Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –25
Design of Condenser-4

Hello everyone. This is the 25th lecture of the course Process Equipment Design and here we are at the end of 5th week. If you remember 22nd, 23rd and 24th lecture of this course there we have discussed design of condensers in detail and here we will illustrate the design of condenser with the help of example where each and every steps will be discussed in detail. So, let us start this lecture where I am having example 1.

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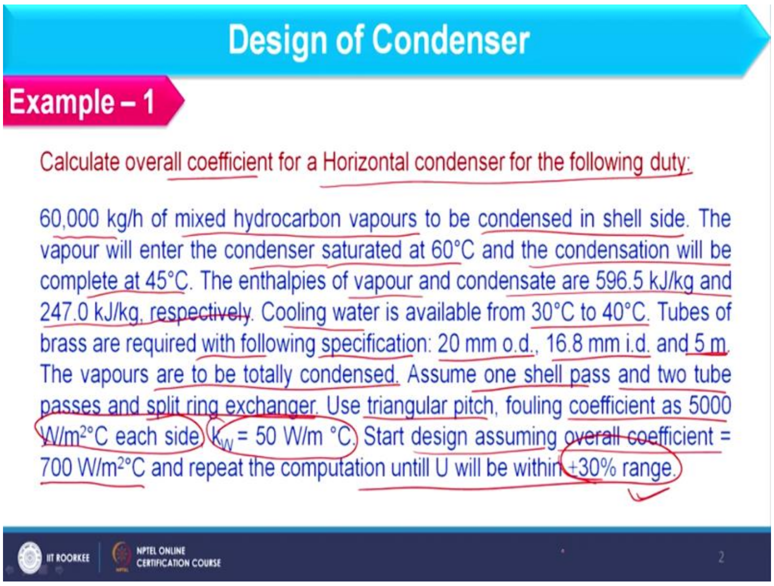

In this example, we have to calculate overall coefficient for a horizontal condenser for a following duty. It means the orientation is already given to you so that is the horizontal condenser and the system is like we have 60,000 kg per hour of mixed hydrocarbon vapour. So, this is not a pure component here we are going to design the condensate having mixed hydrocarbon feed so which is condensed in shell side.

So, you see orientation as well as condensation side is already given we have shell side condensation with horizontal condenser. So, the vapour will enter the condenser saturated at 60 degree Celsius and condensation will be completed at 45 degree Celsius. So you see because I am considering hydrocarbon vapour mixture I should consider non isothermal condition in condensation side and that is why temperature variation is given over here.

So feed of vapours enters at 60 degree and condensate exits at 45 degree. The enthalpies of vapour and condensate are given like this. Coolant we have the cooling water which is available from 30 degree to 40 degree Celsius and tubes of brass are required for the following specification where OD of the tube is 20 ID of the tube is 16.8 mm and length of the tube is 5 meter.

And in this case vapours are totally condensed so we have to consider total condensation for which we have discussed design in previous lectures. So, here we have to assume one shell pass and two tube passes with split ring exchanger. So, type of exchanger, number of passes all these are given to you. We have to use triangular pitch and fouling coefficient as 5,000 we should consider for both stream it means that is for water as well as for vapour.

Thermal conductivity of the material is given as 50 watt per meter degree Celsius we have to start the design assuming overall coefficient as 700 watt per meter square degree Celsius and repeat the calculation until I am getting U value within plus minus 30% range. So, in this way we have to design a condenser which is horizontally placed, condensation is occurring in shell side with mixed hydrocarbon vapour.

So as far as design of condenser are concerned, the steps will be same as we have discussed in shell and tube exchanger, but here whatever change will be there that also we will discuss in detail, but before starting the design we should collect the physical properties and as far as physical properties are concerned that you can collect at average temperature that is the average temperature where condensation is occurring and the average of that average temperature as well as wall temperature. So in this way you can find out the average temperature where you can see the properties.

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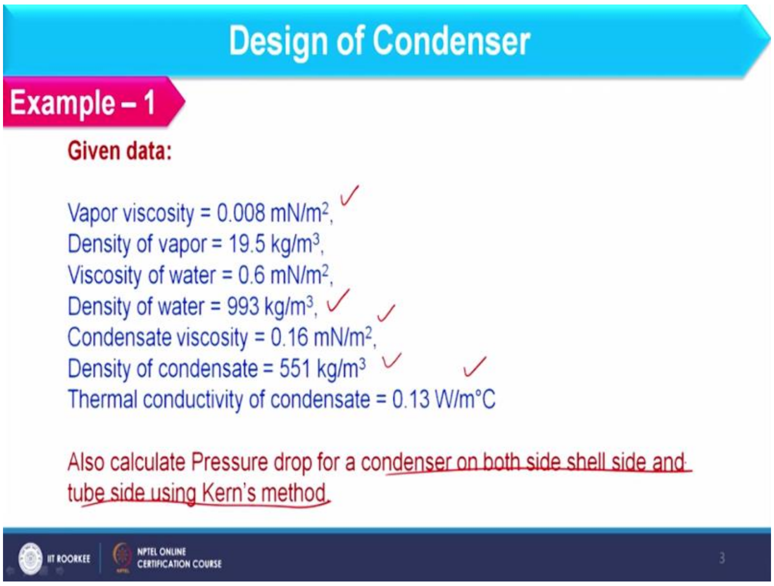

However, in this problem the properties of the fluids are already given such as we have vapour viscosity as 0.008 millinewton per meter square and density of the vapour is 19.5 kg per meter cube, viscosity of the water is 0.6, density of the water 993 and condensate viscosity is 0.16 and density of the condensate is 551 and thermal conductivity of the condensate is given as 0.13 watt per meter degree Celsius.

So as far as design is concerned you have to find out heat transfer coefficient in this condenser and along with that you have to find out pressure drop in shell side as well as in tube side and for that you should consider Kern's method as it is shown over here. So, this is basically the example 1 for design of condenser and let us start the solution of this problem. So as far as shell and tube heat exchanger design is concerned the first step is to find out the heat duty.

In the similar line here in design of condenser we have to first find out the heat duty and how I can find out the heat duty whatever vapour is available to us for condensation and that should be multiplied by heat of condensation which should be equal to enthalpy of vapour minus enthalpy of liquid and all these values are given to you.

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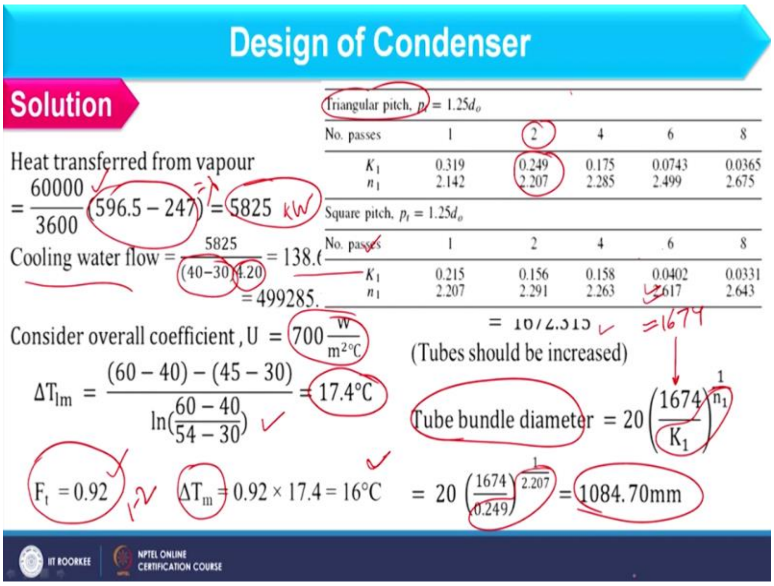

So, we are having 60,000 kg per hour of vapour and these are basically enthalpy of vapour as well as enthalpy of liquids. Difference of these two will give the lambda value and if you find it you can find 5825 kilowatt as the total heat duty of condenser. Once you have this heat duty you can find out flow rate of another fluid and that fluid is nothing, but the cooling water.

So 5825 divided by 40 – 30 because this is the temperature range of water is given to us and 4.2 is basically the specific heat of the water. Instead of that you can also consider 4.187, but here I am considering 4.2 specific heat of the water. Considering this you can find out the flow rate of water as 138.69 kg per second. Overall, heat transfer coefficient initial guess is already given to us and that is 700.

And to find out the area of the condenser you have to first find out mean temperature difference. So, as far as mean temperature difference is concerned if you see in both side we have non isothermal condition and if you remember the last lecture when both side of condenser are having non isothermal conditions in that case we have to find out log mean temperature difference for counter flow along with F t correction factor because we may have the chance of temperature cross which we should avoid.

So, for that we have to find out F t correction factor. So, first of all we will consider log mean temperature difference which comes out as 17.4 degree Celsius F t value we can obtain from 1-2 pass shell and tube heat exchanger graph where depending upon (()) (09:06) you can see the value of F t which is coming out as 0.92 and true mean temperature difference you can find out multiplying F t with LMTD and that should be equal to 16 degree Celsius.

So, now once you have the heat duty mean temperature difference and overall heat transfer coefficient you can find out the heat transfer area of the condenser and which comes out as 520.09 meter square because you can solve these parameters. So, here you can see the steps whatever we are following it is same as we have discussed in design of shell and tube heat exchanger. So, the next step is we have to find out the number of tubes.

However, in this problem tube dimensions are already given to you so you are not supposed to choose the diameter as well as length of the tube. However, if you have to choose that the same method which we have discussed in shell and tube heat exchanger design you have to follow here as well. So, first of all we have to find out surface area of one tube and then we will proceed to find out the number of tubes.

So, surface area of one tube you can consider as pi d 0 L effective. Here also you should consider L effective because whatever section of the tube inside the tube sheet it will not participate in heat transfer. So, considering effective length we can find out surface area of one tube as 0.311 meter square. Total heat transfer area is given to me like this, division of these two will give me 1672.3 number of tubes.

However, you understand that number of tubes will never be in decimal so if I consider next value to this it should be 1673, but here I am having 1-2 pass so I should consider at least even number of tubes, so 1674 will be the final value of number of tubes therefore it should be 1674. So, next we have to find out the bundle diameter and you can use this number of tube to find out tube bundle diameter expression is given to you that should be equal to d 0 N t / K 1 and power 1 / n 1.

So, this is basically corresponding to 1-2 pass. So, from this table you can find out that we have triangular pitch number of passes are 2 so these are the value of K 1 and n 1 as you can see here. So, considering these we can find out bundle diameter as 1084.7.

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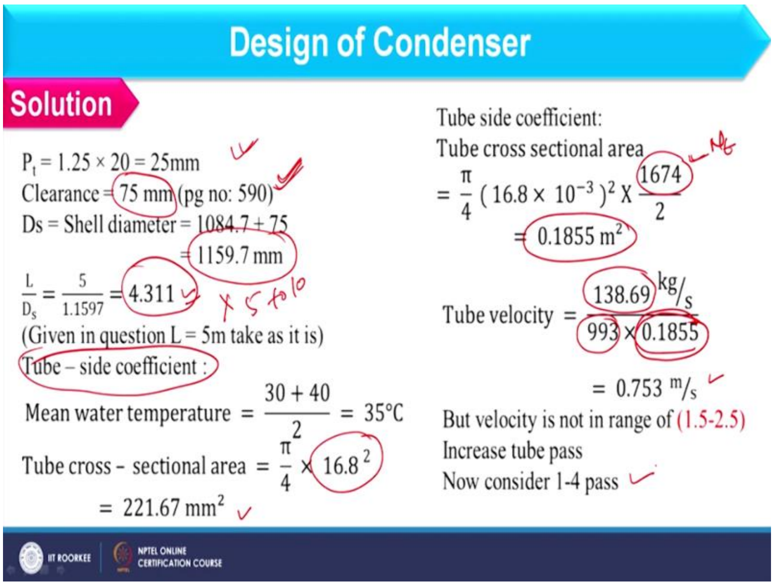

And after that we have to find out shell dia. So, to find out shell dia you should understand that clearance should be required and this clearance we can find out corresponding to bundle dia as well as the type of exchanger and that is the split ring. It is given already in the problem and that curve of clearance this you can find on page number 590 of Richardson Coulson volume 6 and it is from 4th edition of that book.

So, considering this clearance as well as bundle dia you can find out shell diameter as 1159.7 mm. So, once you have the shell dia you already know the length of the tube you can find out L / D ratio as 4.311 which is nothing, but 5 divisible by 1.1597 meter. So, if you observe this it is not in the range of 5 to 10. So, that should be in 5 to 10, but here length is given to us so we are not going to change this and next step is to find out tube side coefficient.

However, in actual condition the length and diameter ratio should be maintained within the range. Now discuss tube side coefficient and if you understand in the tube side we have water. So, we will follow the same procedure as we have discussed in shell and tube heat exchanger design where first of all we find out the velocity, we check the velocity and then we consider heat transfer coefficient calculation.

So, let us discuss tube side coefficient calculation. So, for this we need tube cross sectional area. So, this is basically ID of the tube and pi / 4 d i square will give you tube cross sectional area. Total number of the tubes will be nothing, but 1674 / 2 as 1674 is total number of tubes. So, you can find out cross sectional area of one pass as 0.1855 meter square and as far as tube velocity is concerned we already have found out the mass flow rate of water as 138.69 it should be divisible by density of the water as well as cross sectional area of one pass.

So, tube velocity you can obtain as 0.753 meter per second. Now here if you see this velocity is not in range. The correct range of water in shell and tube heat exchanger is 1.5 to 2.5 meter per second and here velocity is coming very less than that so what we have to do to bring this velocity within the range. Obviously, we have to increase the passes that we have discussed in previous examples many times. So, let us discuss passes as 1-4 instead of 1-2.

And if you understand we should not change the F t value because I am not changing here the shell passes and tube passes whatever I am considering F t factor will not going to change. Now what factors will be changed when I am changing the passes. First of all, it will change the bundle dia because K 1 and n 1 value will change and after that the shell dia and then we will see the effect of this 1-4 pass on velocity.

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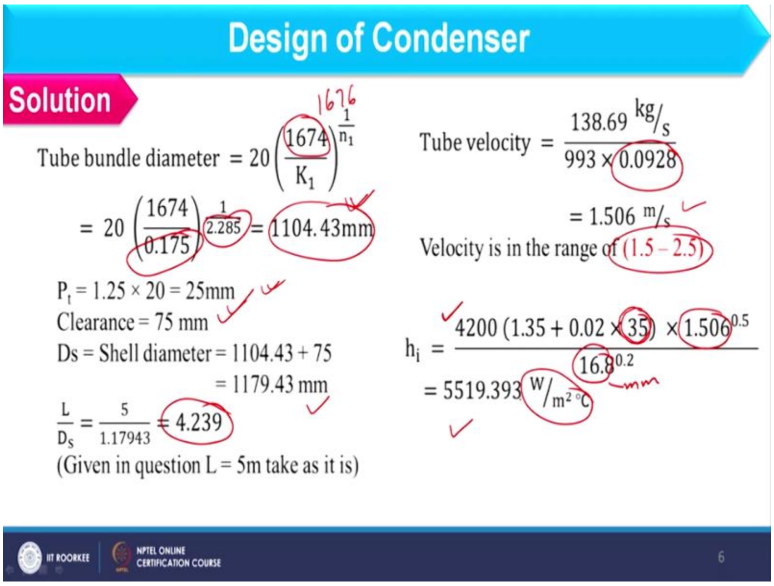

So, let us revise the bundle dia. Now, if I am having that bundle dia considering 1-4 pass you can find out K 1 and n 1 value according to triangular pitch and 1-4 pass you can have value as 0.175 like this as well as 2.285 like this. So, considering K 1 and n 1 value you can find out tube bundle diameter as this and further you have to see the clearance for spluttering exchanger and then you can find out shell diameter as 1179.43.

And considering this shell diameter you can find out L / D ratio it will be less than previous value and it is not again in the optimum range, but for now we are considering this as it is.

So, let us move towards the calculation of tube velocity. So, further as far as tube velocity is concerned we have to find out cross sectional area. So, whatever number of tubes are available to us that should be divisible by 4.

So, here you see the number of tubes are 1674 and if I divide these number by 4 it will come decimal value. So, actual number of tubes I should consider as 1676 so here instead of 1674 you should consider 1676. So, here we will have slight difference in bundle diameter so that variation you should consider please. So, if you see as far as tube velocity is concerned 1676 tubes are to be divided by 4.

And accordingly we can find out the cross sectional area of single pass and therefore we can consider the revised velocity which is coming out as 1.506 and this velocity you can find in the range. Now once I am having the right velocity we can find out heat transfer coefficient for water and if you understand we have a specific correlation for heat transfer coefficient of water and this correlation you can find in previous examples also.

So, when you are considering the average temperature of the water so that should be 35 this is the velocity of the water and this is ID of the tube in mm. So, considering all these value you can find out heat transfer coefficient in tube as 5519.393 watt per meter square degree Celsius. So, in this way you can find out heat transfer coefficient in water side or in tube side. Now, next we have to find out heat transfer coefficient in shell side for that you should understand the process of condensation in shell side.

So, it is basically the horizontally placed condenser where condensation is occurring in shell side and for that we should use the Nusselt equation. If you remember the previous lectures we have discussed heat transfer coefficient for each condition so here Nusselt equation will be applicable which is like 0.95 into properties and then we have N r dash power – 1 / 6. So that equation we can use.

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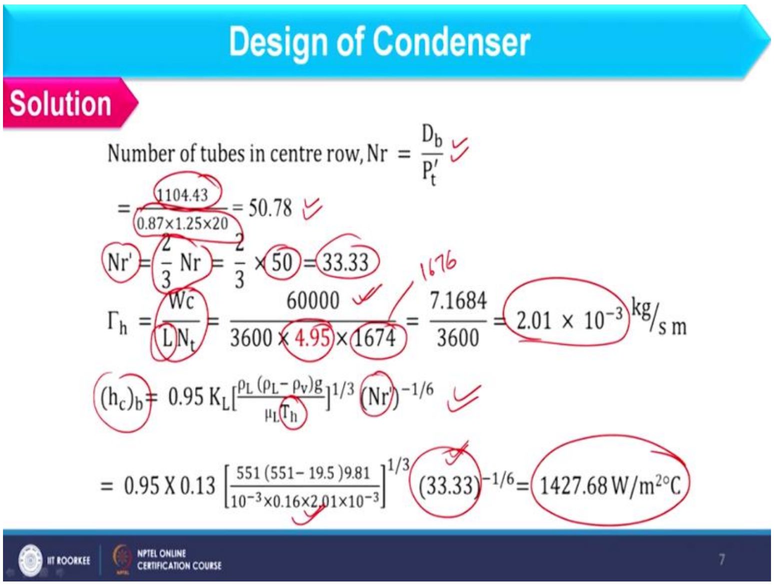

So, if you see the equation is given like this to us and here we have to find out gamma h this is not T h this is basically capital gamma h and further we have to find out N r dash. So, first of all let us calculate N r? So, N r will be what N r will be D b / P t dash. So, bundle diameter we have already obtained and that bundle dia will be divisible by P t dash and P t dash will be 0.87 into P t because I am considering triangular pitch.

So, here I am having number of tubes in center row that is N r as 50.78. Now here you should understand that N r is basically the number of tube rows which will never be in decimal. So, we should consider the correct value and for that purpose we have to round it off I should not round it up I have to round it off because bundle diameter is fixed. So, instead of 50.78 N r value should be considered as 50.

So, once I am having the N r value I should find out N r dash because that will be used in expression. So, let us see the N r dash calculation so that is very simple 2 / 3 into N r. So, here we can find out N r dash as 33.33 and here you consider N r as 50 which is just we have discussed. So, N r dash value we have obtained as 33.33 and next we have to find out gamma h that is the tube loading and that you can find out based on W c / L into N t.

And we have discussed this should be L effective considering all these expression and L effective length we can find out gamma h as 2.01 into 10 to the power – 3 and here also we should consider number of tubes as 1676. So, considering all these value we can find out h c b and if you see here I am putting N r dash in decimal only and the reason behind this is that N r dash is not a physical quantity which is existing in the bundle.

This is only to find out averaging of the bundle so N r will exist because that is the number of tube rows so that we have made in complete number. However N r dash whatever is obtained the same value you can consider to find out heat transfer coefficient. So, here I am having 33.33 and considering all these value in Nusselt equation you can find out heat transfer coefficient as 1427.68 watt per meter square degree Celsius.

So, once I am having heat transfer coefficient in tube side as well as in shell side and fouling coefficient is also given to us as 5,000 for both fluids thermal conductivity of the material is given to us.

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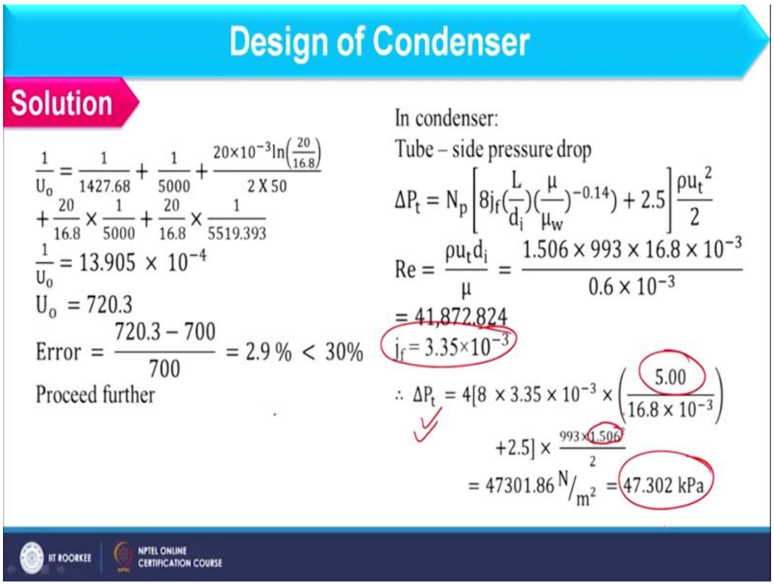

So, we can simply calculate overall heat transfer coefficient by a known equation with 5 terms and this equation we have discussed in shell and tube heat exchanger design as well as double pipe design also. So, you can consider this equation with different terms and overall heat transfer coefficient I found as 720.3 watt per meter square degree Celsius. So, once I am having the revised value I should compare with the assumed value.

And the error is found as 2.9% which is very less than 30% so we consider here the design is acceptable till now. Next step is to find out the pressure tube in shell side as well as in tube side. So, first of all we will focus on pressure tube calculation in tube side where water is flowing and as far as tube side pressure drop expression is concerned this expression you have already used in shell and tube heat exchanger.

So, depending upon the velocity you can find out delta P t, but before that you should know the value of j f and now we have passes as 4. So, to find out j f value I have to find out Reynolds number and you can use this expression to find out Reynolds number which comes out as 41872.8 and according to the Reynolds number you can find out j f value from the graph as this.

So, if you see Reynolds number is around 4.1 into 10 is to the power 4 so somewhere here the value will lie and if you consider you can consider this value as j f value. So, it means it will be around here. So, the value should be slightly lesser than 3.5 so we have considered 3.35 into 10 to the power – 3 as j f value. Considering all these parameters, you can find out pressure drop in tube side where complete length of the tube is considered because total length will give the pressure drop.

And here we are considering the velocity which is within the operating range and so delta P t value you can obtain as 47,301.86 Newton per meter square or 47.302 kilopascal. So, in this way we can find out tube side pressure drop.

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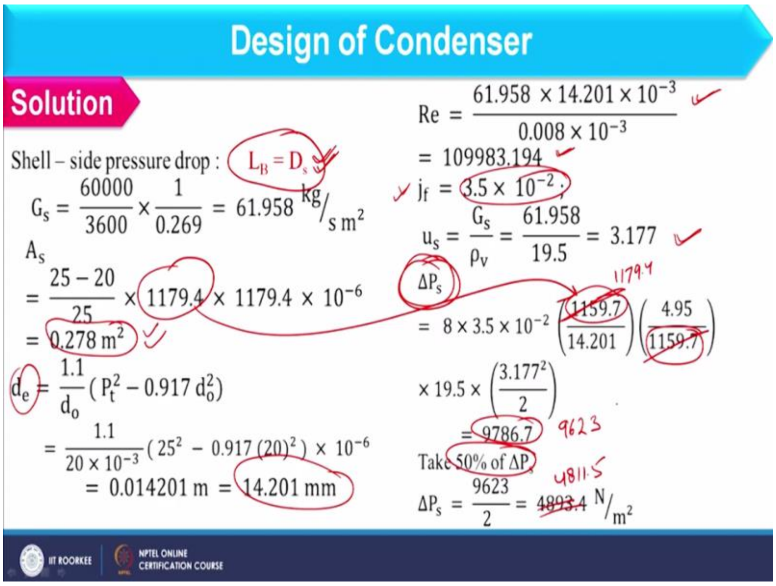

And now we will see the shell side pressure drop. So, to find out shell side pressure drop you have to fix the baffle spacing and that should be equal to shell diameter which is the specific change in construction of condenser and considering the vapour flow rate you can find out A s value because here you should consider Kern’s method to find out pressure drop in shell dia.

So, A s value you can obtain like this next we have to find out equivalent diameter which is coming out as 14.2 mm and after that we can find out Reynolds number and based on Reynolds number you can find out j h value. So, Reynolds number as coming as 1.099 into 10 is to the power 5. So, here I am having 10 is to the power 5 value and we have considered 25% as baffle cut.

So this value I can obtain and that value should come as 3.5 into 10 is to the power – 2 as you can see from here and finally you can find out velocity in shell side and then you can use this expression to find out pressure drop in shell side and here we can consider D s as well as baffle spacing as same, but here value should be written as 1179.4 as it is shown over here. So, this is the mistake however it will not affect the result as both shell diameter as well as baffle spacing are same.

So, if you consider this value you can obtain as 9623 and division of this will be equal to 4811.5 Newton per meter square. Why I have divided because you have to consider pressure drop in shell side as 50% of whatever you will obtain with vapour velocity as well as vapour properties. So, in condensation side we have to find out the pressure drop considering the vapour velocity as well as vapour property.

And accordingly you have to reduce the pressure drop in condensation side by 50%. So in that way you can find out the shell side. However here I am considering total length as L effective not the total length because that is not available completely for shell side. So, in this way you can design a shell and tube condenser.

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And here I am having some of the references.

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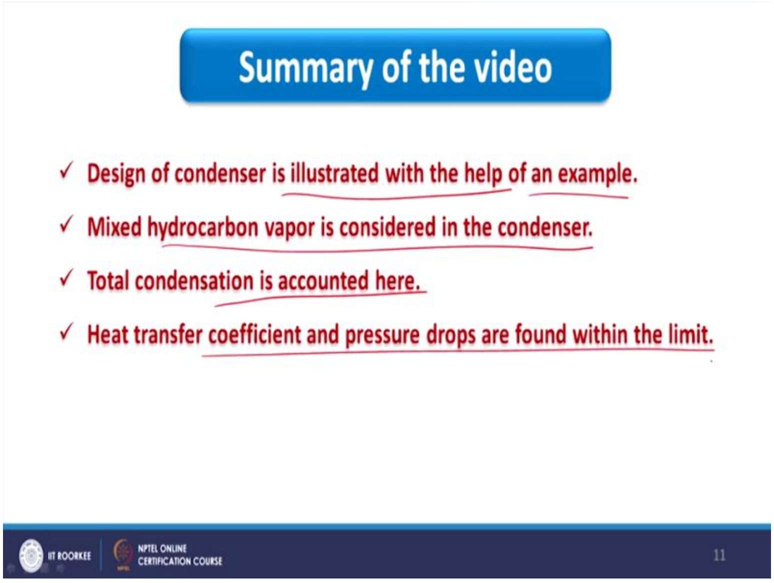

And now I am summarizing this video as design of condenser is illustrated with the help of an example. Mixed hydrocarbon vapour is considered as a feed, total condensation is accounted here, heat transfer coefficient and pressure drops are found within the limits and that is all for now. Thank you.