Process Equipment Design
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Lecture –26
Design of Condenser-5

Hello everyone. Welcome to the 6th week of the course Process Equipment Design and this is the first lecture of this course and overall it is 26th lecture and here I am going to discuss a few examples to illustrate design of condenser. If you remember the 25th lecture, there we have discussed detail example to design a shell and tube condenser and here we are considering two more example to make you understand different conditions while designing the condenser properly.

So, let us start with example 2. Example 1 we have already covered in 25th lecture. So, example 2 says that 60,000 kg per hour of corrosive vapour is to be condensed. So, you are given a hint over here that where the condensation should be carried out. It is a corrosive vapour which should be allocated to tube side, so here I am having tube side condensation. Further, vapour enters the condenser at saturated condition at 80 degree Celsius where complete condensation is achieved.

So, here you can consider that vapour which is entering to the condenser at saturated condition therefore quality of the vapour should be 1. However, complete condensation is obtained so at exit condition vapour quality should be 0.

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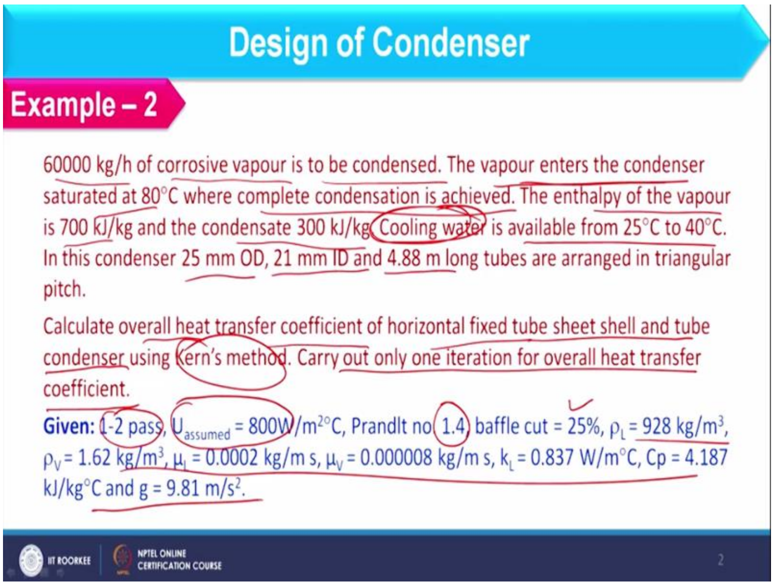

So, enthalpy of the vapour is 700 and that of condensate is 300 kilojoule per kg. Cooling water is available from 25 to 40 degree Celsius where this is used as a coolant. In this condenser 25 mm OD and 21 mm ID along with 4.88 meter long tubes are arranged in a triangle pitch. So arrangement is triangular and what we have to find out over here let us see that.

We have to calculate overall heat transfer coefficient of horizontal fixed tube sheet, shell and tube condenser. So, positioning of the condenser is horizontal and condensation is occurring in tube side and further we have to find out overall heat transfer coefficient using Kern's method. So, to shell side calculation we will apply Kern's method where normal operation will be carried out where water is available.

And further it is given that we have to carry out only one iteration for overall heat transfer coefficient. Along with this, some properties are given to us and some other information also let us see that. We are given 1-2 pass and initial assumption of overall heat transfer coefficient is given as 800, Prandtl number is given as 1.4 and baffle cut 25% is given and we are given other properties of the fluids like this.

So, here let us start the solution of this example. So, as you have to find out overall heat transfer coefficient we have to find out heat transfer coefficient in shell side as well as in tube side. For shell side, we can simply apply Kern's method and for tube side we have to find out the correct correlation which is used to estimate heat transfer coefficient in horizontal condenser where tube side condensation is occurring so that also we should keep in mind.

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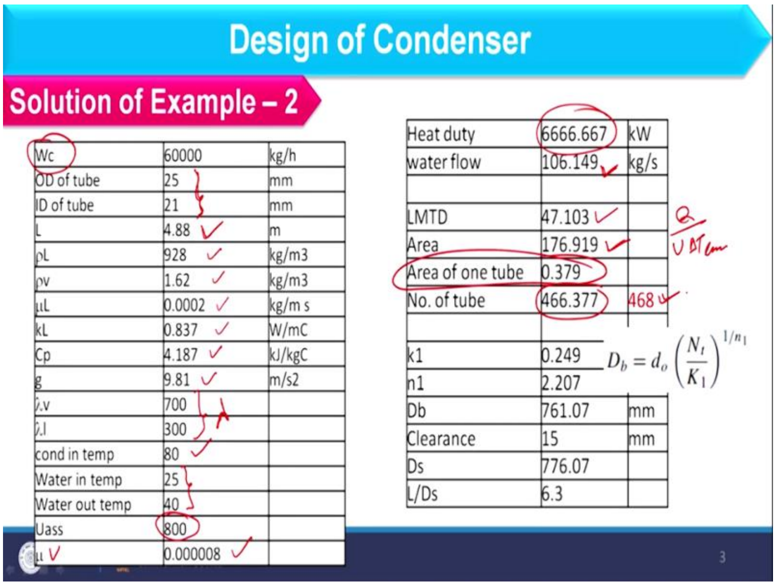

So, let us see what information are given to us? We are given condensate flow as 60,000 kg per hour, OD of the tube and ID of the tube is given to us and total length of the tube is 4.88 meter. Density of liquid, vapour, viscosity of liquid, thermal conductivity of the liquid, specific heat of water and g value is given to us along with enthalpy of vapour as well as enthalpy of liquid.

So, difference of these two will give the lambda value and condensation is carried out at 80 degree Celsius, water is available from 25 to 40 and assumed overall heat transfer coefficient is given as 800 and viscosity of vapour is given as this value. So, what we have to calculate first obviously the heat duty. So, let us start that we are given the vapour flow rate or we can say the condensate flow rate and lambda value.

Considering these values, we can find out heat duty as 6666.667 kilowatt. Accordingly I can find out water flow rate as 106.149 balancing the heat between condensate as well as water and here because condensation is carried out only at one temperature that is 80 degree. So, isothermal condition is there however in water side I am having non isothermal condition so in this case we can find out LMTD directly without considering F t factor.

So, LMTD you can find as 47.103, heat transfer area we can simply find as Q / U delta T lm that is a well known expression and you can find it and further we have to find out area of one tube and here we should also consider length of the tube is L effective. Considering 25 mm of tube sheet thickness and tube sheet should be available at two end of the tube. So, number of tube you can obtain as 466.377 and even value of it should be 468.

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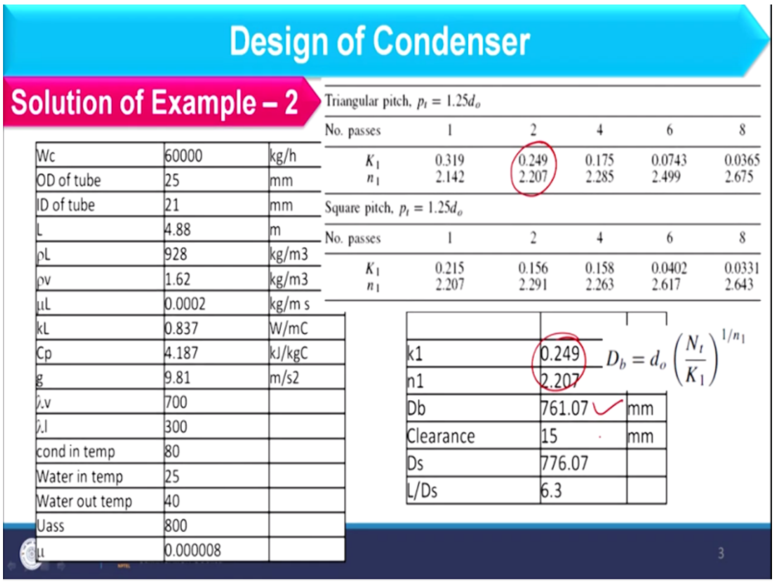

Considering this number of tube we can find out bundle diameter and that should be corresponding to triangular pitch and two passes. So, value you can obtain like this and bundle dia you can find like this and after that we need to find out shell dia and for that we should find the clearance.

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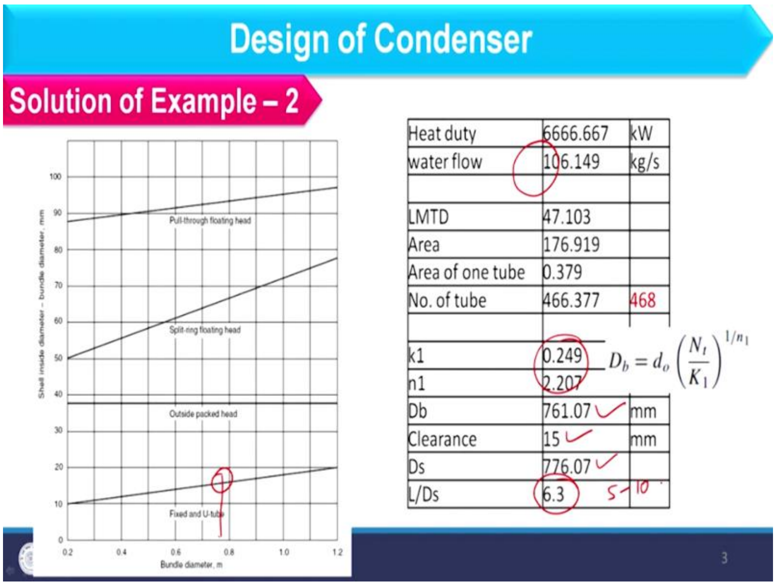

So, clearance should be corresponding to 761 and so bundle diameter you can find as 761 and as far as heat exchanger type is concerned it is fixed tube sheet it is already given in the problem otherwise you can also consider the same exchanger because maximum temperature you can find in this problem is less than 90 degree. So, fixed tube sheet you can consider on your own also.

So, considering bundle diameter as 0.76 it will lie somewhere here and you can see the value of clearance and that should be equal to 15 then we can find out shell diameter and finally we can find out L / D ratio which is within the limit. So, this condition is satisfied.

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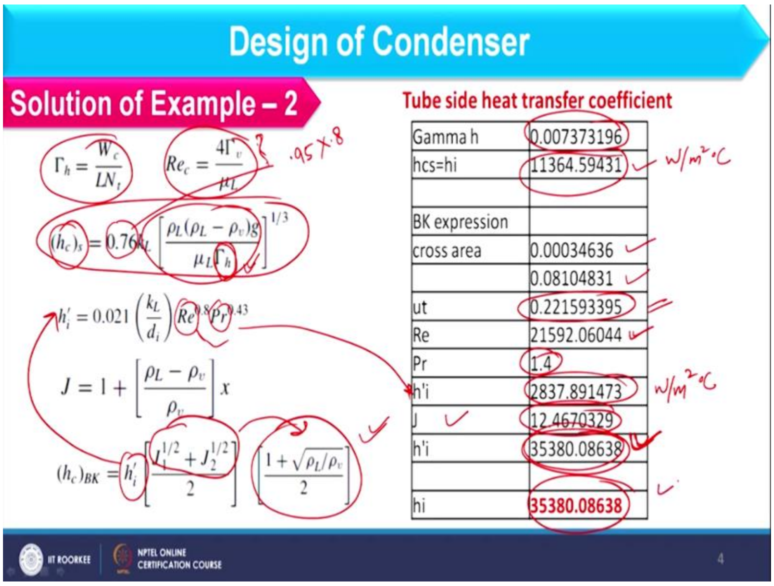

Now, once I am having correct L / D ratio we have to find out heat transfer coefficient in tube side as well as in shell side. So, as far as condenser is concerned it is basically horizontally placed and condensation is occurring in tube side. So, for this combination we are given two model that is stratified flow as well as annular flow if you consider the design of condenser lectures.

And we have to find out heat transfer coefficient using two models and we have to select the larger value of heat transfer coefficient as the final value. So, as far as stratified flow is concerned we can consider Nusselt equation that is 0.95 into some properties and that should be corrected by some factor and that factor is 0.8. So, correct expression I am having for stratified flow is this.

So here 0.76 that we can simply obtain by multiplying 0.95 with 0.8 and other properties are given to us. Gamma h is given as the tube loading and that you can find out considering effective length using this expression and Reynolds number we can find using this expression and wherever this Reynolds number will be used that we will see. So, first see the stratified flow and the corresponding correlation.

So, here you can simply find out gamma h which you can obtain like this. So, I am not going into detail of each expression as well as each term I am assuming that you can find these value just I am giving you the values. So, once you have the gamma value you know all other properties you can find out heat transfer coefficient in tube side for a stratified flow and that you can obtain as 11364.59 watt per meter square degree Celsius.

And second flow in tube side is the annular flow and to find out heat transfer coefficient for this flow we can consider Boyko Kruzhilin correlation and if you remember Boyko Kruzhilin correlation there I am having h i dash which is the heat transfer coefficient when I am considering condensate only and two phase we can consider based on J 1 and J 2 value and if you remember here vapour is entering at saturated condition.

So x value should be 1 and complete condensation is occurring at the end so x value will be 0. So, for that we have combination of J 1 and J 2 which is given like this, this is the J 1 and J 2 combination. It means it is basically this value and h i dash you can find out using this expression for that you need to calculate Reynolds number as well as Prandtl number and to find out Reynolds number I am not using this expression.

So, to find out Reynolds number I am not using this expression because it is simply a condensate of single phase because it is the condensate which is a single phase. So, we will find out the velocity and show the Reynolds number and after that we will compute h i dash value. So, for that you have to find out cross sectional area as we have done in previous examples also.

Velocity you can find like this now this velocity you should not compare with any range because this is for the condensate and whatever flow is given accordingly you have to find out the velocity and Reynolds number you can simply find out as 21592.06, Prandtl number is given to you so you can apply this equation and find out h i value as 2837.89 watt per meter square degree Celsius.

This J factor you can obtain like this and further you can find out final h i dash value. So, when I compare this value as well as this value obviously it is higher so we can choose this value as final tube side coefficient.

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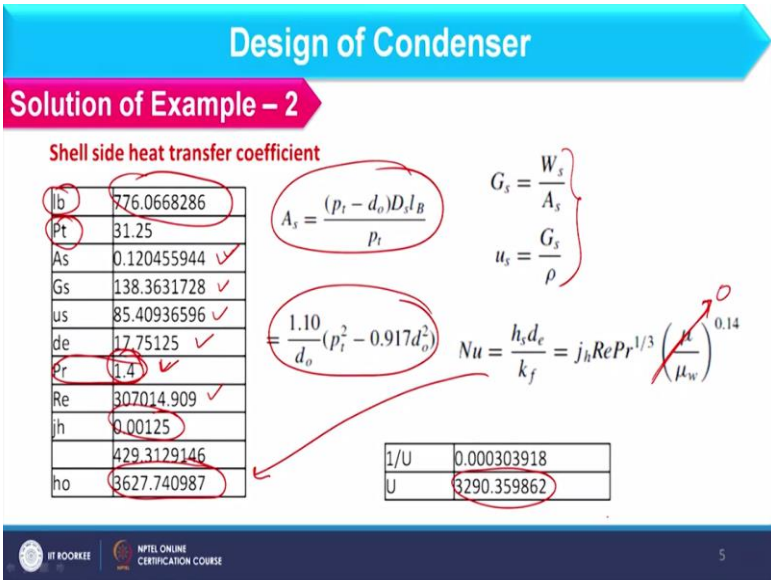

So and further I have to find out shell side heat transfer coefficient using Kern's method. So, this method is well known to you we will simply see the values of different parameters. So, here I am considering baffle spacing which is equal to D s and that we usually consider in condensers, P t triangle pitch is given depending upon OD of the tube, cross flow area you can find out depending upon this expression.

And then we can find out G as well as well as u s so the expressions are given here and after that we can find out equivalent diameter and the expression is given over here. Prandtl number is already given to you, Reynolds number you can find out because velocity and all other parameters are given to you. So, Reynolds number you can find out based on the velocity.

And if you see here I am having another point to tell that Prandtl number is given as 1.4 and this Prandtl number is applicable to both side. So, depending upon the Reynolds number you can find out j h value from the graph as we have discussed in previous examples also and so you can find out heat transfer coefficient in shell side considering this expression neglecting viscosity correction factor.

So, based on that you can find out overall heat transfer coefficient which is coming out as 3290. So, in this problem you are not known with the dirt factor as well as thermal conductivity of the material. So, you can simply find out 1 / U value based on two terms including h i as well as h o. So, based on that overall heat transfer coefficient is obtained in this example.

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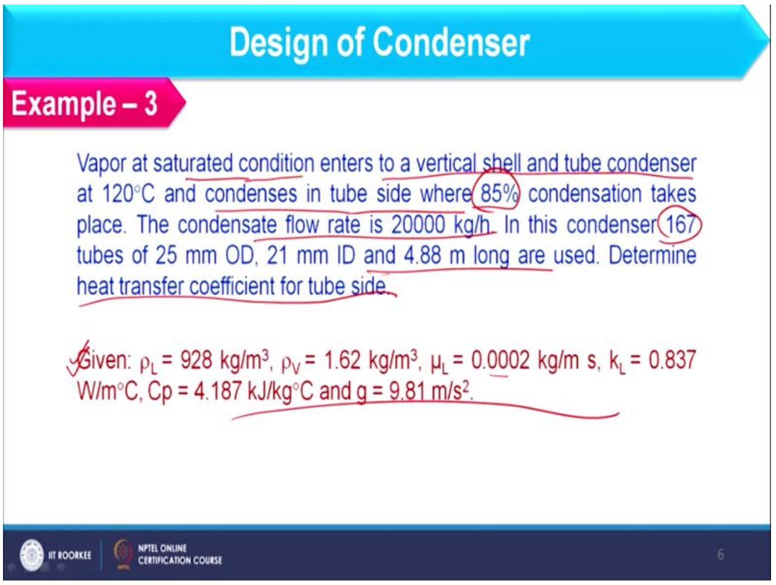

Now, I am having another example which is basically example 3 for design of condenser and this example says that vapour which is available at saturated condition enters to the vertical shell and tube condenser. So, orientation is given to you that is vertical shell and tube condenser and in this case condensation is occurring in tube side where 85% condensation takes place.

So, vapour is entering at saturation condition x value should be 1 and 85% condensation is occurring so at the exit point x value should be 0.15. So, condensate flow rate is given to you that is 20,000 kg per hour. In this condenser 167 tubes of 25 mm OD, 21 mm ID and 4.88 meter length is given and we have to determine heat transfer coefficient in tube side. So, you see it is vertically placed and condensation is occurring in tube side.

So in this case we have to apply correct method to find out heat transfer coefficient in tube side. Further, some properties are also given to us as you can see here.

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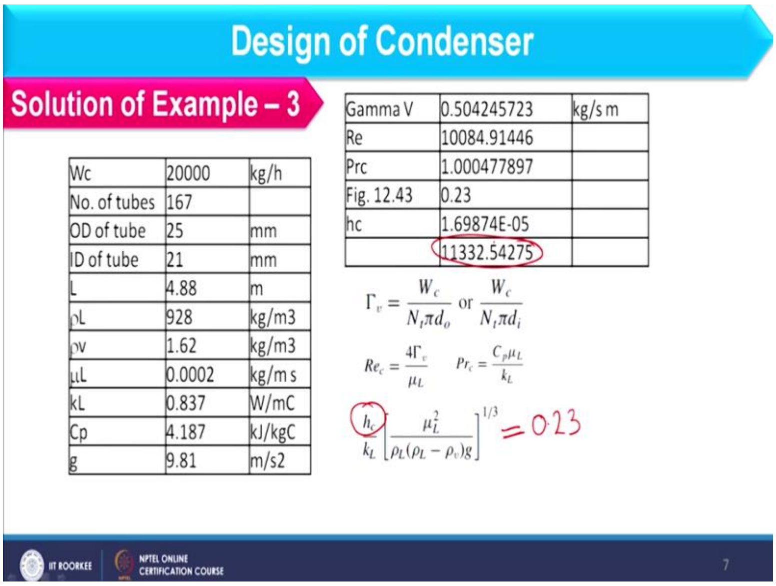

So, let us start the solution of example 3. So, if you see here we have vertical condenser where condensation is occurring in tube side. To solve this problem or to calculate heat transfer coefficient in tube side we have two methods. First is when I am using the graph to find out heat transfer coefficient inside the tube and second is we should use Boyko Kruzhilin correlation to find out heat transfer coefficient inside the tube compared the values of coefficient and select the larger value as the final value.

So, let us start the solution of this example. So, condensate flow rate is given as 20,000, number of tubes is given as 167, OD and ID of the tube along with the length are given like this and we are given properties of the fluid and first of all we have to use the graph to find out heat transfer coefficient in tube side. So, if you see the graph is like this where I should know the Reynolds number and the Prandtl number.

So, first of all we should find the Reynolds number and then we will proceed further. To find out Reynolds number this is the expression where I need gamma v and that gamma v should be this expression because condensation is occurring inside the tube. So, perimeter of inside tube I should consider. So, you can consider W c as 20,000 per hour, N t 167 and pi d i value and gamma value you can obtain as 0.504.

Considering this gamma value and viscosity of the fluid you can find Reynolds number as 1 into 10 is to the power 4. Prandtl number you can simply find out by considering the properties and its value should come as 1 and the graph that I should consult is figure 12.43 it is as per Richardson and Coulson Volume 6 4th edition. So, let us see the value in graph. So, you see Reynolds number is given as 1 into 10 is to the power 4.

So this is the value Prandtl number is given as 1 so you can find value of this factor somewhere here. So the value should come as 0.23. Now this value we have seen from the graph which is coming out as 0.23. After solving this, you can find out h c value from this and which should come out as 11332.54. So, in this way we can find out heat transfer coefficient in tube side considering graphical approach.

Next point is we have to find out heat transfer coefficient of tube side using Boyko Kruzhilin correlation. So, let us see that.

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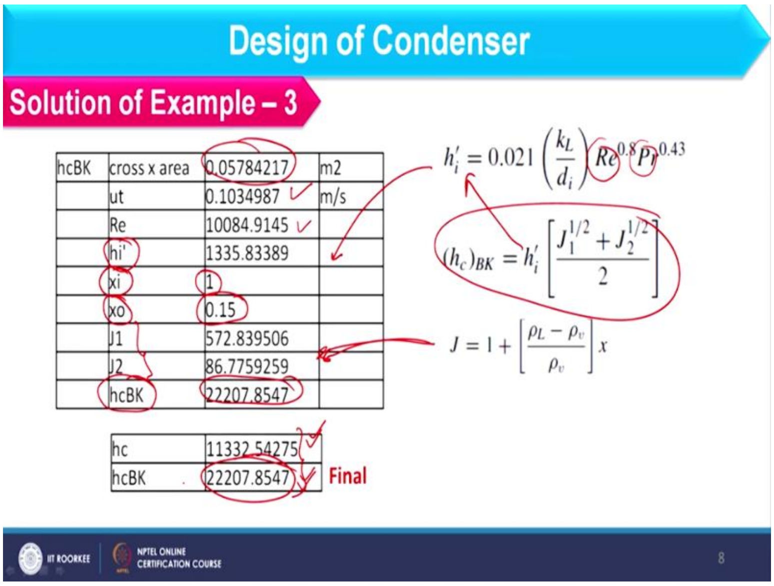

So this is basically Boyko Kruzhilin correlation and h i dash you can find out by this. So, to find out h i dash value we should know Reynolds number as well as Prandtl number. So that Reynolds number you can find out depending upon the cross flow area and velocity and so you can find out Reynolds number which is coming out same as we have calculated in the last slide and the reason is very simple because both are condensate.

So, in this way we can find out Reynolds number and I can find out h i dash value considering this expression and it comes as 1335.834 watt per meter square degree Celsius. Here x i or x 1 is given as 1 because I am having saturated vapour at the entry of the condenser. At the exit, we have condensate which is only 85% condensation is done where only 85% condensation is done and vapour availability is around 15%, so x o should be 0.15.

Accordingly we can find out J 1 and J 2 value considering these equations. So, based on that J value and h i dash value we can find out heat transfer coefficient using Boyko Kruzhilin correlation which is coming out as 22207.8547. Now, if I compare the heat transfer coefficient which we have obtained from the graph as well as that from the Boyko Kruzhilin correlation obviously this will be the final value.

So, in this way you can find out heat transfer coefficient of condensers depending upon the orientation and the condensation side and detailed design of the condenser we have already covered in example 1 which we have discussed in lecture 25.

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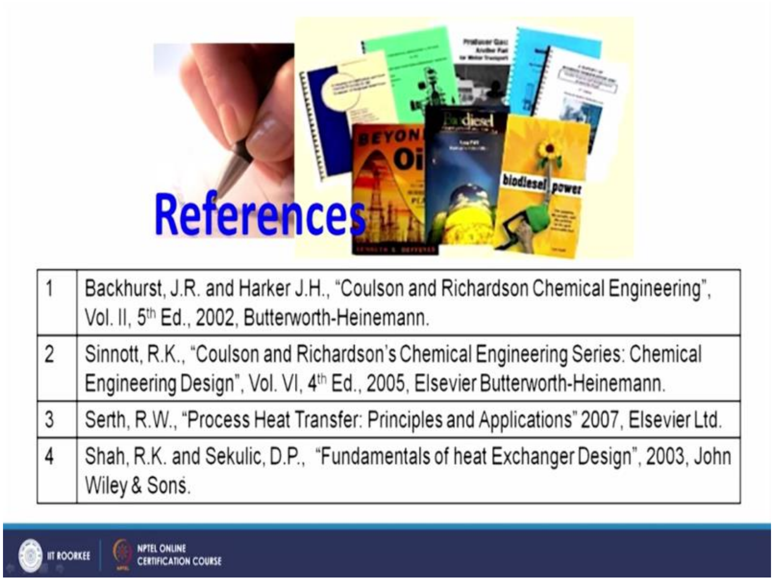

And here I am having some of the references which you can consult.

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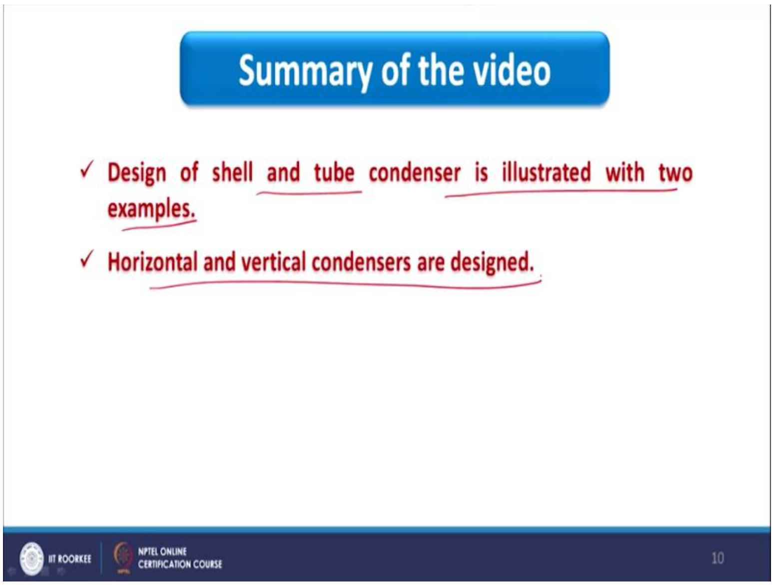

And now we have the summary of this video. In this video, design of shell and tube condenser is illustrated with two examples horizontal and vertical condensers are designed. So, in this way you have to design different combination of condensers and that is all for now. Thank you.