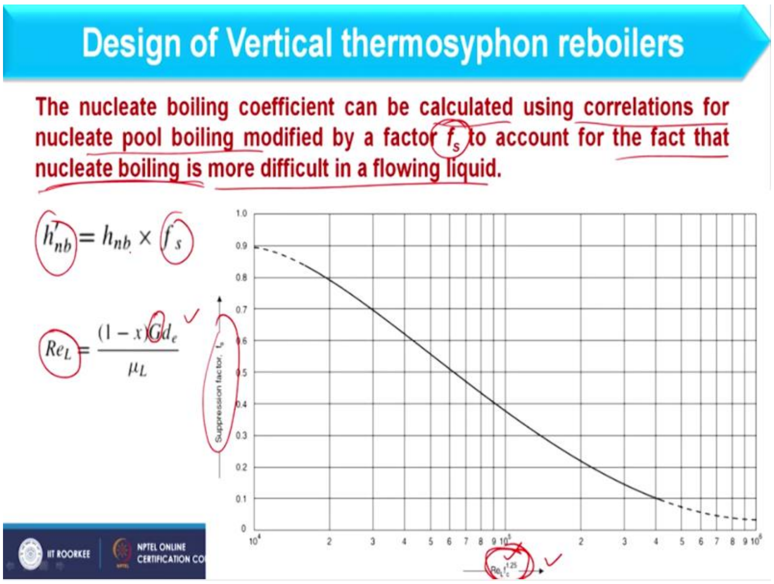

So, first of all we will focus on nucleate boiling coefficient. So that can be calculated considering the correlations for nucleate pool boiling which we have just seen in the last slide and that should be modified by a factor fs and this fs basically accounts for the fact that nucleate boiling is more difficult in flowing liquid because when we consider a nucleate boiling we understand that the fluid is at stagnant position, but here fluid is continuously moving.

So, whatever coefficient we obtain for nucleate boiling that should be reduced by factor fs. Now maximum value of fs should be 1 and here we have this graph to find out fs which is basically separation factor and it can be obtained corresponding to Re L fc power 1.25 as you can see on x axis. So, first of all we will consider what is Re L basically 1 – x G de / mu L. Now what is this Re L because we have already considered recirculation ratio.

So, whatever feed is entering to the reboiler whole will not remain in liquid position when the mixture exits the reboiler. So, let us say if I am having 3 is to 1 ratio so 1 – x value should be 0.75 and G is the mass flow rate per unit area which will be fixed at inlet and outlet both conditions. So, in this way you can find out Reynolds number for liquid only at exit position. So, once you have Re L we can find fc value in next slide and so you can see fs value from this graph. So, h nb dash is basically equal to h nb into fs.

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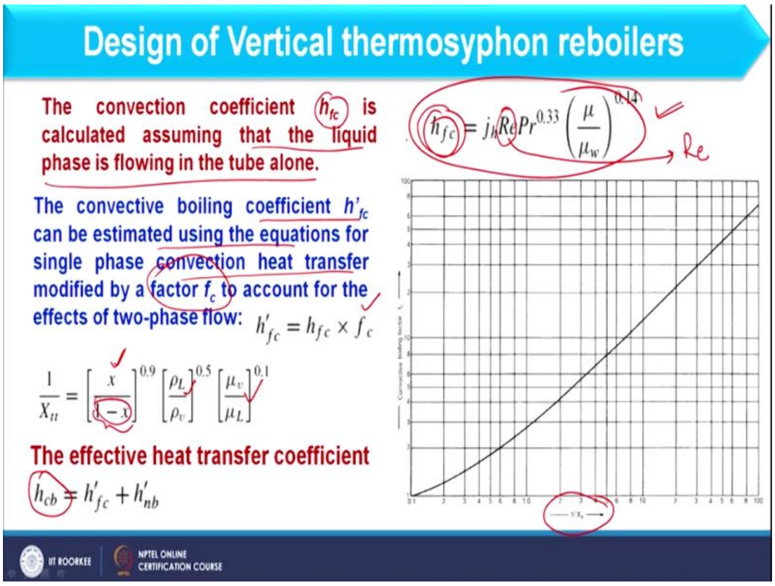

And further we have to consider convective coefficient because when liquid is available and vapour is available we have both mechanism of heat transfer convective heat transfer as well as nucleate boiling. So, convective coefficient that is h fc is calculated assuming that liquid phase is flowing in tube alone. So, here we have the correlation for convective heat transfer which we also consider in shell and tube heat exchanger.

However, in vertical thermosyphon reboiler fluid is continuously moving. So, whatever Reynolds number we obtain as Re L the same Reynolds number will be applicable over here because this h fc is purely corresponding to liquid. So, convective boiling coefficient h fc dash can be estimated using equation for single phase convection heat transfer and that should be corrected by factor fc to account for the effect of two phase flow.

So h fc dash should be equal to h fc into fc. So, fc you can obtain from this graph where on x axis 1 / X tt is there. So, the value of 1 / X tt you can find from this where you are considering X as well as 1 – x. So, this is basically vapour quality and this is for liquid and similarly we have liquid and vapour properties. So 1 / X tt basically counts two phase flow and considering fc and h fc we can find out corrected convective heat transfer coefficient.

And once you have the value of fc from the last slide you can also find out value of fs. So, the effective heat transfer coefficient when the mixture is exiting the reboiler should be equal to h fc dash plus h nb dash. So, that heat transfer coefficient is available at the exit. Now what will happen when the fluid is entering into the reboiler. In that case, the complete feed is available in liquid form and there only convective heat transfer will take place.

So, we will use this expression as it is with a change that this Reynolds number corresponding to complete feed not 1 – x as we have considered in h fc dash. So, this Reynolds number will change and you can find out h fc value at the inlet of the reboiler. So, the final heat transfer coefficient in tube side should be average of h cb as well as h fc. So, in this way you have to find out heat transfer coefficient in tube side.

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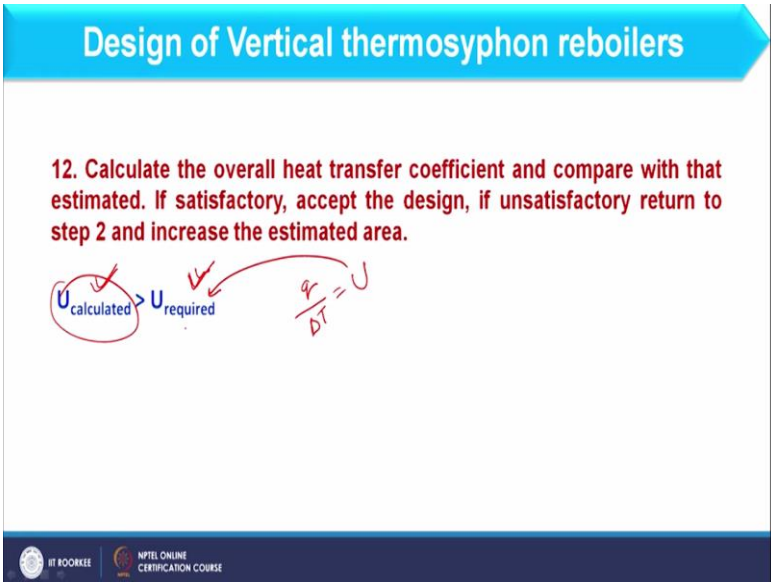

And shell side heat transfer coefficient you can find because steam will be available or if any other vapour will be available you can simply consider condensation process and find out heat transfer coefficient in that side. Once you have these two values, you can find out overall heat transfer coefficient and compare that with the estimated. So, you calculated you have already found from this thermosyphon reboiler calculation.

And U required or U estimated you can find out from the system because you already know the heat flux until unless you will not fix q value you cannot proceed further. So, q value you already know and that should be divided by delta T mean. So, it will give me U value and this U value you can consider here. So, whatever U you have calculated it should be more than U required.

However, when I am considering more overall heat transfer coefficient my area should be less. However, if I consider U required lesser than U calculated it means I am already having sufficient heat transfer area. So, this condition should be satisfied I hope you understand the procedure to design vertical thermosyphon reboiler so that is all about vertical thermosyphon reboiler.

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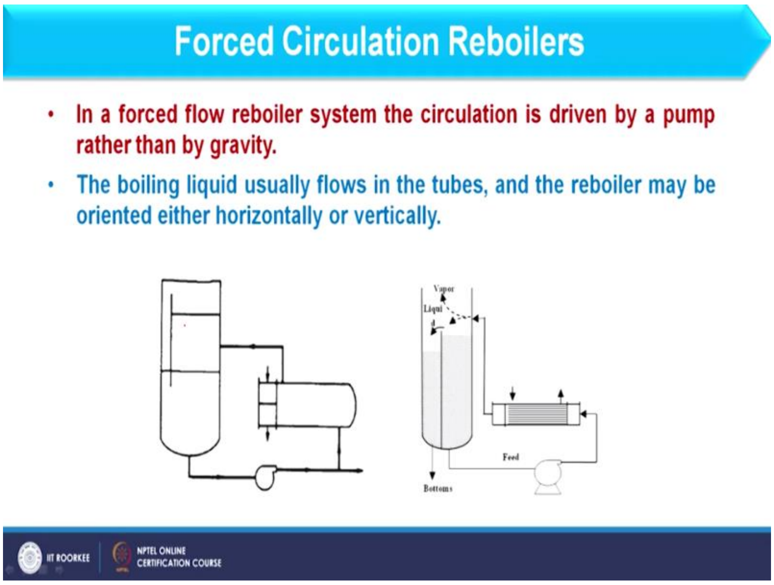

Now we will see forced circulation reboilers, but I am not going into detail design of this. So, as you know that forced circulation reboiler includes pump and in that we can consider boiling either in tube side or shell side because we are using the pump.

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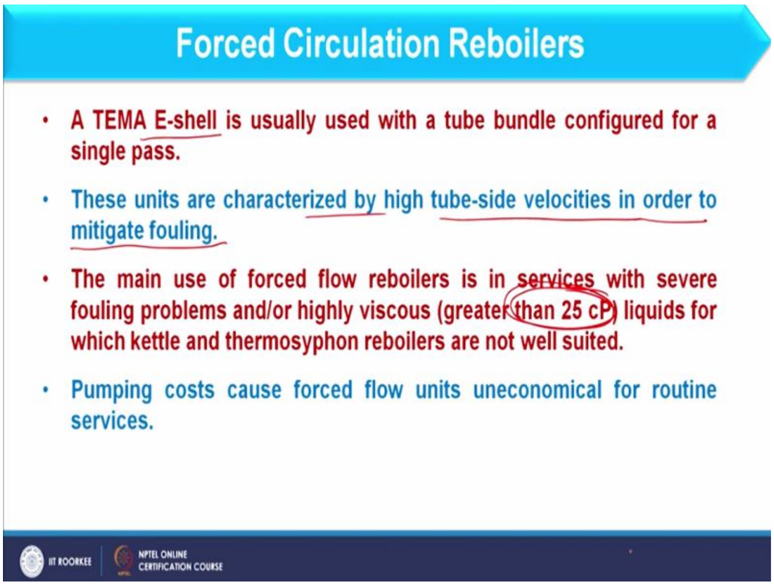

And few more points we will discuss about forced circulation reboiler that it includes TEMA E-shell and these units are characterized by high tube velocity because I am using the pump in order to mitigate the fouling. So, scale formation can be reduced by increasing the velocity and that can be done with the help of pump. Now, if you think that why we need forced circulation.

When the fluid is not able to circulate on its own and when it will happen when I am dealing with highly viscous liquid. So, forced circulation reboiler should be used when viscosity of the fluid increases then 25 centipoise otherwise we should use other reboilers because forced circulation reboiler when you are using you are using the pump which gives extra cost. So, for each purpose such type of reboiler utilization becomes uneconomical. So, that you have to keep in mind.

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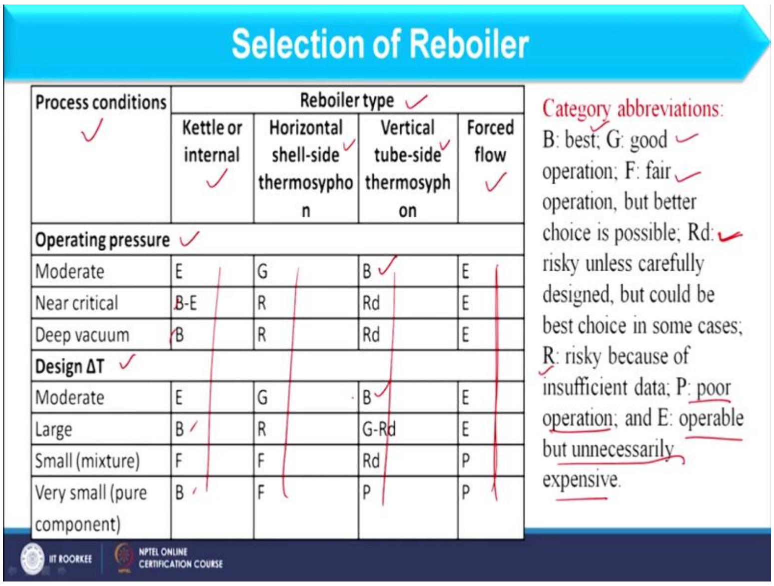

Now, in this slide we will see the selection of reboilers and if you see I am having different process conditions and reboiler type so we are comparing kettle or internal and here I am having horizontal shell side thermosyphon reboiler we are having vertical tube side thermosyphon reboiler and forced flow reboilers and we are having different operating condition.

This table extends to this section also we are having different other properties. Now, if you consider different alphabets which are shown like this if we elaborate this B stands for best it means the reboiler gives best performance. G is for good operation, F for fair operation, but better choice is possible. Similarly, Rd is risky until unless we have not design it carefully and capital R is risky because of insufficient data.

P is poor operation and E operable, but unnecessarily expensive. So, depending upon all these category we have given different alphabets to different reboilers. So, in this table you can find out where B is available. So, if you keep on counting the B in most of the condition you will find B in vertical tube side thermosyphon reboiler. Let us see that here I am having B like 1, 2 and 3, 4 and here I am having no B and here I am having B at two position.

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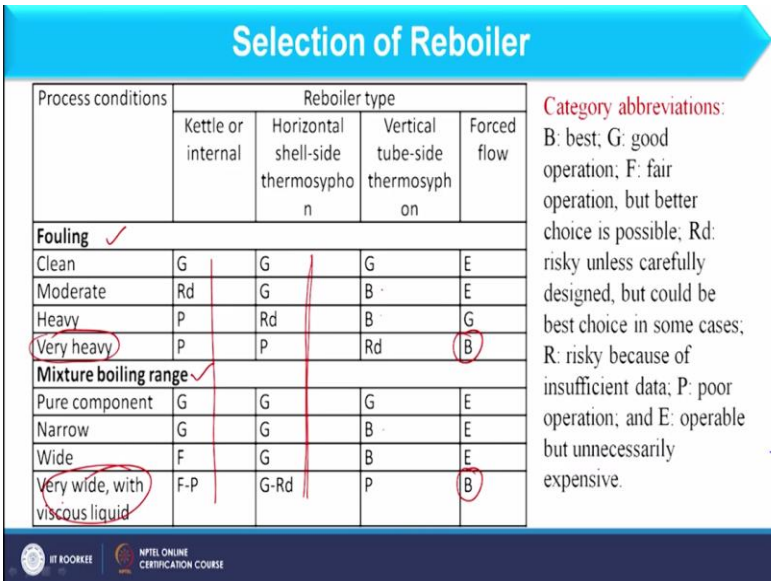

Process conditions	Reboiler type			
	Kettle or internal	Horizontal shell-side thermosyphon	Vertical tube-side thermosyphon	Forced flow
Fouling				
Clean	G	G	G	E
Moderate	Rd	G	B	E
Heavy	P	Rd	B	G
Very heavy	P	P	Rd	B
Mixture boiling range				
Pure component	G	G	G	E
Narrow	G	G	B	E
Wide	F	G	B	E
Very wide, with viscous liquid	F-P	G-Rd	P	B

Now, if I see next part of this table we do not have any B in kettle reboiler and in horizontal shell side thermosyphon reboiler also however we can have B 1, 2, 3 and 4, 4 B over here for vertical tube side thermosyphon and forced circulation we have B like this where we are dealing with heavy fouling liquid and highly viscous liquid. However, if you compare these B you will find that vertical tube side thermosyphon reboiler is most versatile.

And its utility is maximum as far as industrial operations are concerned. So, in this way you can choose the desired reboiler depending upon the conditions.

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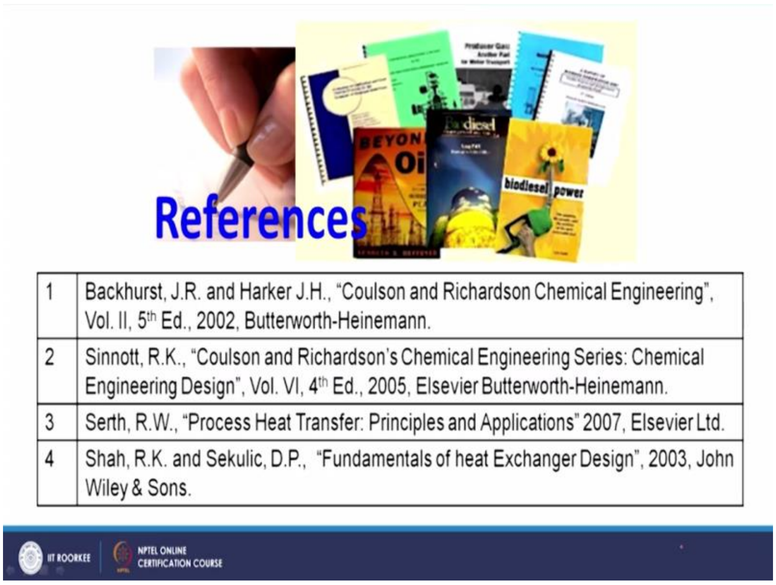

1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4th Ed., 2005, Elsevier Butterworth-Heinemann.
3	Serth, R.W., "Process Heat Transfer: Principles and Applications" 2007, Elsevier Ltd.
4	Shah, R.K. and Sekulic, D.P., "Fundamentals of heat Exchanger Design", 2003, John Wiley & Sons.

And here I am having some of the references which you can go through and now I am having summary of the video and this summary includes the summary of the complete topic that is design of reboiler which we have considered in lecture 27, 28, 29 and this lecture that is 30th lecture.

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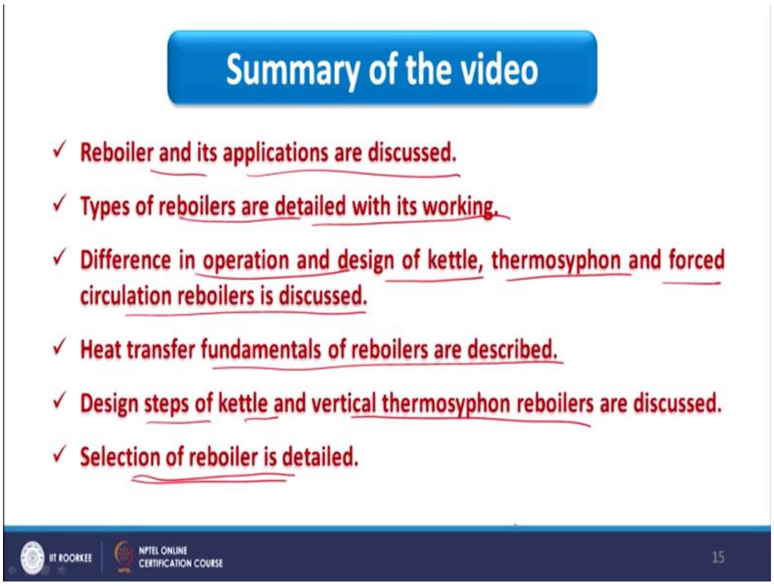

So, summary of these videos are here reboiler and its applications are discussed, type of reboilers are detailed with its working, difference in operation and design of kettle thermosyphon and forced circulation reboilers is discussed, heat transfer fundamentals of reboilers are described. Further, design steps of kettle and vertical thermosyphon reboilers are discussed in detail.

Finally, we have seen how to select the desired reboiler depending upon the condition. So, that is all about design of reboilers and I am stopping this lecture over here. So thank you everyone.