Process Equipment Design
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Lecture –32
Design of Reboiler-6

Hello everyone. I welcome you all in 32nd lecture of week 7 of the course Process Equipment Design and in this lecture we are going to illustrate the design of reboiler through some examples. Now, if you remember the 31st lecture there we have discuss design of kettle reboiler with the help of two examples and in the similar line here we are going to discuss design of vertical thermosyphon reboiler with the help of example. So, let us start the example 3.

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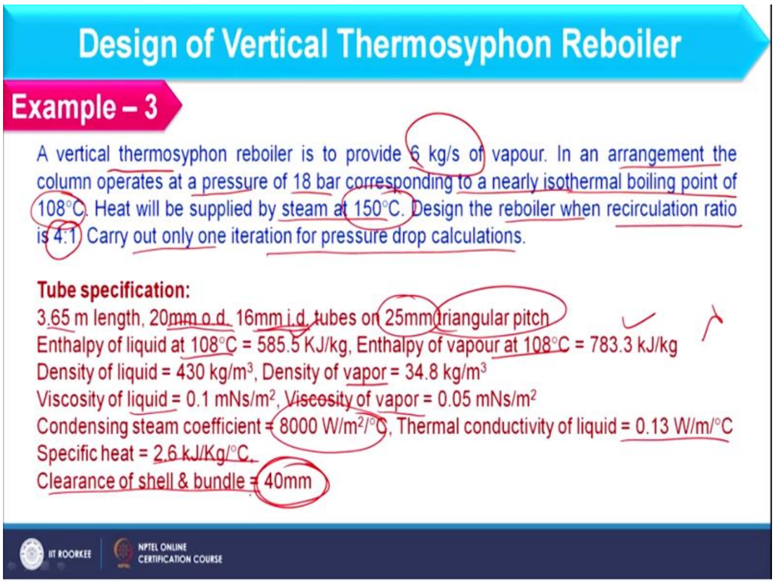

So, in this example a vertical thermosyphon is used where we have to generate 6 kg per second of vapour and if you recall the lecture of 6th week there we have discuss that in vertical thermosyphon reboiler boiling takes place only in tube side. So, that you have to keep in mind that in this problem also boiling is in tube side and the heating media is available in shell side.

So, in this arrangement column operates at a pressure of 18 bar which is corresponding to nearly isothermal boiling point of 108 degree Celsius. Heat will be supplied by steam at 150 degree Celsius. So, you see in this case either tube side or shell side we have isothermal condition so we have to find out mean temperature difference accordingly and here we have to design the vertical thermosyphon reboiler to maintain recirculation ratio of 4 is to 1.

Further, we have to carry out only one iteration for pressure drop calculations. So, along with this we have some other data such as tube data it has 3.65 meter length, 20 mm OD and 16 mm ID and tube are arrange in triangular pitch with 25 mm pitch and along with that we have other physical properties such as enthalpy of liquid, enthalpy of vapour so difference of this as well as this will give me lambda value.

Further, we have density of liquid as well as vapour, viscosity of liquid, viscosity of vapour, condensing steam coefficient. So, shell side coefficient is already given to us. So we do not have to do anything and further we are given thermal conductivity of the liquid, specific heat and finally we have clearance between shell and bundle as 40 mm. So, in this way the complete problem statement is given and let us start the solution of this problem.

So, first of all as you know that for heat transfer equipment we find out heat duty. So, that will depend on how much vapour we have to generate and the latent heat.

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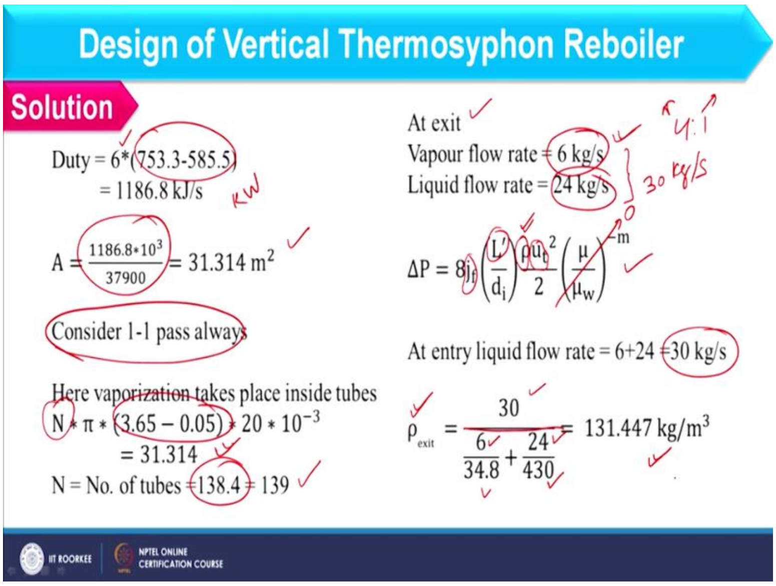

So, you see according to the problem we have 6 kg per second of vapour and this is basically the latent heat. So total 1,186.8 kilojoule per second or we can say kilowatt of heat duty is available. Now in vertical thermosyphon reboiler we have a different approach to find out area. Here we fix the maximum critical flux. Here we fix the maximum critical flux if you remember the lectures of 6th week and as far as vertical thermosyphon reboiler the maximum critical flux is 37,900 watt per meter square and heat duty is already given to me.

So, we can find out heat transfer area accordingly which is coming out as 31.314 meter square and this is the simple calculation. Now as I have told you that in vertical thermosyphon reboiler boiling takes place only in tube side. So, this is the special unit where we always have 1-1 pass no other unit have such combination only vertical thermosyphon reboiler has.

So, we have to find out number of tubes accordingly. So, you can see we have total heat transfer area and we can find area of single tube based on effective length because each tube will enter twice into tube sheet at two different ends. So, in that case we have expression like N that is the number of tubes which is multiplied by pi d 0 L where this is L effective and that should be equal to 31.314 and so the number of tubes we can obtain as 138.4.

And further we can make a complete number of this as 139. So, as it has 1-1 pass only, number of tubes will be even or odd it is in material, you have to consider the next value available. So, here we have 139 tubes. Now, next is we have to find out pressure drop. So, we will consider pressure drop in tube side in two ways first is pressure drop due to friction because liquid or we can say the fluid is continuously moving in the tube.

And secondly because tubes are completely filled with the fluid it must have the static head also. So, pressure drop due to frictional loss and pressure drop due to static head will give total pressure drop in tube side. And if you remember the 6th week lecture, we have discussed that for frictional pressure drop we consider the pressure drop at exit condition and at inlet condition separately.

And average of this will give the total frictional pressure drop in tube side. So, let us focus on the exit condition. So, at exit condition you see we have total vapour which is generated is 6 kg per second that is given in the problem. Now, if I am having 4 is to 1 recirculation ratio and 1 is the vapour so obviously 6 into 4 that is 24 is total flow rate of liquid. So, if I consider the inlet condition my total feed is 30 kg per second I hope it is clear to you.

Now, once I am having the vapour flow rate as well as liquid flow rate at exit condition we should calculate the pressure drop due to friction and for that the expression is like this and here we have to find out jf factor which will depend on the Reynolds number this L is the total length of the tube. This rho will depend on the feed. So, at inlet feed is total liquid and at exit feed is the mixture.

So, we have to find out density of the mixture and further we have to find out velocity. If I consider mass flow rate that will be equal at inlet as well as exit condition, but velocity will differ because it will depend on the density of the fluid and here we will further neglect this viscosity correction factor. So, at the entry point we have total feed as 30 kg per second that we have already discussed.

Now at exit condition how I should find out the density that we can calculate as 30 which is the total feed should be divided by 6 and that should be divided by density of the vapour and we have 24 liquid and here we have density of the liquid. When we solve this we can find density at exit condition as 131.447 kg per meter cube. So, in that way we have density at exit condition.

And at entry condition we consider density of the liquid only which is 430 kg per meter cube. Now, once I am having the density at exit condition we should calculate velocity at the exit condition.

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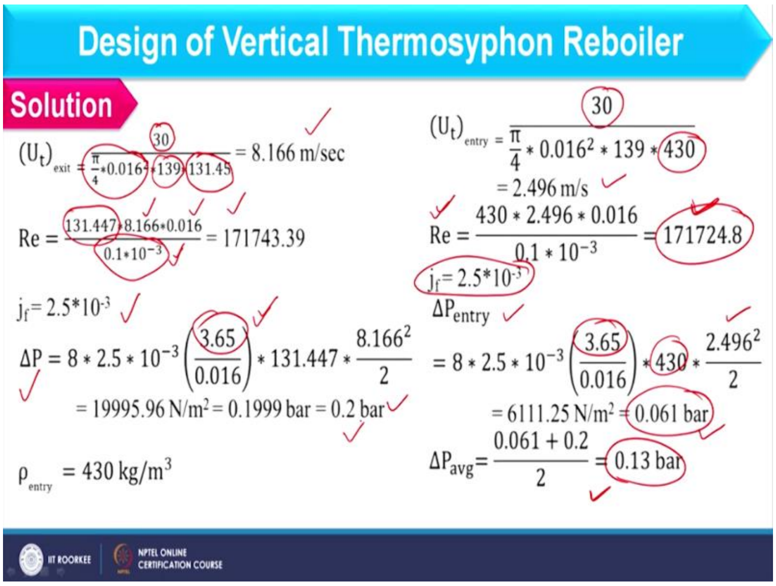

So, you see at exit condition total flow is 30 kg per second and here we have the mixture density because mixture is exiting the tube. Total flow area is basically 139 tubes into area of single tube. So, in this way we should find out velocity which comes as 8.166 meter per second. And if I know the velocity I can find out Reynolds number and here density of the mixture is considered and velocity is here and this is the tube ID.

Now what is this? This is basically the viscosity. Now here I am not considering the viscosity of the mixture, I am considering viscosity of the liquid because we have 4 times more liquid which is at exit condition. So, obviously when I compare the viscosity of liquid as well as vapour the viscosity will be more towards liquid side. So, in this way we are considering viscosity of liquid like 0.1 into 10 is to the power – 3.

And considering all these parameter I can find Reynolds number as 1.72 into 10 is to the power 5.

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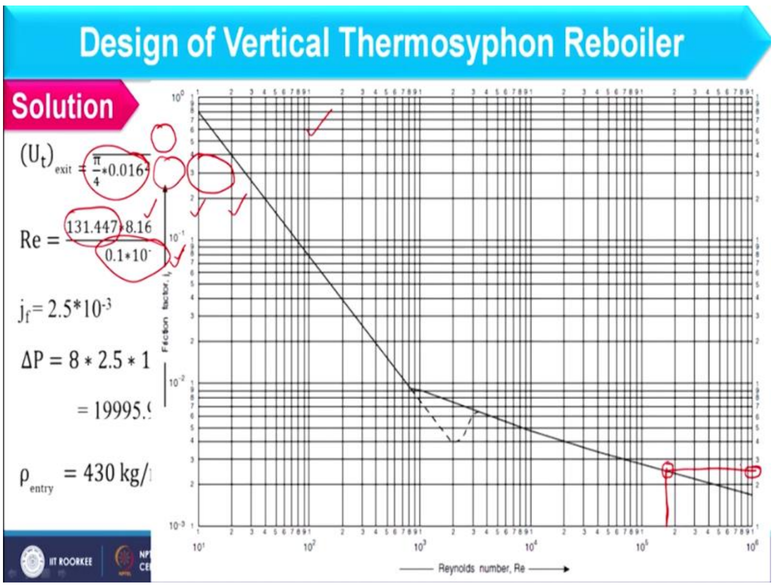

And we can find out jf factor from this graph where I have to locate 1.7 into 10 is to the power 5 so somewhere it will lie and this would be value of jf factor and you can see the value as 2.5 into 10 is to the power – 3. So, once I am having all these value we can find out pressure drop due to friction at exit condition and in this case I am considering total tube length because whole length is available to provide frictional loss.

So, in this way total pressure drop we can obtain at exit condition as 0.2 bar. Now, we have to calculate pressure drop due to friction at entry condition where liquid is available and density we should consider as 430 kg per meter cube. So, let us calculate the velocity and then Reynolds number and then the pressure drop. So, if you see velocity is like 2.497 where total feed is 30.

However, density I am considering as that of liquid and Reynolds number you can find out which is same as we have calculated for entry condition and the reason is very simple that here we have density of the liquid and accordingly velocity of the liquid changes. So, Reynolds number is same. So, jf factor is also same considering all these parameters we can find out pressure drop due to friction at inlet condition and that should come out as 0.061.

Here, you can consider velocity, density and total length of the tube. So, therefore, the average pressure due to friction in tube is 0.13 which is the average of this pressure as well as this pressure. So, in this way we can find out pressure drop due to friction in tube side.

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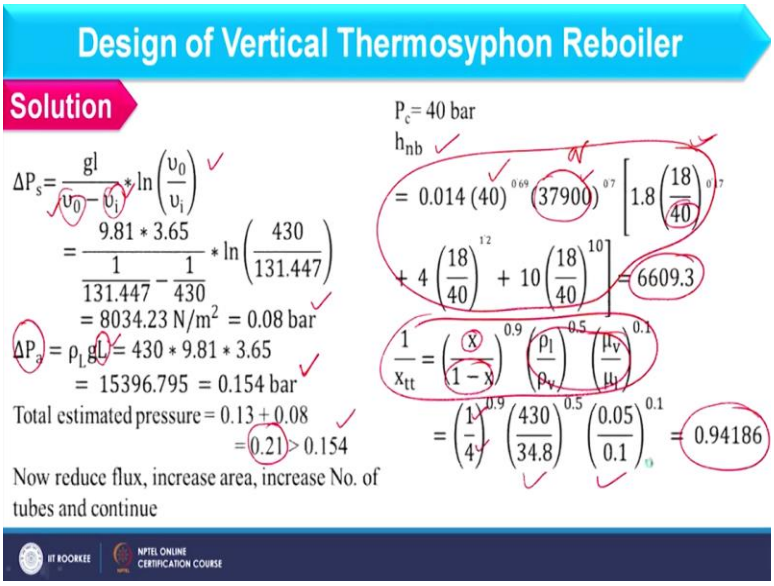

And next we have to find out the pressure drop due to static head and for that we have expression like this delta Ps = gl v 0 – v i into ln v 0 / v i right. So, this v 0 and v i are basically specific volumes and that will be nothing, but the reciprocal of density. So you can consider rho gl here, however, continuously phase is changed. So, we have consider specific volume instead of density.

So, here you can find out delta Ps value as 0.08 bar. So, total pressure drop due to friction we have 0.13 bar and total pressure drop due to static head we have 0.08 bar. Addition of these two will be 0.21 which is the total pressure drop available in tube side. So, that we have to compare with available pressure drop in distillation column side. So, total pressure drop available is basically rho L gl.

So, here I am considering length of the tube instead of length of the liquid or level of the liquid available in distillation column and the reason is very simple that if you remember the 6th week lectures where design of vertical thermosyphon we have discussed. So, we have observed that the upper tube sheet of tube bundle is available in the level of liquid which is present in distillation column.

So, total length of the liquid level available in distillation column will be equal to the length of the tube. So, considering this we can find out available pressure drop as 0.154 bar and if you compare this with the pressure drop available in the tube. So, tube pressure drop is coming more than the available pressure drop. So, it means that recirculation ratio is not maintained.

So, what we have to do further? We have to reduce the heat flux in such a way so that pressure drop in tube side should be lesser than the available pressure drop because you cannot change the available pressure drop until and unless you will not change the length of the tube. So, usually available pressure drop is constant. However, because of change in flux we can observe change in pressure drop due to friction in tube side.

So that iteration you have to carry out, but as mentioned in this problem that we should carry out only one iteration for pressure drop. We are further moving with the same values otherwise in ideal case first of all we are supposed to maintain this pressure drop and then we should proceed further. So, let us start the further calculations. Further, we have to find out heat transfer coefficient in tube side.

So, if you understand this vertical thermosyphon reboiler you should understand that at exit condition we have one part of vapour and that vapour is generating through boiling process. So, at exit condition in the tube we have vapour due to nucleate boiling condition as well as we have convective boiling in liquid also. So, total heat transfer coefficient at exit condition of the tube is h nb + h fc.

So h nb is the nucleate boiling heat transfer coefficient which is corrected with the factor. Correction why we require? Because this heat transfer that is h nb we have obtained for the flowing fluid because fluid is continuously moving. So, we have to correct the h nb as well as we have to correct the h fc. So, first of all let us find out h nb? To find out h nb that is heat transfer coefficient through nucleate boiling we have this expression I have already put the values over here.

But I hope you can identify the expression it will depend on the critical pressure. So, critical pressure is 40 bar and here we have flux. This is basically the q which is the flux. So, right now I am taking the same flux that is the maximum heat flux which is 37,900. However, in ideal case the flux which maintains the pressure drop in the system that flux should be considered over here, but here because we have carried out only one iteration we should consider the maximum flux as q value.

So, considering all these we can find out h nb value as 6609.3 watt per meter square degree Celsius. Now, we have to find out the correction factor and to get that correction factor we have to first find out 1 / x tt value that considers the two phase flow. So, 1 / x tt expression is given over here where x is the vapour quality and 1 – x is the liquid so it is basically 1 / 4 and here we have the property of liquid as well as vapour. So, accordingly we can put the value and find out 1 / x tt value as 0.94.

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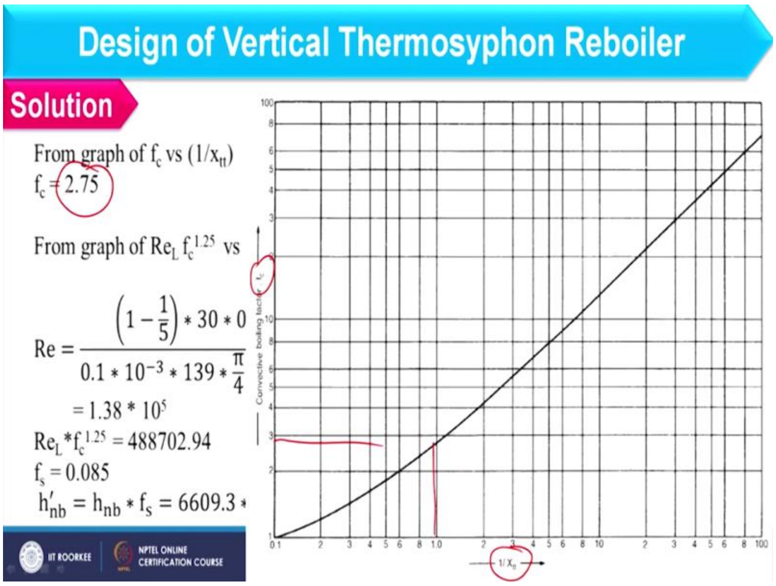

Now, once you have the value of 1 / x tt as 0.94 so somewhere it will lie here. So, you can find out value of fc from here which will come out as 2.75. However, for h nb the factor is fs not fc.

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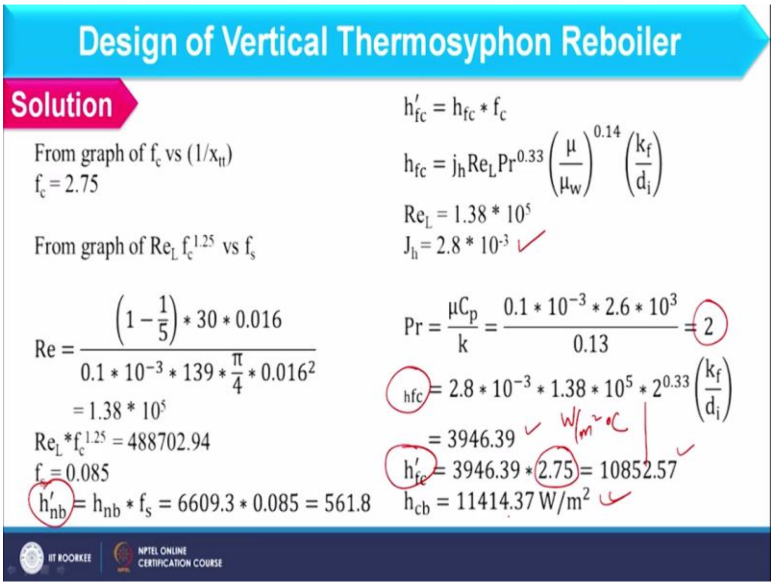

So, fs we will find out further as this expression in which we have to find out Reynolds number for the liquid and then fc we have already computed so we can find out fs value. So, Reynolds number for liquid we can find out considering 1 – x. So, you can see here because total feed is 5 in which 1 is vapour so 1 / 5 is the x value and total feed is given over here and we can find out Reynolds number like this which comes out as 1.38 into 10 is to the power 5.

So, that should be multiplied with fc power 1.25 and total value comes as 4.89 into 10 is to the power 5.

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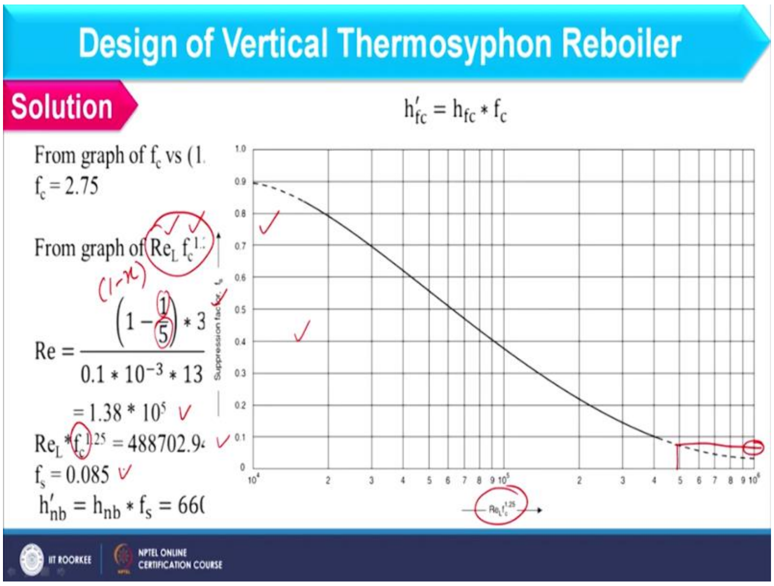

Now, once I am having the value of this expression as 4.9 into 10 is to the power 5 so somewhere it will lie here and value of fc you can obtain as this value which will come out as 0.085. So, here when I read the graph because of nonlinear line you can find that value is not exactly 0.085, but when you will see this in exact graph you can find the same value taking the scales.

So, we can find out revised value of h nb which is h nb prime and value you can obtain as 561.8 multiplying h nb with fs and further we have to find out h dash fc where fc I have already calculated and h fc we have to find out and this is corresponding to the heat transfer coefficient of liquid at exit condition. So, this is the expression where I will neglect viscosity correction factor.

And Reynolds number we have to find out which I have already calculated as 1.38 into 10 is to the power 5. So, for that value we can find out Jh from this graph it is coming as 1.38 into 10 is to the power 5 so somewhere it will lie here so you can see the value of Jh as 2.8 into 10 is to the power – 3 and Prandtl numbers we can find out because I know all properties and so h fc value we can find out as 3946.39 watt per meter square degree Celsius.

And we can multiply this with fc that is 2.75. So, complete value of h fc dash you can have as 10852.57 watt per meter square degree Celsius. So, we should add this as well as this to find out total heat transfer at exit condition of the tube which is 11414.37. So, in this way you can find out heat transfer coefficient at exit condition of the tube and further we have to find out heat transfer coefficient at entry condition of the tube.

So, you see at entry condition we have pure liquid which is 30 kg per second. So, at that point we have only convective boiling.

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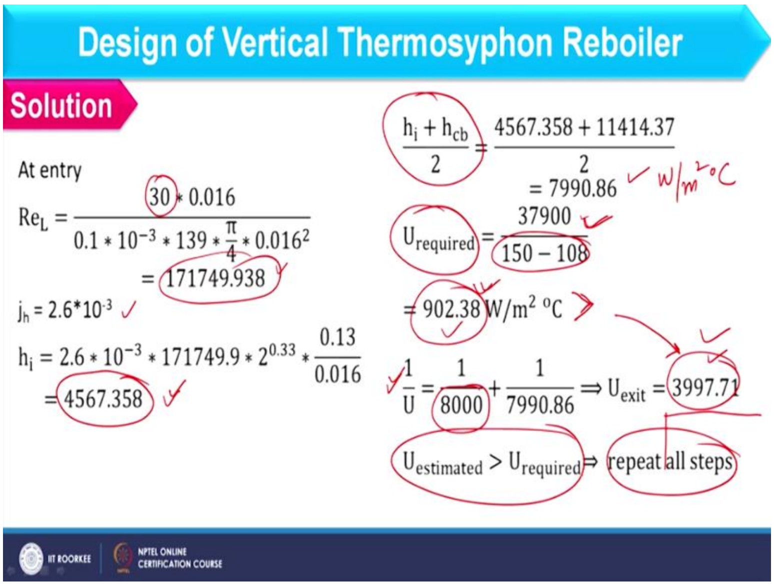

And the expression of convective boiling you have already used and in that expression we have to change the Reynolds number because instead of considering 1 – x we have to consider total feed as liquid. So, Reynolds number you can revise and that will be for complete feed and here the Reynolds number comes out as 1.72 into 10 is to the power 5 which is the Reynolds number we have also seen during pressure drop calculation.

So, in this graph you can find out the value so it should be 1.7 into 10 is to the power so somewhere here you will find out the value of jh which comes out as 2.6 into 10 is to the power 3. So, considering all these value you can find out heat transfer coefficient at inlet condition which is 4567.358 watt per meter square degree Celsius. Now, we will average the heat transfer coefficient at inlet and exit condition in the tube.

And total heat transfer coefficient you can obtain as 7990.86 watt per meter square degree Celsius. So, this is basically heat transfer coefficient. Now you have to find out overall heat transfer coefficient at shell side 8,000 watt per meter square degree Celsius value of heat transfer coefficient is already given. So, you can find out overall heat transfer coefficient in the tube as 3997.71.

So, this is the calculated U or estimated U. Further, we have to find out required U. Required means what? We have the flux because this flux we can fix and this is the same flux at which we will fix the pressure drop. So this is basically watt per meter square. If I divide this by temperature difference we can find out required U and that comes out as 902.38. So, you see we have to require this much U and we have obtained this much U.

And if I compare the area, area in this case will be larger in comparison to this. So, in the system this much U will be there and we have sufficient area than the required. So, this condition is satisfied and if this condition will not be satisfied we have to check the flux again and repeat all calculations. So in this way we have to design vertical thermosyphon reboiler and now we have another example which I will cover quickly.

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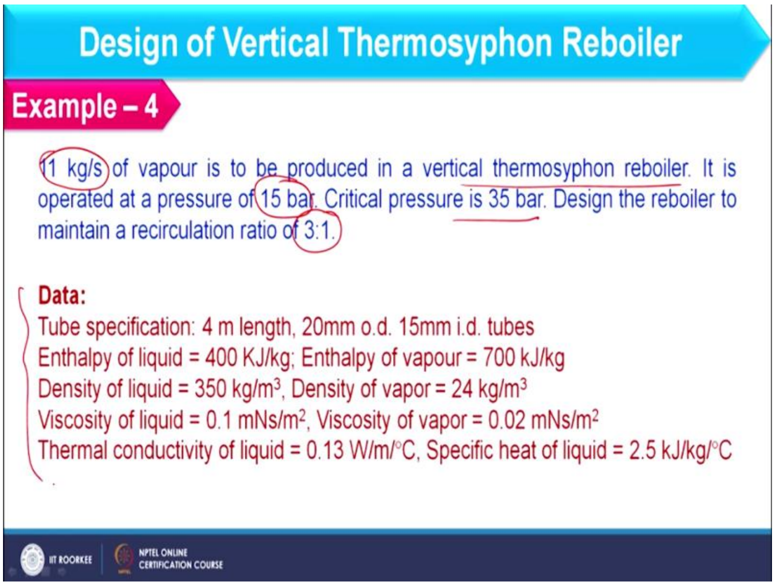

So, here you see we have 11 kg per second of vapour which is produced in vertical thermosyphon reboiler, operating pressure is 15 bar, critical pressure is 35 bar and here recirculation ratio of 3 is to 1 we have to maintain. Tube length and other properties are given I am not going into detail of these.

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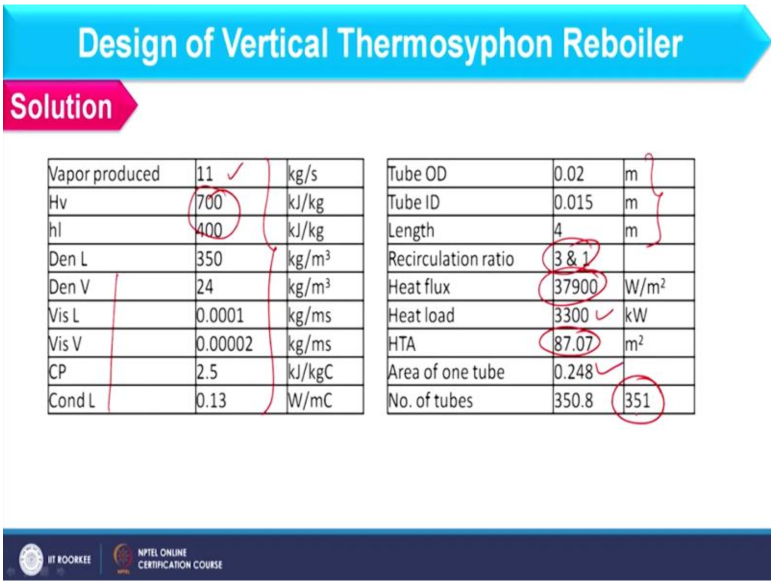

So, you see here I am having the values which are known to me that is 11 kg per second and this is basically the enthalpy of liquid and vapour and other properties and tube dimensions are given to us. Recirculation ratio is 3 is to 1, maximum reflux is 37,900 that we already have discussed that it is for vertical thermosyphon reboiler. So, accordingly we can find out heat duty depending upon vapour generation and latent heat of vapourization.

Total heat transfer area we can obtain as 87.07 area of one tube considering L effective you can find as this. So, total number of tubes you can find as 351.

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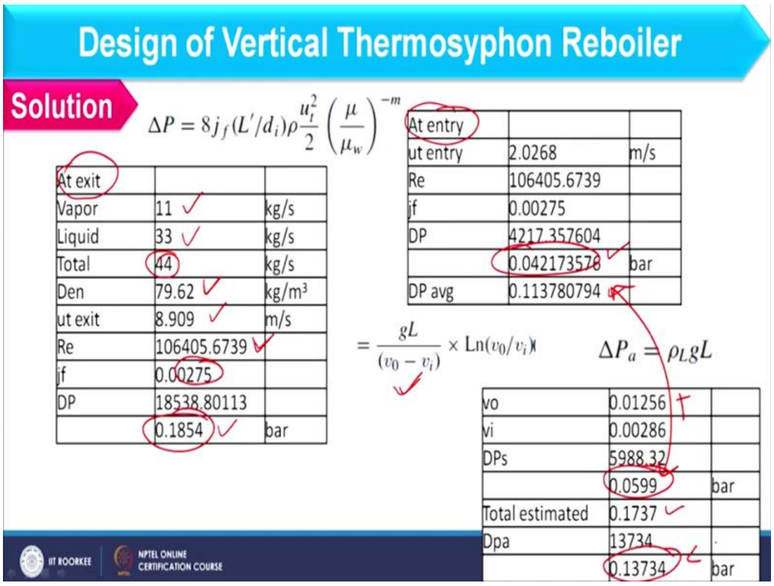

Now, let me calculate the pressure drop in tube side and that should be due to friction as well as static head. So, at exit condition of the tube we have this much vapour and 33 kg per second of liquid. So, total feed is 44. Density of the mixture comes as 79.62. This you can find in the similar line as we have calculated in previous example. Velocity at exit condition we can find as 8.9.

And similarly we can find out the Reynolds number as we have discussed in previous example jf value we can obtain as 2.75 into 10 is to the power – 3. So, total 0.1854 bar pressure we can obtain due to friction at exit condition of the tube and further at entry condition we can find out pressure drop in the similar line which comes out as 0.042 bar. So, average of this and this gives the total pressure drop in tube side due to friction which comes out as 0.1138 bar.

Next, we have to find out pressure drop due to static head so that value you can obtain as 0.06 bar and when I add this as well as this we can find out total pressure drop as 0.1737 bar in the tube side and total available pressure drop in distillation column side is simply rho L gl. So, that we can obtain as 0.13734 bar. So, if you see this value is again less than this value. So, in this case we can consider that pressure drop is not maintained. So, what we have to do? We have to reduce the flux.

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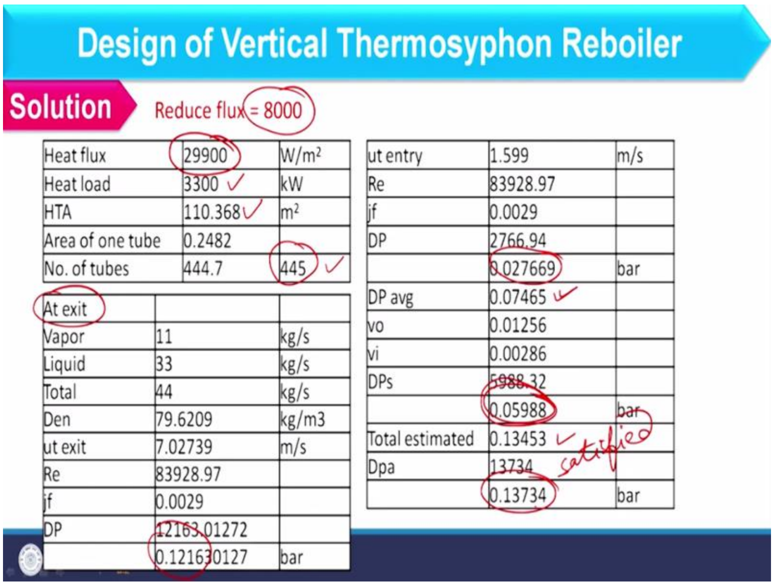

So, now I am reducing the flux by 8,000 value and next flux you can consider as 29,900. Total heat load will remain same, heat transfer area will change and so the number of tubes. So, now we are using 445 tubes and we will find out pressure drop due to friction and static head in the similar line. So, now the pressure drop at exit condition due to friction is 0.12 and that at entry condition is 0.027.

So, average pressure drop due to friction in tube side is 0.7465 bar. So, further if I consider the static head that will remain same as we have considered in previous iteration. So, total pressure drop in tube side due to friction and due to static head is 0.1345 bar and total available pressure drop is 0.137. So, here condition is satisfied. It means the recirculation ratio as 3 is to 1 will be maintained.

And further we can consider the heat transfer coefficient calculation based on the flux 29,900 and here I would like to mention one point that we have reduce flux by 8,000. You can reduce flux further also, but at the same time you will increase the heat transfer area. Though, the pressure drop is already maintained at 8,000 flux reduction. So, when we reduce it further like 10,000 in one go or let us say 15,000 in one go.

You will provide unnecessarily larger heat transfer area. However, recirculation ratio will definitely be maintained, but the cost of heat exchanger will increase manifold. So, you have to reduce the flux, but that should be only for maintaining the recirculation ratio. So, in that case available pressure drop should be slightly higher than the pressure drop available in tube side. So, you have to be very careful while reducing the flux.

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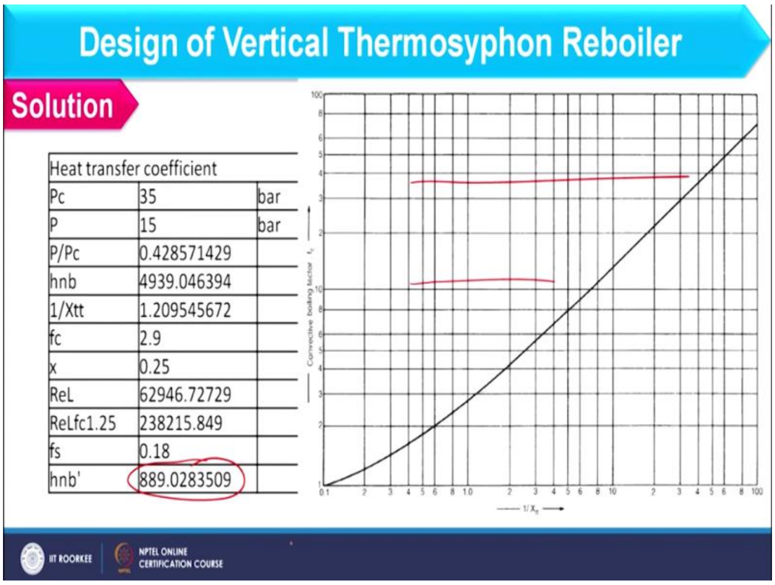

Now, heat transfer coefficient calculations are same as we have discussed in previous example so h nb dash you can find out as 889.03 watt per meter square degree Celsius. So, at exit point we have to find out pressure drop due to convective boiling.

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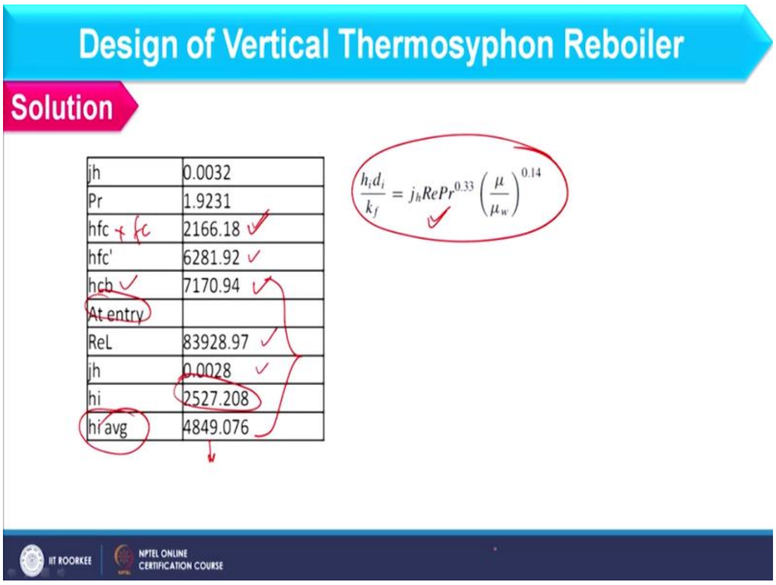

So that we can find out as this. This is in the similar line as we have discussed in the last example using this expression. So, h fc dash we can find out like 6281.92 watt per meter square degree Celsius multiplying h fc with fc. So, total h cb will be addition of h fc dash + h nb dash and value you can obtain as 7170.94 watt per meter square degree Celsius. And similarly at entry level of the tube, we can find out heat transfer coefficient using this expression where complete liquid is available.

So, Reynolds number you know jh factor you can obtain. So, heat transfer coefficient we can obtain as 2527.2 averaging of these two will give the heat transfer coefficient in tube side which comes out as 4849.076 watt per meter square degree Celsius. So, in this way we have solved two example to illustrate the design of vertical thermosyphon reboiler and I hope the approach is clear to you. So, we will further consider a few example in next lecture and that is all for now. Thank you.