**Process Equipment Design**
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**Lecture –51**
**Distillation Column – 4**

Hello everyone. Welcome to the 11th week of the course Process Equipment Design and here we are in lecture 51. So, in this lecture we will discuss the distillation column which we have already started from last week.

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So, here I am having the process design of this and in this process design we are going to cover plate efficiency in this particular lecture. So, let us start with the plate efficiency.

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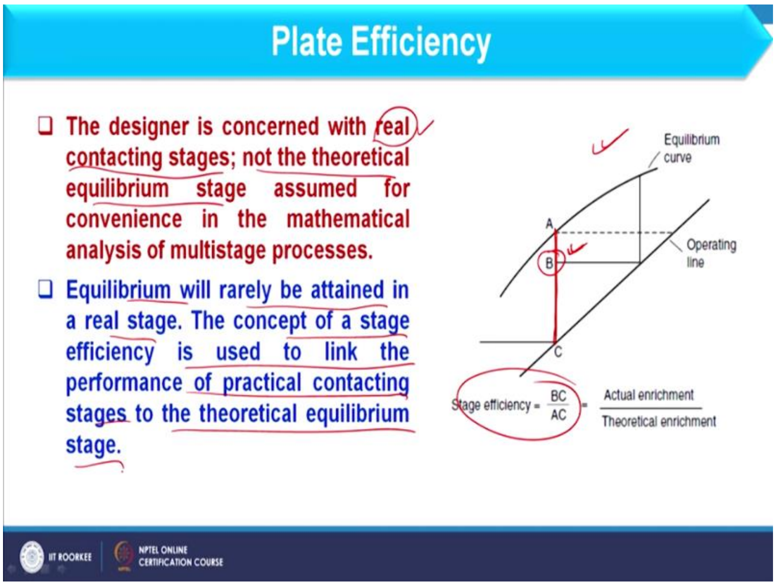

Now, as far as this plate efficiency is concerned why it is required? Because we do not reach up to the desired separation which should be reached in ideal condition. So, in that case if we consider this schematic there you see we can consider enrichment from C to B. However, I am suppose to consider the enrichment from C to A and that difference is basically considered in calculation and that is represented by stage efficiency.

So, the designer is concerned with the real contacting stages not the theoretical equilibrium stages because theoretically we consider that this C to A should be available. However, only we can reach up to B. So, based on this actual concentration or actual enrichment we should calculate number of trays. So, therefore the main concern of the design is with the real number of trays.

Further, equilibrium will rarely be attained in real stages the concept of stage efficiency is used to link the performance of practical contacting stage to theoretical equilibrium stage. So, this you can see how much we should enrich and how much we have enriched as far as concentration is concerned in the vapour phase. So, in that way we consider the plate efficiency and as a basis of that some information is already available with you.

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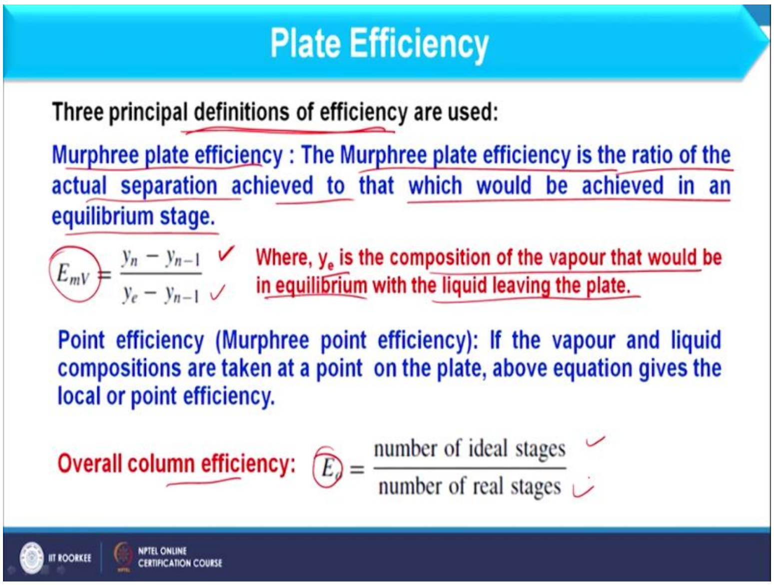


So, let us revise that and then we will discuss plate efficiency in detail. So, usually we have three principle definitions of the efficiency. The first one is the Murphree plate efficiency and this Murphree plate efficiency is the ratio of actual separation achieved to that would be achieved in equilibrium stage. So, that should be yn – yn – 1 divided by ye – yn – 1. So, in this way we consider the Murphree plate efficiency where ye is the composition of vapour that would be in equilibrium with the liquid leaving the plate.

So, I think this definition is known to you already and further we have the point efficiency and that is again the Murphree point efficiency because the scientist name was Murphree. So, if we know the vapour and liquid composition at a particular point in the plate we consider that as point efficiency. And if I am considering that it is available throughout the plate or we can say homogenously available over the plate we consider that as plate efficiency.

And further we have third definition and that we call as the column efficiency and that is basically represented by Eo which is equal to number of ideal trays divided by number of real trays or stages. So, in this way some of the definition about plate efficiency we already know.

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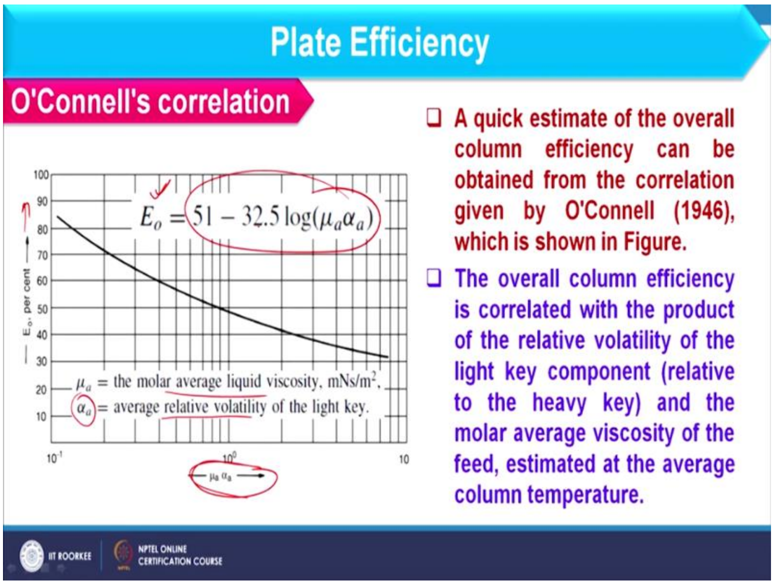


And now we will consider the plate efficiency depending upon different method. So, first method we have is given by O'Connell. So, that is O'Connell's correlation and that is for column efficiency or basically overall column efficiency. So, let us see how to use this correlation? So, it gives basically quick estimation about column efficiency and it is given by this graph where on y axis we have E 0 that is the column efficiency. On x axis we have mu a alpha a. So, mu a is basically molar average liquid viscosity.

And alpha a is basically average relative volatility of light key with respect to heavy key and this E 0 we can also calculate from this expression. So, this is basically the method to calculate column efficiency and then we will solve one example on this method.

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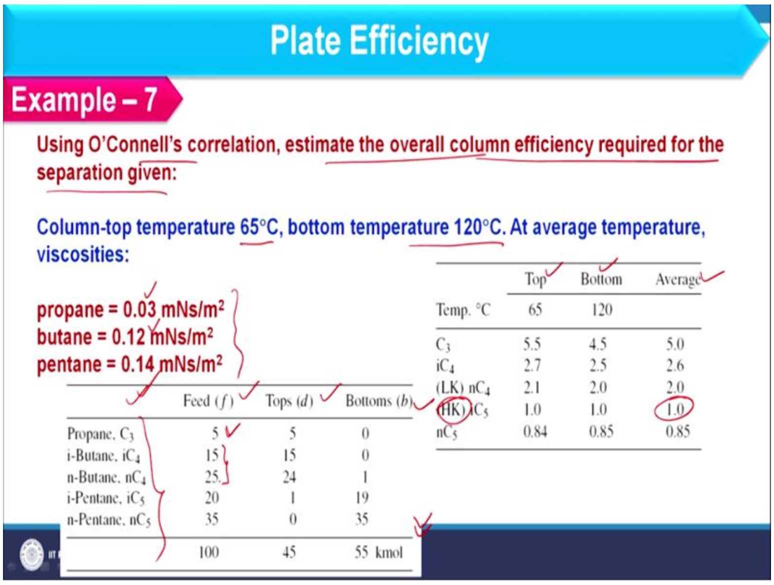


So, here I am having 7th example. Actually these number of examples are as per the example I have used in distillation column. If you consider the first lecture of the distillation column from there you can find example 1 or maybe in the next lecture to that and number of example is as per it is available in different lecture which we have discussed previously. So, here I am having 7th example.

In this example O'Connell's correlation is to be used to find out overall column efficiency which is required for the given separation and here we have the condition. The composition in feed, top and bottom and we have these five components and this example I have taken directly from the volume 6 book and here we have column top temperature 65 and bottom temperature 120.

At average temperature we can consider the viscosity of components that is propane, butane and pentane as this. We also need to find out relative volatilities. So, at top and bottom it is given we can find out the average relative volatility with respect to heavy key. So, as it is shown 1 over here. So, here we have to first find out the average molar viscosity of the liquid. So, if you see here I am having the propane which is the composition of propane is 0.05 and the viscosity is 0.03 and for butane we have viscosity 0.12 and composition is 0.15 + 0.25.

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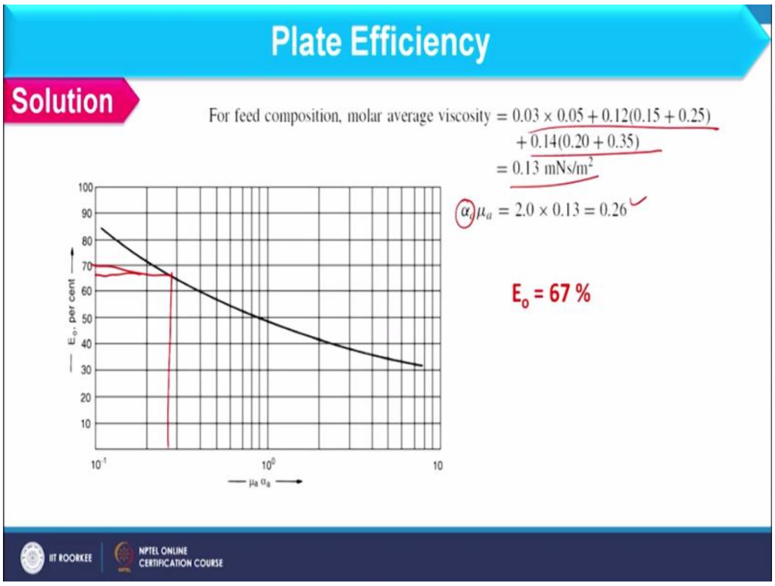


So, in this way you can find out the average molar viscosity of the liquid in feed and alpha a is already known to you. So, you can find out this factor which comes out as 0.26. So, if you see here I am having 1 and this is 2 so here I am having 0.26. So, the value you can obtain from here and that should be 67%. So, in this way you can simply calculate overall column efficiency.

And now we will focus on plate efficiency. So, here I am with AIChE method which is the detailed method to find out plate efficiency. Usually, if you consider Murphree plate efficiency there we consider only the composition depending upon the inlet stream as well as outlet stream for vapour.

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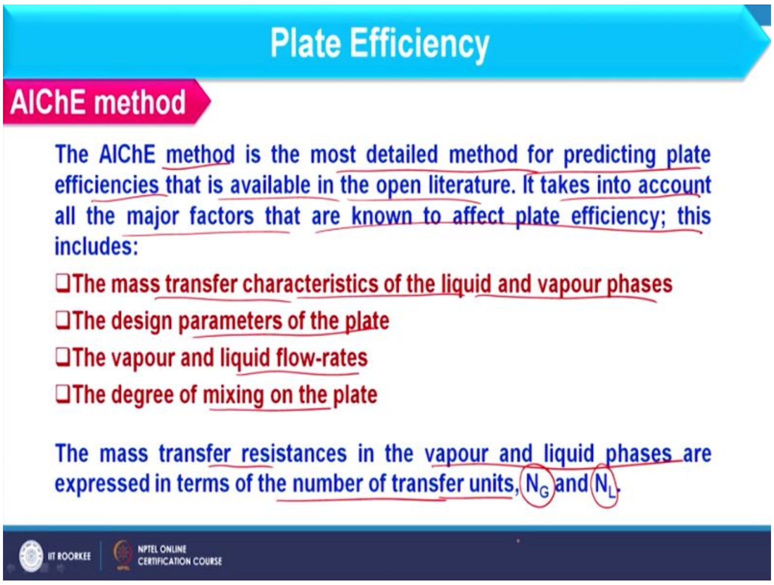

So, however in this AIChE method we consider other points also along with the concentration. So, let us see that. AIChE method is most detailed method for predicting plate efficiency that is available in open literature. It takes into account all major factors that are known to affect plate efficiency and this includes mass transfer characteristics of liquid and vapour phases, design parameters of the plate, vapour and liquid flow rates and degree of mixing on the plate.

So, you can see the number of factors are considered in AIChE method and so it is more accurate and detailed method. So, let us see how this method will be used. So, to use that method we should consider mass transfer resistances in vapour and liquid phases and these are expressed by number of transfer units that is N G as well as N L. So, we need to find out values of N G and N L and then we will consider the plate efficiency using AIChE method.

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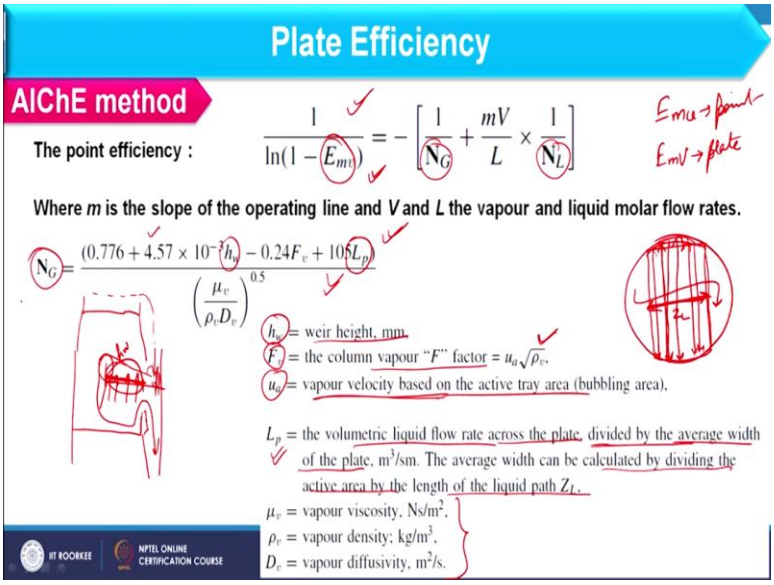


So, let us start this. As far as AIChE method is concerned, first of all we will consider point efficiency using AIChE method and then we will calculate the plate efficiency. So, let us see the expression of point efficiency first. So, here I am having the expression for point efficiency where E m v is the point efficiency. What is the difference in point efficiency and plate?

If I consider E m v if v is small it is point efficiency and if I am representing like this. If v is capital it is basically the plate efficiency. So, if you see this expression is equated to – 1 / N G + m V / L into 1 / N L. So, that is basically the transfer unit in gas and liquid phase. We need to find out the correlations of N G and N L and then we can use the m and V / L. These are basically the slope of equilibrium line and the operating line.

So, I think this information you know already. So, let us focus on the expression of N G. So, N G is usually given by this expression where N G = 0.776 + 4.57 into 10 is to the power – 3 h w. What these parameters are that we will discuss. So, here we have the nomenclature hw is basically weir height. Now, as far as this discussion is concerned first of all you should understand that how the parameters are available in actual column.

If I consider this plate another plate will be like this and here I am having the weir and this is basically the downcomer section. All these points we will discuss in detail when the plate hydraulic design will be discussed. So, this is basically hw weir height and this is the weir also so this is hw. So, next parameter we have is F v that is the column vapour F factor and that should be given by u a square root rho v.

And u a is basically vapour velocity based on active tray area. So, what is active tray area is basically this area only. Now, what will happen over here because when I consider the upper tray over here. So, upper tray liquid will move and liquid will fall in this zone and then it will move like this and it will move like this. So, this section is basically the active area where holes are available and vapour can enter from this section only.

Vapour will never enter from this section because here complete liquid is falling from the top. So, there mass transfer is not possible so this is only the active area. If I show in cross sectional point of view, this is the cross sectional of the column and you consider this is the inlet downcomer and this is the exit downcomer. So, this is basically the active area. So, how we will find out this ua that we will discuss.

So, first of all we will consider the active area value and volumetric flow of vapour we already know so based on that we can calculate vapour velocity. Next parameter is L p so that L p is the volumetric liquid flow rate across the plate. So, if you consider this plate L p is basically liquid flow rate across the plate and that should be obtained by dividing the volumetric flow by average width of the plate.

How we can find the average width? Average width is basically this section because if you consider this section it is more like as rectangle. So, this is the flow pattern over the plate and if I divide the active area by this distance we can simply find out this distance. I hope it is clear to you. So, this is basically Z L value. So, the average width can be calculated by dividing the active area by length of liquid path that is the Z L.

So, you can consider this length by dividing active area by Z L and Z L is this I have already explained and this will be more clear when you will see the example based on AIChE method. So, here we have the properties and based on that you can find out NG value.

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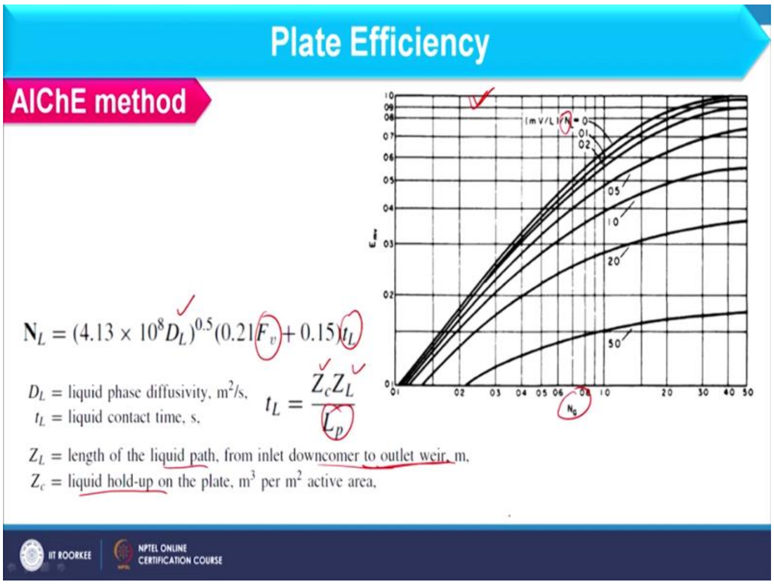


Instead of using that equation of E m v you can also use this graph, but in both cases we need N G as well as N L value. N G we have already calculated. This is the N L expression where F v we have already discussed in the last slide D L is the diffusivity of liquid and t L is the liquid contact time and that can be calculated by Z c into Z L / L p. So, Z L is the length of the liquid path from inlet downcomer to outlet weir that we already discussed in the last slide.

So, Z c is basically liquid hold up that is given in meter cube per meter square of the active area. So, it means that how much volume we can obtain over the plate. So, it will depend on the type of plate.

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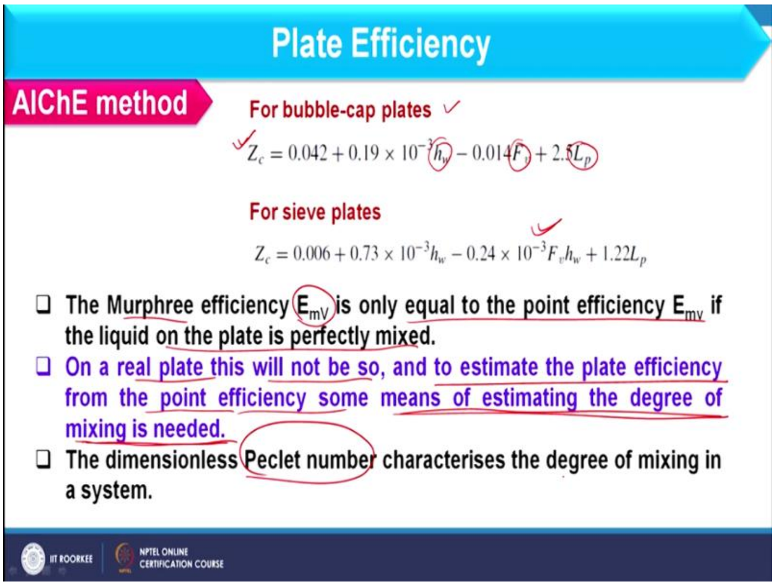


So, in that case we consider the bubble cap plate where Z c you can obtain by this expression where h w is the weir height Fv and L p all these we have already calculated and for sieve plate we can use this particular expression. What is this bubble cap, sieve plate and wall tray these trays we will consider when we will discuss the plate hydraulics. So, that will come in subsequent lectures.

So, there it will be more clear, but I hope you have the idea that what is sieve plate, what is bubble cap plate? Right now you please bear with it in subsequent lectures it will be clear. Further, Murphree efficiency that Emv is only equal to point efficiency if liquid on the plate is perfectly mixed. It means if homogenous concentration is there in the plate that will be in the plate as well as at a particular point.

So, we can say that these two efficiency will be equal in that case. However, on the real plate this will not be so and to estimate the plate efficiency from point efficiency some means of estimating degree of mixing should be consider and for that we consider dimensionless number that is the Peclet number which counts degree of mixing.

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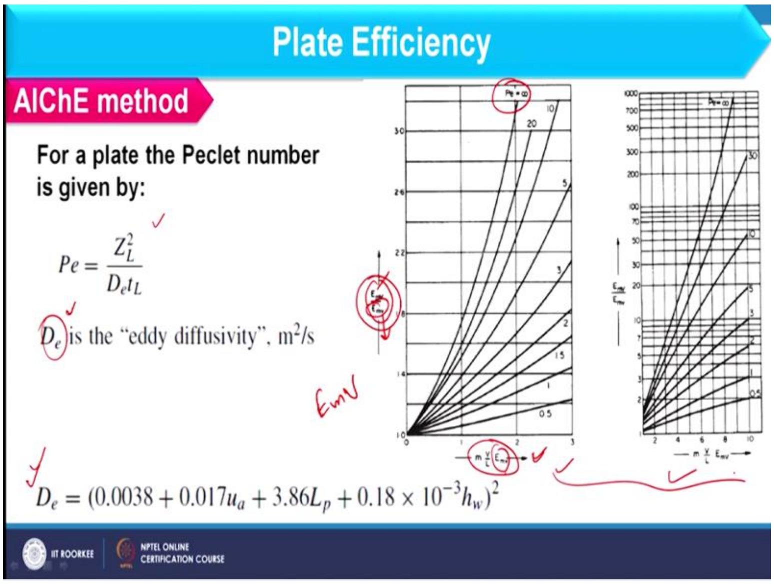


So, you can consider this Peclet number and that is basically Z L square / D e into t L and D e is basically the eddy diffusivity which counts the mixing over the plate and this is the empirical correlation to calculate eddy diffusivity. And once you have the Peclet number you can find out this m V / L E m v because E m v you can already calculate based on N L as well as N G value.

And here I am having E m v / E m v. So, this is the plate efficiency, this is point efficiency which you have already calculated. So, depending upon the Peclet number and this value you can find out the ratio of E m v be E m v small and this value you already know so you can calculate E m v value that is basically the plate efficiency and if you see this graph it is basically the extension of this these two graphs are same graphs.

So, any graph where the value will lie that you can choose. So, this is basically the AIChE method to calculate the plate efficiency.

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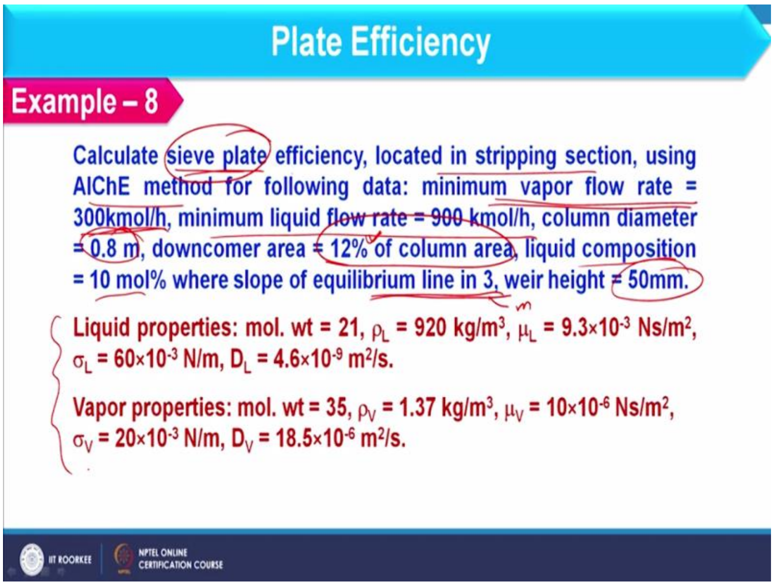


And now we will discuss this method based on example. So, here I am having example 8. In this example, we have been asked to calculate sieve plate efficiency. So, type of plate is fixed which is located in stripping section and this we have to carry out using AIChE method. Minimum vapour flow rate is 300 kilomole per hour, minimum liquid flow rate is 900 kilomole per hour, column diameter is given as 0.8 meter, downcomer area is 12% of column area.

So, what is this that we will discuss? Further, liquid composition is given as 10% mole where equilibrium line slope is 3 that is the value of m and weir height is given as 50 mm and here we are having some vapour as well as liquid properties. So, let us start the solution of this example. First of all, I need to find out active area.

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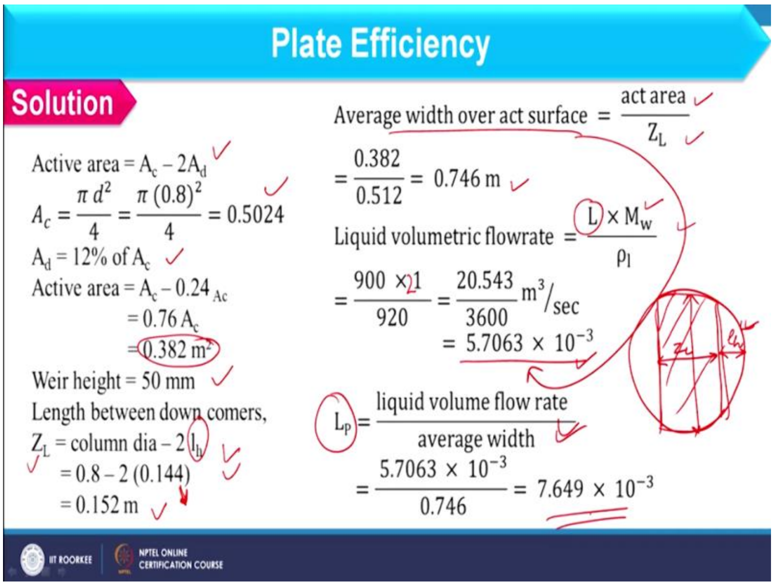

And as you know the active area basically the area between two downcomer that is the inlet downcomer and exit downcomer or we can say the exit weir also. So, this is basically the active area. Now, if you see in this problem we are given that downcomer area is 12% of the column area. Column area you can calculate because diameter is given to us as 0.8 meter. So, column area we understand and twice of downcomer area if we deduct we can find out the active area.

So, that is basically column area – 2 Ad that is downcomer area. So, column area you can find 12% of this is the downcomer area. So, active area you can calculate as 0.382 meter square, weir height is given as 50 mm. Now to calculate N G value what we have to find? We have to find F v factor, we have to find L p, we have to find h w. So, h w is already given as 50 other properties which will be used in this expression that you already know.

So, let us start the calculation of L p as well as Fv. So, to find out L p we should know Z L and to find out Z L we consider this expression. So, this how Z L can be counted if I consider the cross sectional area of the column further. Z L is basically this distance. So, if I know this distance that I can represent l small h I can simply deduct twice of this from diameter to find out Z L value. So, at present I am having l h value which is given as 0.144.

In next example I will speak that how this l h can be obtained. So, once you have this lh value you can find out Z L that is 0.152 so this is the simply calculation. Average width over the active surface that you can find because active area you know this is basically the average width because this we can consider as rectangle. So, we can simply divide active area by Z L. So, the average width over the plate we can obtain as 0.746.

So, further we can find out L p and for that we need liquid volumetric flow. So, molar flow rate is given to us and this is the molecular weight so that should be 21 not the 1. And so you can find out liquid volumetric flow which comes out as 5.7063 into 10 is to the power – 3. L p you can simply divide this value by the average width which you have calculated as it is shown over here. So, L p value you can obtain as 7.649 into 10 is to the power – 3.

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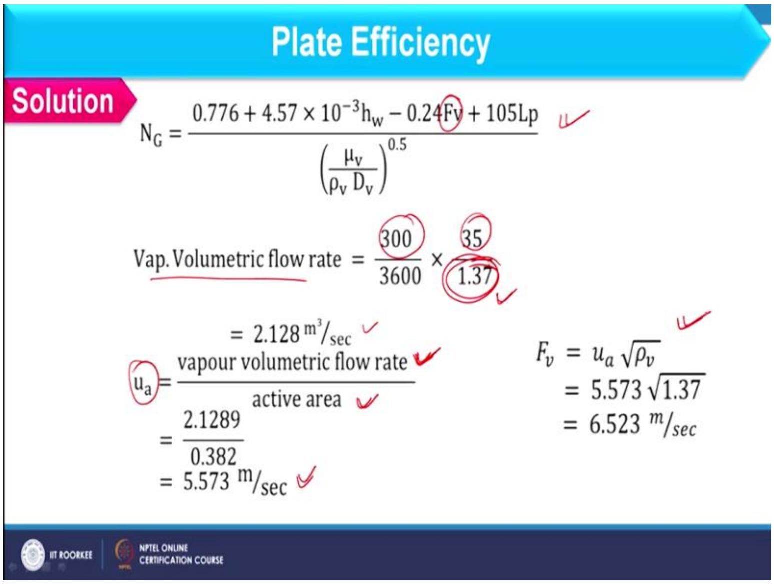


And we have the expression of N G where F v I need to calculate further. For this I need vapour volumetric flow. So, 300 is the molar flow given to us, 35 is the molecular weight and considering other parameters you can find out vapour volumetric flow as 2.128 meter cube second. This is basically the density of the vapour and considering the vapour volumetric flow you can calculate u a parameter that is the vapour velocity by dividing this with active area and active area you have already calculated.

So, ua value you can obtain as 5.573 meter per second and so you can calculate F v value. Now, you have all parameters based on which you can calculate N G value.

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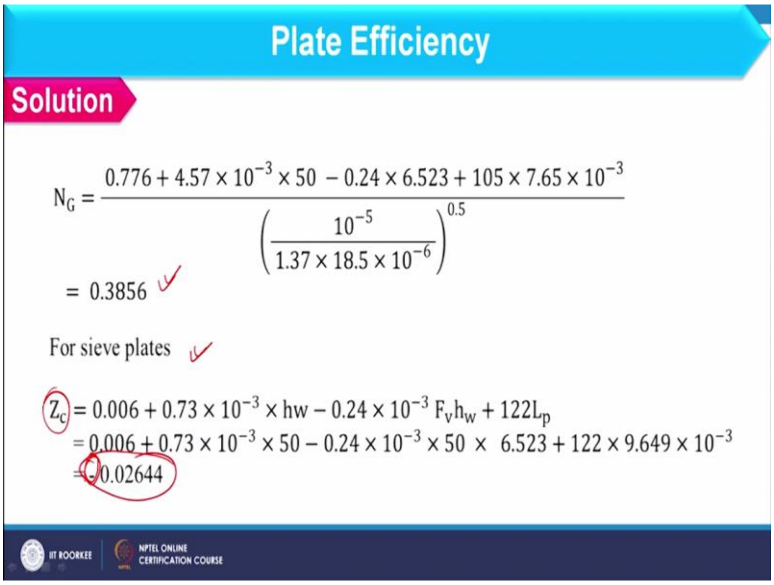


And so N G value you can obtain as 0.3856 and next we have to find out N L and for that I need Z c and for sieve plate because this plate is given in this problem you can find Z c value as 0.02644 and if you see value is coming as negative. However, Z c is basically the liquid hold up so that value will never be in negative. However, in this problem the parameters are selected in such a way so that Z c value is coming negative.

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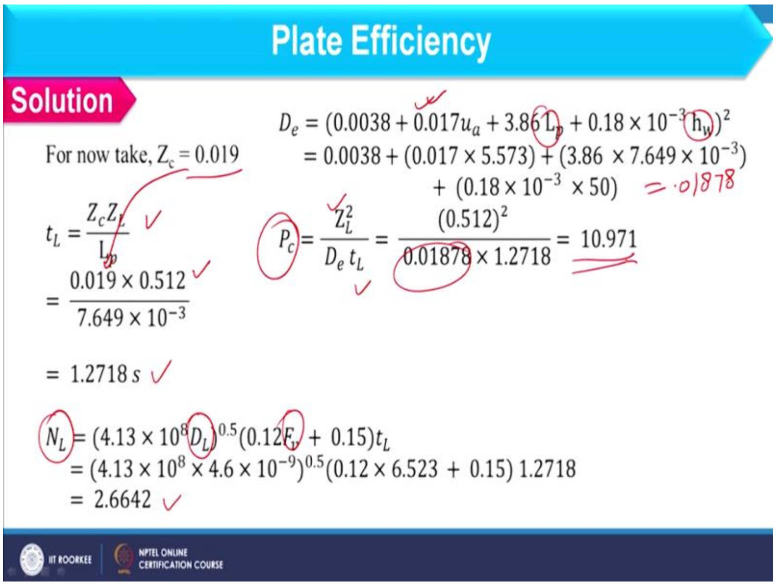


So, that we should avoid and therefore we will consider another value of Z c for further calculations and this value is 0.019. So, in that case we can calculate t L where Z c you can consider and Z L you can consider and L p and so t L you can obtain as 1.2718 seconds. So, considering all these values you can find N L because all these parameters you have already calculated and so N L can be obtained as 2.6642.

Further, we need to find out Peclet number and for that I have to calculate eddy diffusivity and for that we can use this expression where Lp hw can be used. Now, here you should keep in mind that when you are considering weir height that is h w. Either it is in the expression of NG or it is in the expression of D e you should consider that in mm because these are the empirical correlation.

And we should use the parameter as per the requirements of these correlations. So, here we can consider eddy diffusivity which can be obtained as 0.01878 when you solve these equation it should come out as this. And I know already Z L and t L value. So, I can calculate Peclet number which is coming out as 10.971.

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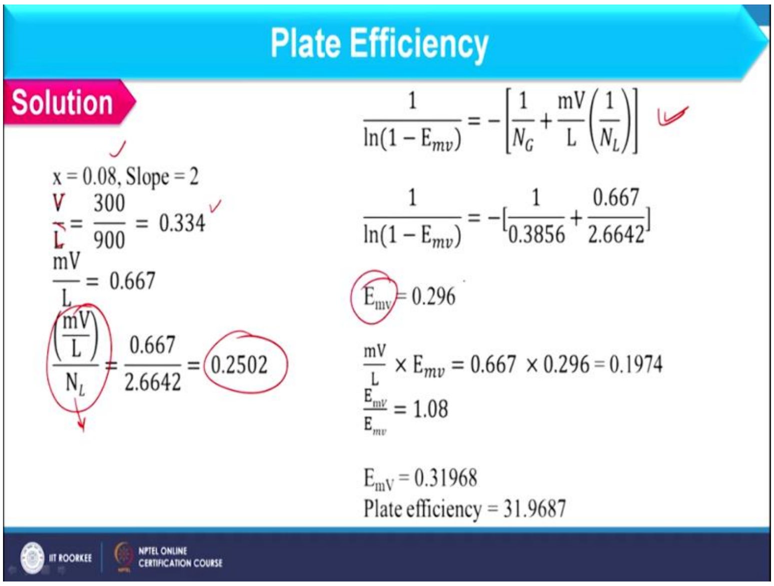


So, here I am having the slope which is given corresponding to this and V / L we can obtain from the given data and that is 0.334 considering m V and L you can find this expression which also includes N L value and the whole expression value can be obtained as 0.2502. So, now you can use this expression to find out point efficiency which is coming out as 0.296 and so here we can calculate point efficiency and you can use the graph further to find out plate efficiency. So, let us see that.

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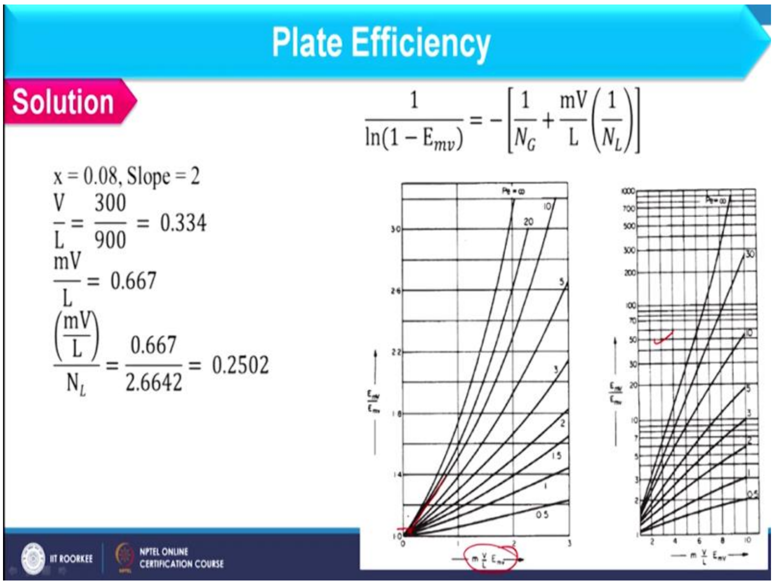


Here, I am having plate efficiency and this parameter I have to calculate first which I can obtain as 0.1974 and that value will lie somewhere here and Peclet number curve is here. So, the value will be very close to 1. So, if we will see E m v / E m v small the value should come as 1.08 that we can obtain by carefully seeing the graph. So, plate efficiency we can obtain as 31.9%. So, in this way we can solve the example.

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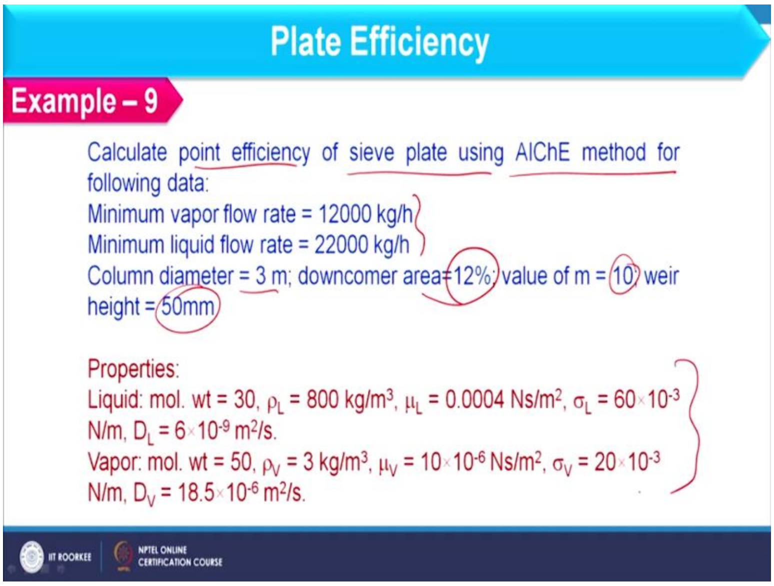


Now, quickly we will cover another example. Here, we have to calculate point efficiency for sieve plate considering AIChE method these are the flow rates of vapour and liquid, column diameter is given, downcomer area is given as 12%, value of m is given as 10, weir height is 50 and these are some of the properties.

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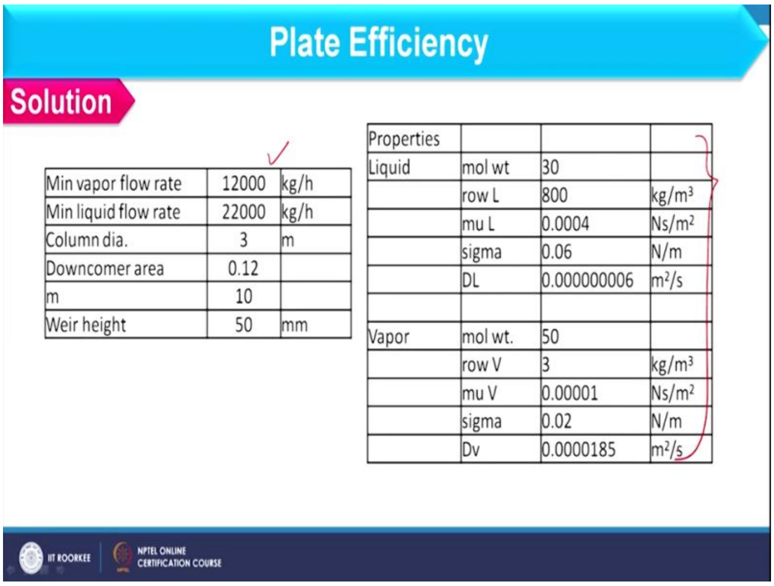


So, here you can see we have shown the given values. So, this is nothing, but the given data.

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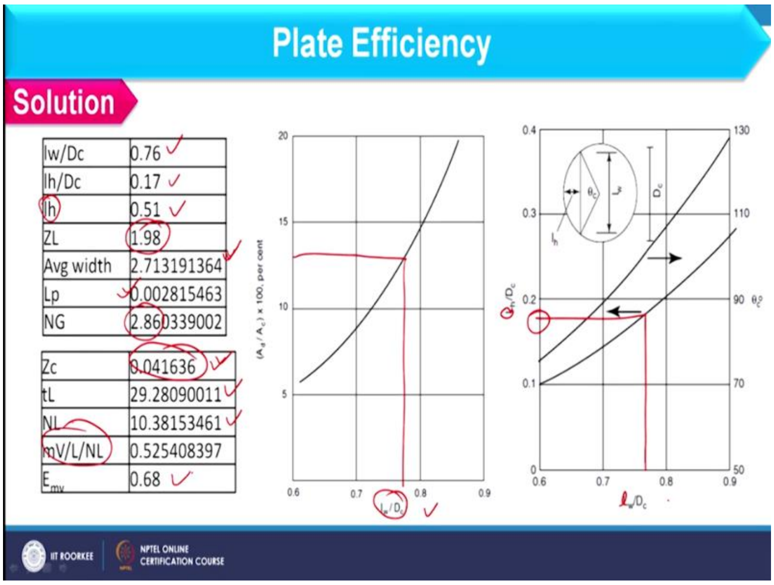


And here we have to find out first Z L. How I can find out Z L? I need to find out l h. So, if you consider the downcomer area is 12% of the column area. So, if I consider this graph here it is around 12% and corresponding to this I can find out l w / D c which should come as 0.76. So, l w / D c we can use in this graph where this is basically small l only and this is the small h only.

And 0.76 value if I consider we can use this graph and if I focus on this we can find small l h / D c as 0.17. So, accordingly I can find the value of l h. So, average width you can calculate by dividing active area by this Z L value and Z L value you can obtain considering l h as well as column diameter as we have discussed in the previous example. So, this average width you can find out which is coming out as 2.7.

I am not going into detail of active area calculation that I have already covered in the last example. So, accordingly you can find out L p as well as N G value. Z c if you consider here for sieve tray you can find the value which is coming correct as 0.04 and t L you can obtain like this and so the N L. And considering all these parameters you can find out point efficiency which is coming out as 68%.

So, in this way you can use AIChE method. I hope this method is clear to you and this lecture ends here. So, that is all for now. Thank you.