Process Equipment Design
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Lecture –37
Design of Evaporator-4

Hello everyone. I welcome you all in the 2nd lecture of 8th week of the course Process Equipment Design and this is 37th lecture of this course and here we are going to discuss design of evaporators. If you remember in the last lecture, we have discussed the design of evaporator and there we have derived the governing equation for triple effect evaporator system and solve those equation using Badger McCabe method.

So, in that lecture we have observed that for a single effect we require at least two equations. So, we were having 6 equations for triple effect evaporator system along with that we have 6 unknown. So, unique solution was there so that we have solved with the method Badger McCabe. So, in this particular lecture, we will discuss another method to solve the set of equations which we have developed in the last lecture. So, let us focus on the equation.

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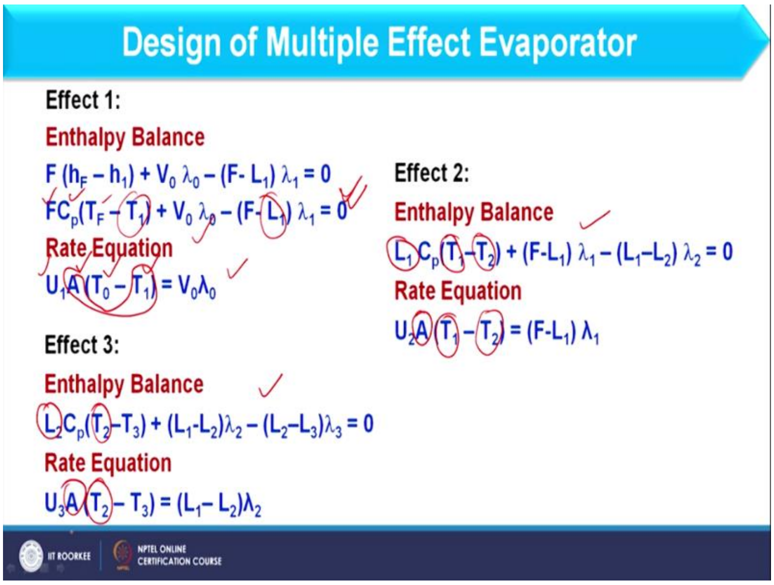

So, if you recall for triple effect evaporator system we have this type of equations. So, let us discuss these equation. I am not going to details about these equation because that you have already seen in the last lecture. Here, we will discuss the nonlinearity of the equation. Now, someone of you can ask that in all these 6 equation can we solve these equation using linear method where we can solve set of linear equation using Gaussian elimination method or Gauss-Jordan Method.

But if you see these equations are basically nonlinear in nature. Those methods like Gaussian elimination method and Gauss-Jordan Method these are applicable to solve N number of linear equations, but here we have nonlinear equation. So, first let us see how the nonlinearity will occur in these equation. So, if we focus on the first equation we have this equation. So, if you see in this equation FC p TF will be known to me only T 1 will be unknown.

So, this is not a nonlinear here lambda 0 is known to me V 0 is unknown to me and similarly in this term we have L 1 which is unknown. So, this equation is purely linear in nature. However, if I focus on second equation that is this equation here U 1 is known to me, A is unknown to me, T 0 is known to me however T 1 is unknown to me. So, if I consider this particular term the equation becomes nonlinear in nature.

So, in this way we can say that one equation is linear and one equation is nonlinear for first effect. Let us focus on the second effect. Here, if I consider this equation L 1 is unknown to me and T 1 and T 2 are unknown to me. In the similar line, this A and T 1 and T 2 all these are unknown to me. Further, if we focus on third effect equation we can have this equation and here L 2 T 2 are unknown to me.

And further we can consider A and T 2 as unknown terms. So, in this way we can find that some of the equation are linear in nature and some of the equations are nonlinear in nature. However, if I am having a set of equation and if a single equation in that set is found as nonlinear in nature we consider complete set as a nonlinear in nature. So, in this way we can say that these equations are basically nonlinear in nature.

So, we cannot solve these equations simultaneously using Gaussian elimination method or Gauss-Jordan Method. So, how I can solve these equation? One point is I can solve using Badger McCabe Method which we have already discussed in the last lecture. However, we have another method which considers all these equation simultaneously and that method is called as Newton-Raphson method which is very popular method to huge set of nonlinear equations.

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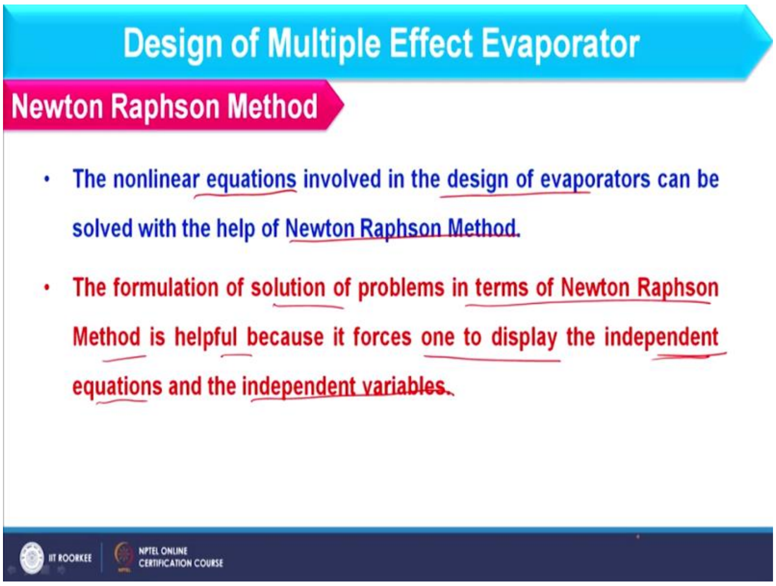

So, nonlinear equations involved in the design of evaporators can be solved with the help of Newton-Raphson method. And formulation of solution of problems in terms of Newton-Raphson method is helpful because it forces one to display the independent equations and independent variables. So, in this way it consider the solution where independent equation as well as independent variables are clearly shown. So, let us see how this method is used.

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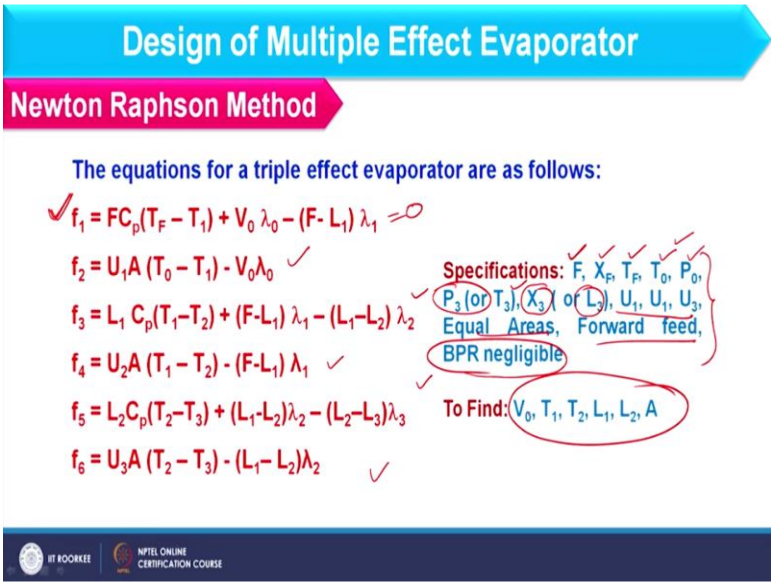

So, in this method first of all we give each equation as a function. So, if I am having 6 equation for triple effect evaporator system we can consider 6 function as I am having f 1 which is equal to the first equation, if you remember right now when it is at balance this equation should be equal to 0. So, f 1 value should be equal to 0, but right now I am considering that as f 1.

And similarly I am having f 2 which is the rate equation, f 3 then f 4 then f 5 and then f 6. So, all these 6 equations we have given a function as f 1 to f 6 and in Newton-Raphson method we will solve these f functions. In the similar line, you should aware that what are the known parameters and what are the unknown parameters. So, these parameters we have also discussed in the last lecture for triple effect evaporator system.

So, let us recall that once and then we will start the method Newton-Raphson. So, as far as specifications are concerned all these parameters are known to me like feed flow rate, feed concentration, feed temperature, steam temperature and steam pressure, last effect temperature or pressure and we also know the product concentration or the product flow rate and all overall heat transfer coefficients we consider equal area.

Forward feed we have considered and we have neglected boiling point rise. So, in this way you can consider that we have 6 parameters which are unknown to me and all these 6 parameters we can find while solving these 6 equation simultaneously using Newton-Raphson method. So, let us see how this method works.

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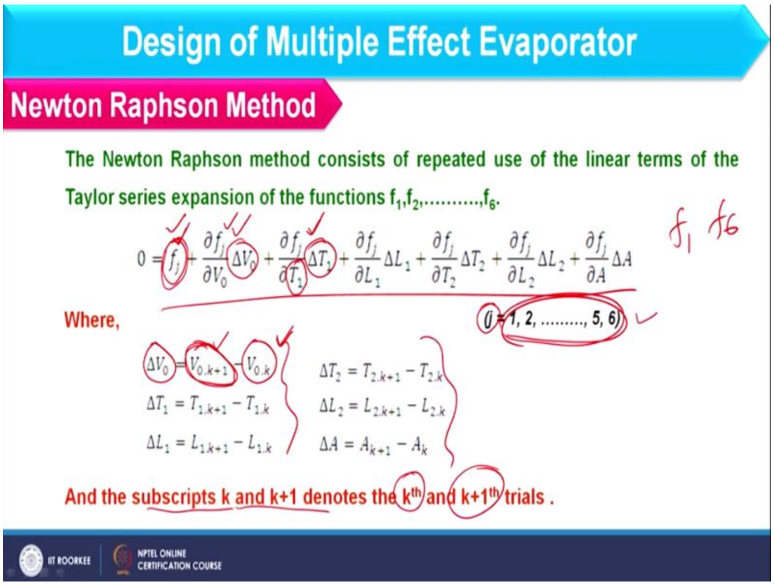

So, the first step of this method that is Newton-Raphson method we convert all equations f 1 to f 6 from nonlinear nature to linear nature and how we do this? We do that with the help of Taylor series expansion. So, I hope you all understand what is this series and how we expand the nonlinear equation with the help of this series and I am not going into detail of the Taylor series expansion.

Just I am considering the application of that Taylor series expansion to linearize f 1 to f 6 functions. So, let us see how we do this? So, if you consider I am having 6 equations f 1 to f 6. So, here we have given a subscript that we consider as j which varies from 1 to 6. So, here I am having Taylor series expansion of one equation and that we have represented as fj generally because we want to generalize it and j we can vary with respect to 1 to 6.

So, let us say the function is fj we will consider first derivative of this del fj / del V 0 delta V 0. So, basically what I am considering if you focus on Taylor series expansion it has the function only. It has first derivative of the function, it has second derivative of the function and so on depending upon the variables. So, here I am having 6 variable and for easiness we consider up to first derivative only.

So, if I am having function like fj, so first derivative of it I have considered as del fj / del V 0 into delta V. Second will be with respect to second unknown so that term will be del fj / del T 1 into delta T 1. In this way we can consider Taylor series expansion for 6 different variables considering only first derivative of it and we can have the function also. So, considering this expansion we can linearize the nonlinear equations.

And whatever linear equations are there that term will remain as 0. So, that we will consider further. So, in this equation let us discuss other parameters such as delta V 0 and other parameters. So, if I consider delta V 0 that is basically the difference of V 0 k + 1 – V 0 k. It means whatever the value of V 0 is in k + 1th iteration that should be deducted with the value of V 0 at kth iteration.

So, in this way we consider all unknowns. So, here we can consider subscripts k and k + 1 as kth and k + 1th trial or k + 1th iteration. So, in this way we consider the difference of variable in two consecutive iterations. And this difference should remain 0 when I am having perfect solution. So, let us focus on this method further.

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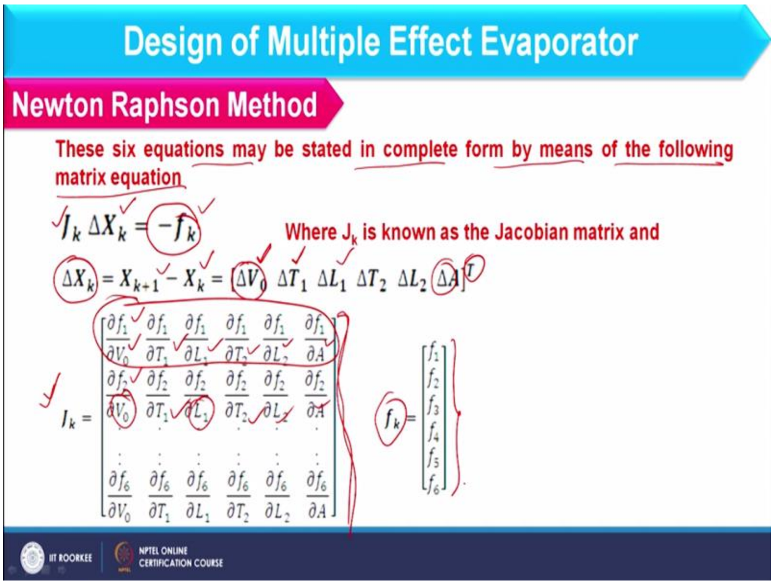

So, these six equation may be stated in complete form by means of following matrix. So, instead of showing these equation individually we can solve that with the help of matrix which is easier for us. So, let us make the matrix and that matrix we consider as the Jacobian matrix. So, here I am having the Jacobian matrix that is capital J k into variables that is delta X k and here I am having the function value.

And if you recall the Taylor series expansion it was added with the derivative term. So, here I am having the minus fx value. So, if I consider the Jacobian matrix that will be in terms of all derivatives like delta f 1 / delta V 0, delta f 1 / delta T 1. So, first row basically consider the first function depending upon all 6 variables. So, similarly second row consider second function with respect to all variables.

In the similar line I can consider all 6 functions depending upon 6 variables. So, let us see what is delta X k. Delta X k is basically the difference in two consecutive iteration and if I am considering k it means the difference of k + 1th – kth iteration. So, in this way I can represent delta X k as X k + 1 – X k and that will be transpose of difference of all variables in two consecutive iteration.

So that we can represent as delta V 0 to delta A and we consider transpose of that. In the similar line, I consider f k matrix and that considers all 6 function value f 1 to f 6. So, if you see this Jacobian matrix it basically includes all derivative terms. So, here it is basically including all linear terms not the nonlinear terms. So, once I am having the Jacobian matrix we represent each term of this matrix with the actual term which are available in 6 functions. So, let us see how to do that.

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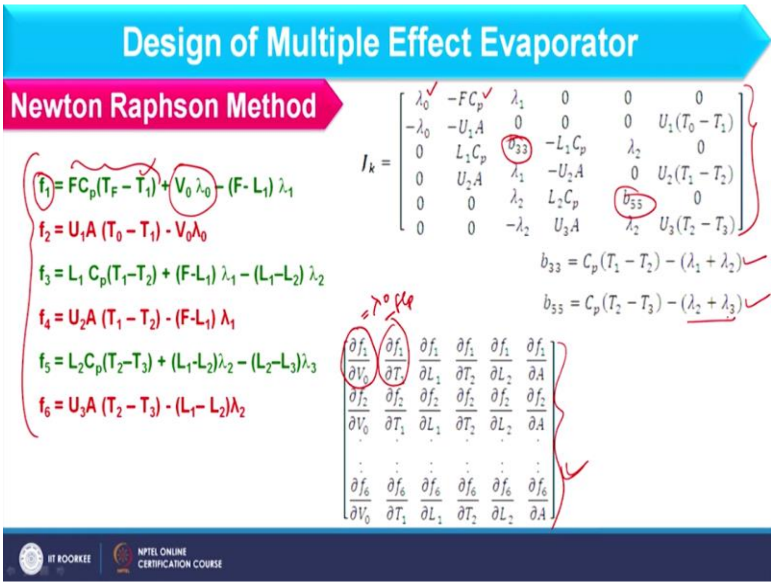

So, here you see I am having all 6 functions which we have also discussed previously and this is the Jacobian matrix. So, if I consider del f 1 / del V 0. So del f 1 / del V 0 will be for this function and if you see we are considering partial derivative so in this term no V 0 is there in this term I am having V 0 into lambda 0. So, value of this term will be lambda 0. In this way we can consider other term.

So, if I consider del f 1 / del T 1 so you see here I am having this value. So, it should be – FC p. So, in this way we can make the complete Jacobian matrix with the term and first term should be lambda 0 as we have discussed second term of first row is – FC p. In this way, you can consider all these terms and you can make the Jacobian matrix like this. If you differentiate all these term with the respective variable you can find this Jacobian matrix.

And here I am having some parameter which I have to expand. So, these parameters are basically b 33 you can see and b 55 because of long term I cannot put that over here. So b 33 you can consider as Cp T 1 – T 2 – lambda 1 + lambda 2 and similarly b 55 I am having Cp T 2 – T 3 – lambda 2 + lambda 3. So, in this way we can consider Jacobian matrix which includes all term without any variable.

So, this is basically you have linearize the nonlinear equation and these equation are basically set of linear equation. Now you can solve these equation using any linear method. So, let us see how to solve that.

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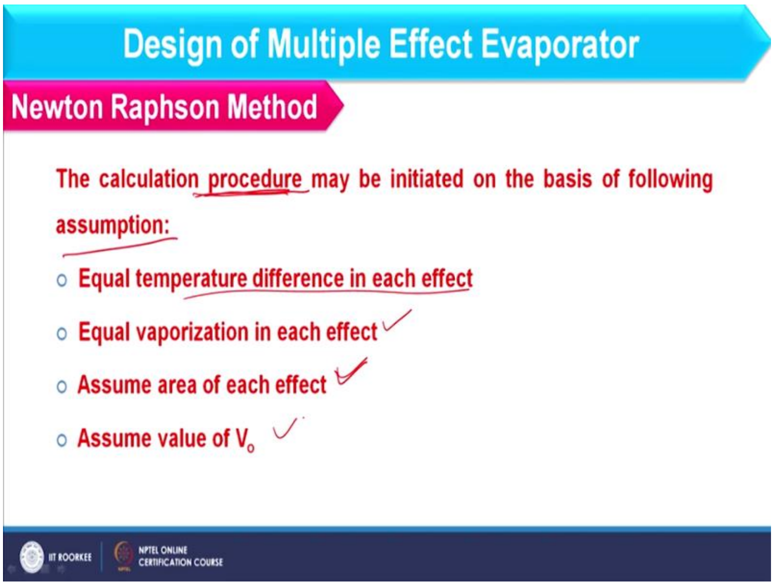

So, the calculation procedure which you can consider to solve set of nonlinear equation using Newton-Raphson method. You have to take some assumptions and these assumptions are basically equal temperature difference in each effect. So, that also we have consider in Badger McCabe method considering equal heat transfer in each effect. So, equal temperature difference it means delta T 1 should be equal to delta T 2 should be equal to delta T 3.

So that will be slightly different in comparison to whatever you have consider in Badger McCabe method. We have equal vapourization in each effect so V 1 = V 2 = V 3. In this way you can fix L 1, L 2 and L 3. You have to assume each effect area as equal and you have to assume value of V 0. So, considering all these initial value because first of all you have to initialize the values of unknown parameters and then only you can solve the function value.

So, in this way you can find the solution of Newton-Raphson method and so the solution of triple effect evaporator system. So, in this course we have consider Badger McCabe method as well as Newton-Raphson method to solve equation of triple effect evaporator system. So, from now let us focus on other topic considering multiple effect evaporator system and that is very important unit of this system which we consider as vapour liquid separator.

So, as you all know that whatever mixture is generated in heat exchanger because vapourization and boiling takes place in the heat exchanger and liquid is converted into vapour. We have to separate these liquid and vapour streams. So, the mixture of vapour and liquid exits the heat exchanger and enters to vapour liquid separator from where vapour and liquid streams are separated.

Vapour exits from the top and liquid settles down and it can be taken from the bottom of the separator.

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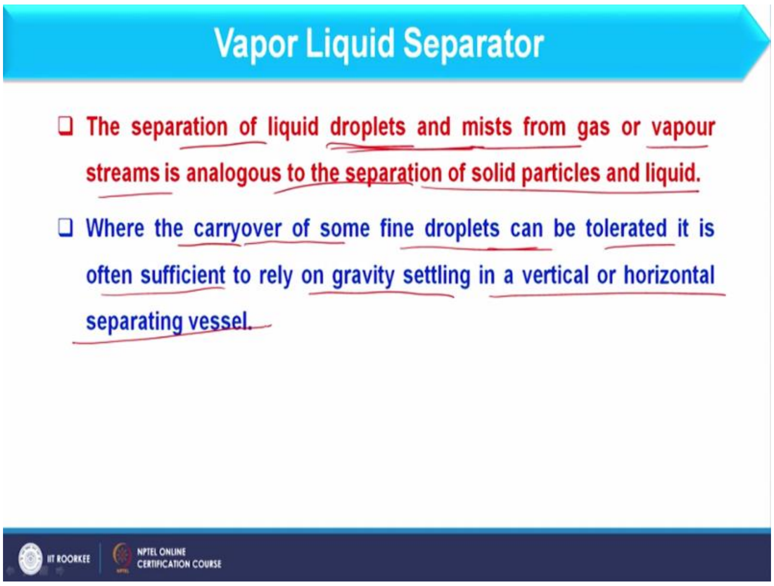

So, let us discuss some of the points related to vapour liquid separator. So, the separation of liquid droplets and mists from the gas or vapour streams is analogous to separation of solid particles and liquid. What is the meaning of that? When the vapour liquid mixture enters into the separator then what will happen because of the circular motion or we can say the centrifugal motion in the separator liquid settles down through the wall and vapour leaves up.

So, when the vapour goes up it takes some liquid droplet with it. So, vapour with liquid droplet we can consider separation of this in the similar line as we consider the separation of liquid containing solid particles. So, in vapour liquid separator where the carryover of some fine droplets can be tolerated. It is often sufficient to rely on gravity settling in a vertical or horizontal separating vessels.

So, here when I have told you that liquid is moving downwards so that happens with the help of gravity. So in that case we consider as gravity settling. Along with this whatever droplets is available with the vapour, it also disengage and settles down with the help of gravity. So, in this way vapour can be separated, but in this way some of the liquid droplets can be taken by the vapour.

And if we can tolerate we can separate with the help of gravity settling otherwise we have to make necessary changes in vapour liquid separator, so that liquid droplet will not move with vapour. So, how we do that? We do that by providing some meshing at the top of the vapour liquid separator.

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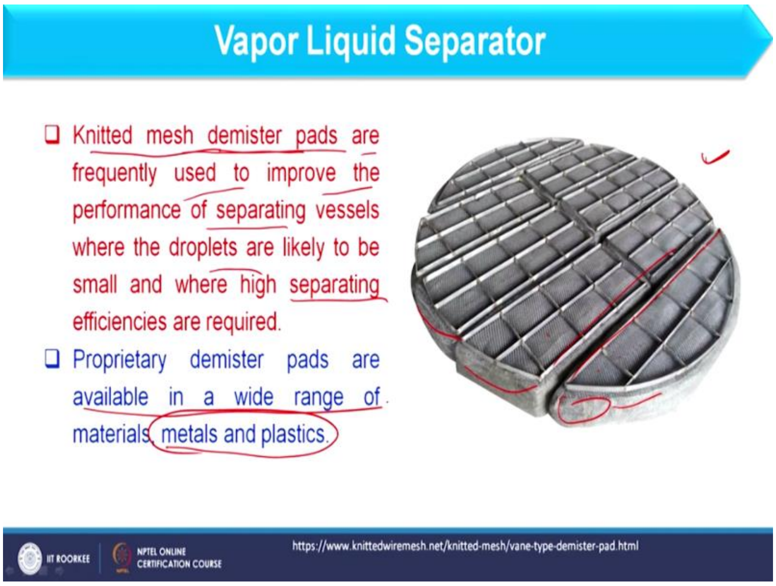

And that we call as knitted mesh demister pads as you can see here. So, here I am having this structure where this assembly is there where some small pores are available if you see this material and liquid droplet can be captured by this. So, knitted mesh demister pads are frequently used to improve the performance of separating vessels where droplets are likely to be small and where high separating efficiencies are required.

So, in this case small diameter of droplets can also be captured by this pads where high separation occurs between vapour as well as liquid and vapour whatever is exiting from this pad it is liquid free or liquid droplet free. So, as far as material of this pads are concerned these are basically made of metal and plastic and these are available in wide range of the material including metals and plastics.

So, you can use these pads to capture the liquid droplet and you can separate the pure vapour accordingly.

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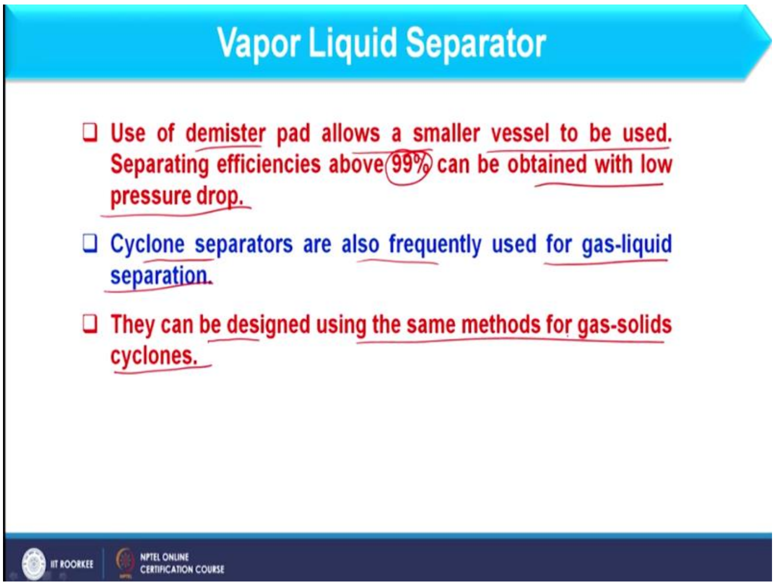

So, now discuss few more points about this like use of demister pads allows a smaller vessel to be used because whatever will be the diameter of the vessel the whole diameter should be covered by this pad. So, if diameter of the vessel will be smaller we can place this pad easily. So, in that case separation efficiency is very high like it is more than 99% and it is having low pressure drop also.

Further, in some of the cases cyclone separators are used frequently for gas liquid separation. So, that cyclone separator which works with the centrifugal action where liquid is available at the inner wall and through that wall liquid settles down. And that somehow happens also in vapour liquid separator because feed enters into vapour liquid separator tangentially. So, some of the separation occur through this section.

However, if vapour contains liquid droplet that can be trapped by demister pads. So, we can also consider cyclone separator as well as that vapour liquid separator with demister pads. So, as far as vapour liquid separator is concerned it can be designed in the same line as we design gas solid cyclones.

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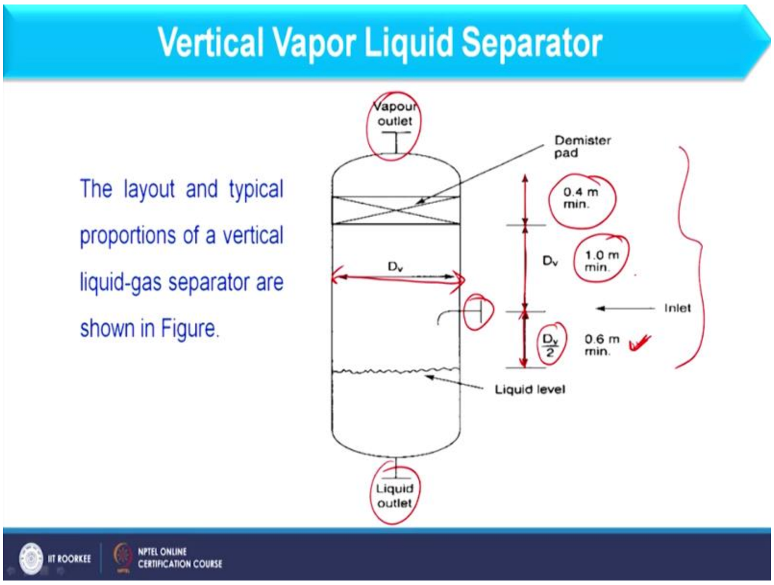

And here we are having some of the dimensions related to vertical vapour liquid separator and this is the layout of this. So, if you consider here we can have liquid outlet and vapour outlet and diameter of this column is Dv. So, if Dv is the diameter we can consider this as a feed inlet. So, distance between feed inlet as well as demister pad is Dv and above that we can consider 0.4 meter minimum as the height.

And the distance between liquid level as well as feed inlet is Dv / 2. So, accordingly we have to design the system considering these guidelines. So, here you see Dv is consider as 1 meter minimum and this should be 0.6 meter minimum. So, if I consider this then then Dv should be 1.2 meter in this way we can consider different dimensions.

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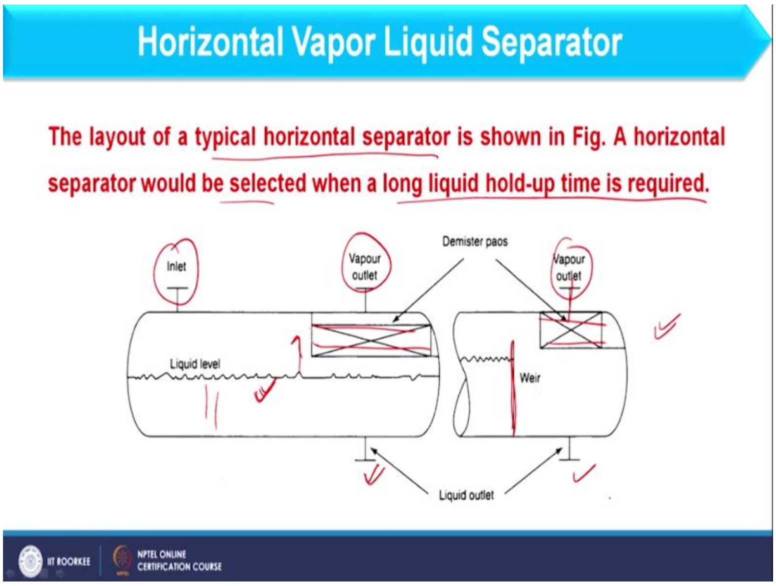

And now we will focus on the horizontal vapour liquid separator. So, layout of a typical horizontal separator is shown here. A horizontal separator would be selected when long liquid holdup time is required. So, in this case you can consider larger volume and liquid holdup is required much time. It means it has more residence time and demister pads are placed at the top of it as we have discussed in vertical vapour liquid separator.

So, vapour exits from the top, but from two different nozzles because of its size and liquid is also exiting from two different nozzles. However, inlet is one only. So, liquid settles down, vapour moves up and then vapour exits through this demister pads and here we have the weir to check the liquid level and so in this way we have discussed the horizontal vapour liquid separator.

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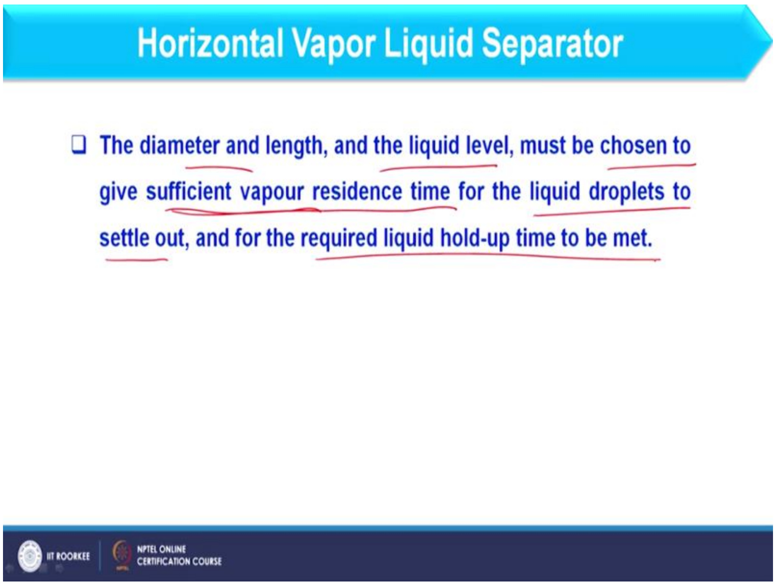

And now we have few more points about this horizontal vapour liquid separator as the diameter and length and the liquid level must be chosen to give sufficient vapour residence time for the liquid droplets to settle down and for required liquid holdup time to be met. So, in this case we have specific D / L ratio. So, what is this ratio is that we will discuss in the next slide.

And as far as this ratio is concerned the most economic length to diameter ratio will depend on the operating pressure and these operating pressures are.

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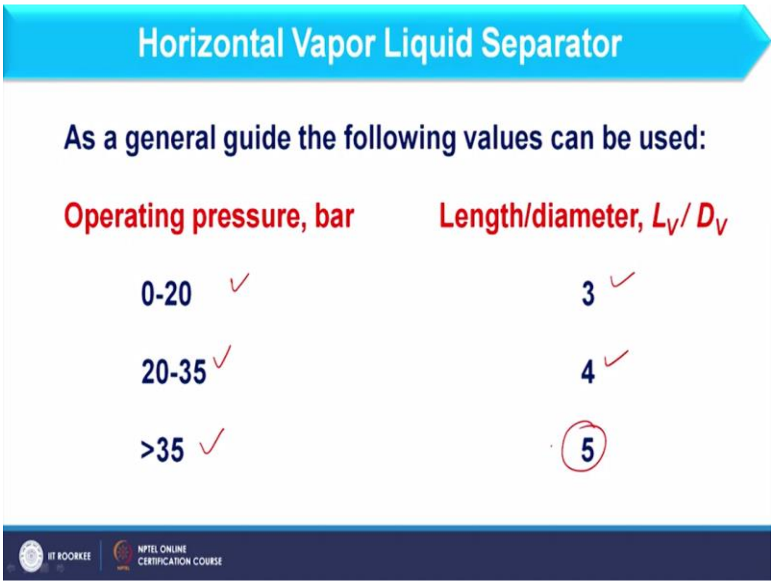

So as far as operating pressure is concerned if it varies from 0 to 20 bar we can have L / D as 3, 20 to 35 bar we can have 4 L / D ratio and similarly if it is more than 35 bar we can consider L / D ratio as 5. So, in this way you can decide height as well as diameter of the horizontal vapour liquid separator. And vertical vapour liquid separator dimensions we have already discussed and in this way you can design these seperators.

So, in this lecture we have discussed Newton-Raphson method, vapour liquid separator and in next lecture we will focus on some of the examples related to triple effect evaporator system. And that is all for now. Thank you.