Process Equipment Design
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Lecture –55
Distillation Column – 8

Hello everyone. I welcome you all in this lecture which is 55th lecture of the course Process Equipment Design and here we are going to discuss distillation column process design. And if you recall the last two lectures of this course there we have discussed design of plate and we call it as plate hydraulic design. So, in this lecture we will illustrate the design of plate with the help of example.

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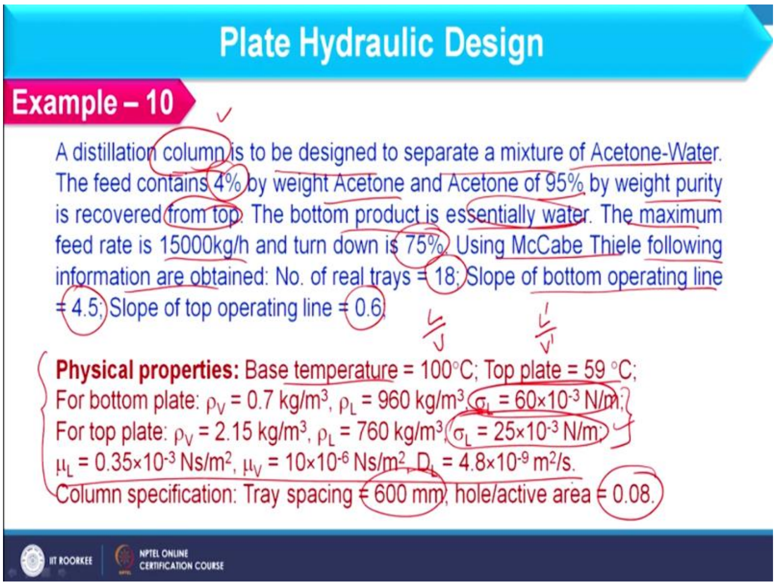

So, let us start this. So, here I am having example 10 actually this example number is as per the problem we have discussed in distillation column topic. So, if you see from the beginning in distillation column this is 10th example. So, in this example a distillation column is to be designed. It means we have to design the plate to separate a mixture of acetone water. Feed contains 4% by weight of acetone.

And from this 95% by weight purity can be recovered in distillate that is the top product. The bottom product is essentially the water and we can consider that acetone is not available in water which is the bottom product. So, the maximum feed rate here is 15,000 kg per hour 75% is the turn down ratio. So, minimum flow rate should be 0.75 into 15,000 of the feed.

Using McCabe Thiele method, following information we can obtain like number of trays are 18.

Slope of bottom operating line is given as 4.5 and slope of top operating line is given as 0.6. So, as far as these slopes are concerned for top operating line it should be L / V and for bottom it should be L dash / V dash. So, along with this we have some physical properties also such as base temperature and top plate temperatures are given. For bottom plate and top plate properties are given.

So, here you should keep in mind that surface tension is 16 into 10 is to the power – 3 and at top temperature it is considered as 25 into 10 is to the power – 3 Newton per meter. Other properties are given like this and column specification that is tray spacing is mentioned as 600 mm and hole to active area is 8% or that is 0.08. So, in this way you consider the complete problem for plate design and what we have to estimate let us see that.

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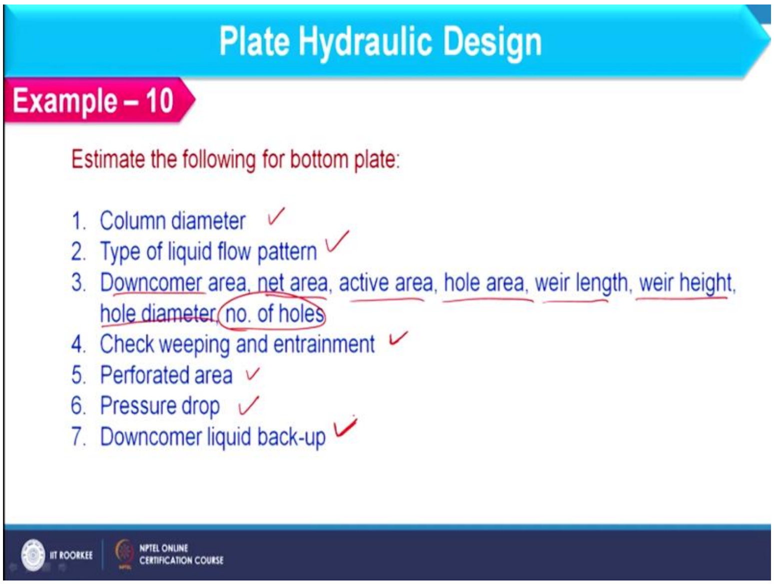

First of all we have to calculate column diameter then decide liquid flow pattern and then decide the plate layout that is downcomer area, net area, active area, hole area, weir length, weir height, hole diameter and number of holes. After that weeping and entrainment condition should be checked and maintained if these are not within the permissible range and next we have to find out perforated area then the pressure drop and then downcomer liquid backup.

So, you see all these parameters we have to calculate. So, these particular calculation should be carried out for bottom plate not the top plate. So, what change will occur when we consider bottom plate as well as top plate that we will discuss while solving this problem. So, let us start with column diameter calculation, but before that we have to find out vapour liquid flow rate in top region as well as bottom region. So, let us see that.

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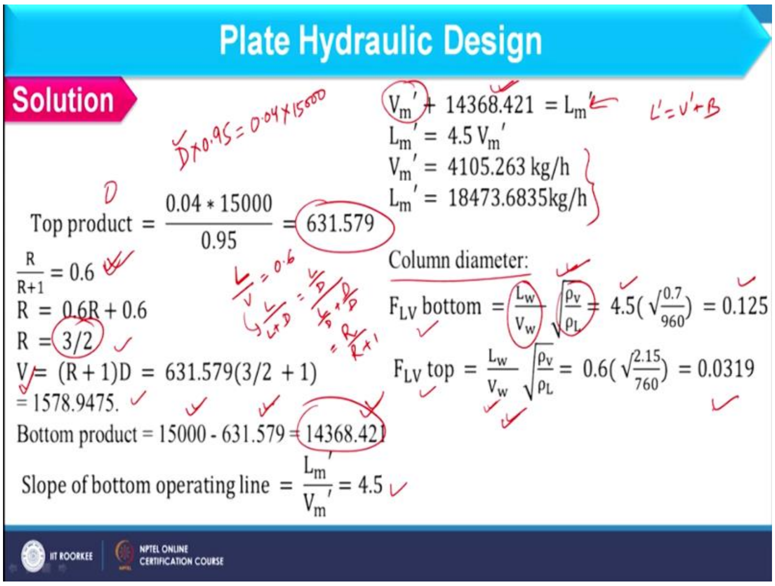

Now when we consider the distillate that is basically the top product in this we can make the balance like D into 0.95 that is 95% of acetone is recovered and in the feed 4% is available so that should be 0.04 into 15,000 that is the total feed. When you solve this you can find out you can find out total top product as 631.579 kg per hour and here we are given by R / R + 1 as 0.6.

How we can consider this because top operating line slope is given to us that is L / V should be 0.6. So, here we can consider L / L + D we can write V can be written like this. So, further if I consider L / D divided by L / D + D / D we can simply show it as R / R + 1. So, that should be equal to 0.6. From this we can calculate the reflux ratio that is R and it should be 1.5 and so we can calculate vapour flow rate in top section.

So, that should be R + 1 into D so value should come as 1578.9475 kg per hour. Now, if you see total feed available to us is 15,000 from which this much we can recover through this distillate. So, this much we can obtain as bottom product. So, further we have to find out flow rates of liquid as well as vapour available at bottom section of the column. So, let us see how to find this.

We are given the slope of bottom operating line and that should be L m dash / V m dash and when we make the balance L dash should be equal to V dash + B. So, L dash we can consider over here V dash we have to find out and this bottom flow rate is already we have calculated. So, considering this you can find out V m dash as well as L m dash as these values. Now, once I am having the flow rates of liquid and vapour at top of the column and bottom of the column I should start the calculation of column diameter.

So, for that we should find out FLV value and then we will further calculate other parameters. So, let us start the calculation. As far as column diameter is concerned FLV we should calculate at bottom as well as at top and the expression is given like this. Now, if you see L w / V w at bottom as well as at top. So, these are nothing, but the slope of operating line. So, that we can consider as 4.5 properties are given to you. So, you can calculate FLV bottom 0.125 and top 0.0319.

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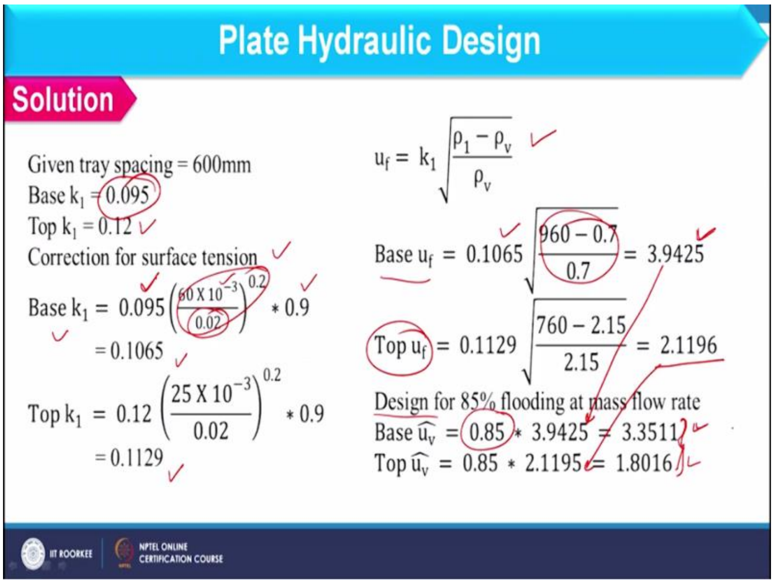

Now, once you have the FLV value at top as well as at bottom. We should further find out factor K 1 and all these values will be required to find out flooding velocity.

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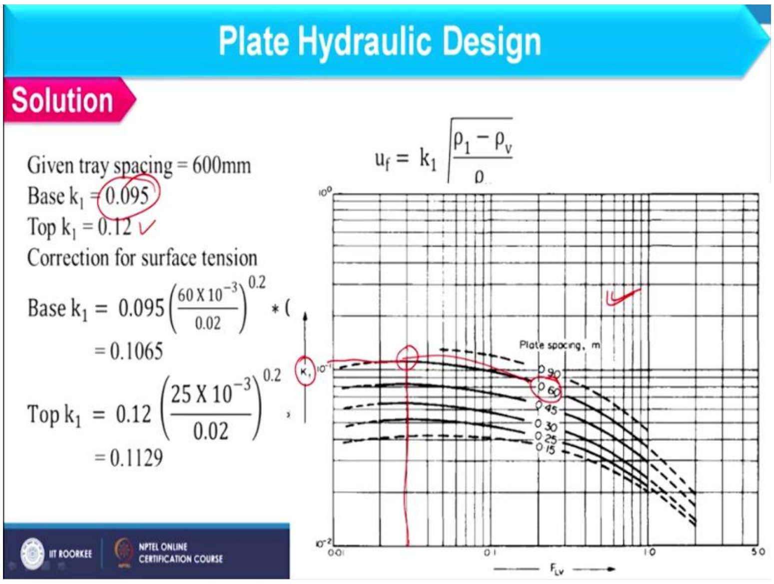

So, let us see how to see the value of k 1. This is the graph from which we can find out k 1 value and if you see as far as tray spacing is concerned it is given as 0.6. Now, if you see FLV value at top of the column so that should be 0.03 which we have just calculated. So, here we must have the 0.03 value and if we consider this we can find out k 1 value corresponding to 0.6 spacing as this.

So, value you can obtain as 0.12 at the top and similarly you can see the value of k 1 at the bottom. Now, once you have this k value from the graph you can correct this. Why you have to correct? Because surface tension of the liquid is other than 0.02 and here we should also consider the correction factor for hole to active area ratio because it is given as 0.08. However, for this graph 0.1 is considered.

So, let us say the k 1 value at top as well as at bottom. So, I am having bottom k 1 this is the value of k 1 and here we have the correction factor for surface tension because 60 into 10 is to the power – 3 is given and 0.02 is the value for which that graph is obtained and further 0.9 because this is the hole to active area correction factor. So, corrected k 1 we can obtain as 0.1065 for the base or the bottom.

And for the top we can find the k 1 corrected as 0.1129 and once I am having the k 1 value we can obtain the flooding velocity at bottom as well as top. So, this is basic equation for the flooding velocity. At the bottom we can use corrected k 1 and so the properties at the bottom and we can find flooding velocity at the bottom as 3.9425 and similarly I can find flooding velocity at the top which is coming as 2.1196.

So, these are basically the flooding velocity you have to fix the minimum vapour velocity and that should be 85% of flooding velocity because the recommended range is 80% to 85%. So, I am considering 85%. So, the vapour design velocity we can consider as 0.85 into the flooding velocity at bottom as well as at top. So, design velocities are given as 3.3511 at bottom and 1.8016 at top.

So, these are basically velocity of vapour and we consider this as a design velocity and now we will see the volumetric flow at top as well as at bottom.

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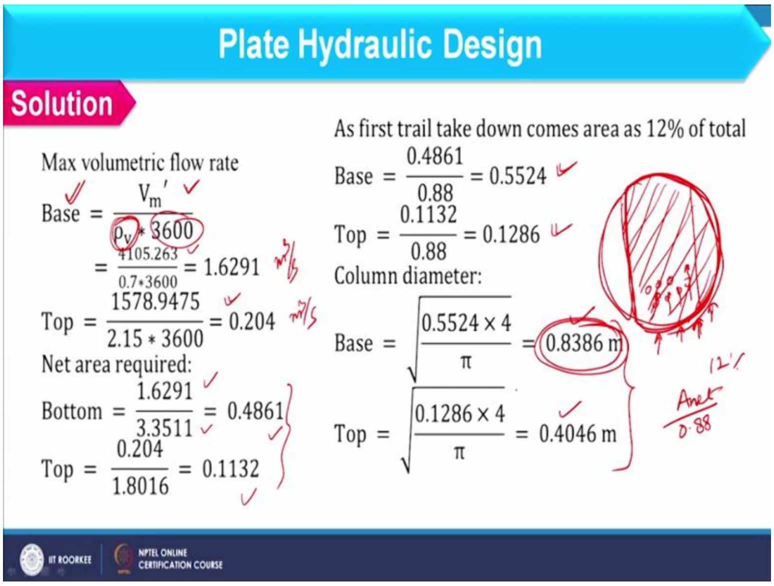

So, as far as volumetric flow of vapour is concerned we have to consider the mass flow rate which we can obtain by balancing which we have already done in previous slides. So, at the bottom mass flow rate of the vapour is obtained as 4105.263 it is divisible by density at the bottom and this is for conversion of hour to second. So, we can obtain volumetric flow at the bottom as 16291 meter cube per second.

In the similar line at the top we can obtain volumetric flow as 0.204 meter cube per second. So, once I am having the volumetric flow rate of vapour as well as vapour velocity we can obtain the net area. So, let us see how the net area is coming into picture. For this let us focus on the cross sectional view of the column and net area is basically this area that is the hole area of the plate.

However, if we consider the holes these holes will be present in active area only. So, whatever vapour is coming from the bottom it will pass through these holes only. So, if vapour is coming from the bottom it can be covered by this hole plate. There is no doubt that it will enter from these holes only, but it will spread throughout this plate and therefore we should consider net area which is this area.

So, net area is basically volumetric flow divided by the velocity of vapour. So, division of this will give the net area and at the bottom net area can be obtained as 0.486 and at the top it is obtained as 0.1132. Now, once I am having the net area how should I obtain the column area? Column area can be obtained by considering downcomer area. So, usually downcomer area is considered as 12% and which is this.

So, once I know this net area and 12% downcomer area if I divide net area by 0.88 I can calculate the column area. So, at the bottom column area can be obtained as 0.5524 and at the top it can be obtained as 0.1286 and so simple calculation gives the column diameter at bottom as well as top. However, if you focus on the distillation column or the absorption column diameter does not change along the height diameter should be same.

So, what we have to do over here whatever diameter is larger in value that we should choose as the column diameter. So, in this case column diameter should be 0.8386. So, what we have to consider over here that whatever will be the location of the plate either it is top or the bottom. Column diameter calculation should be carried out in both the section and we should choose the larger value among the two.

However, from here onward hole calculations will depend on the location of the plate. So, from here onward all calculation will be carried out for bottom plate only. So, let us start that.

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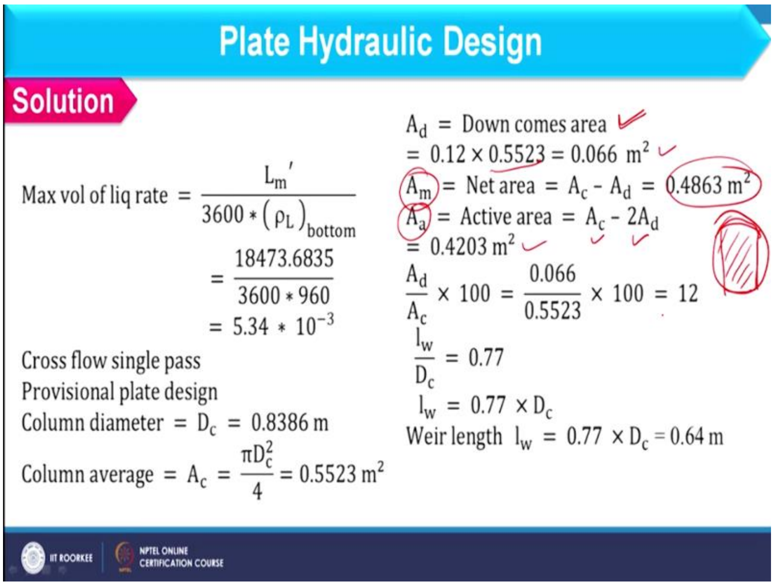

So, next what we have to calculate? We have to find out the liquid flow pattern and for that I should focus on this figure. So, if you see here I am having liquid flow rate that should be in meter cube per second and on x axis we have column diameter. So, as far as column diameter is concerned it is basically 0.83 so somewhere here it will fall and as far as that liquid flow rate we should consider this L m dash because now I am focusing on the bottom plate.

So, at the bottom liquid flow rate is given with this value and that should be converted into meter cube per second. So, the value should be 5.34 into 10 is to the power – 3. So, if we consider that value will lie somewhere here and from x axis we can trace the column diameter. So, somewhere it will lie here so that is basically the cross flow single pass. So, that you can select as the flow pattern.

After that we will carry out the design of the plate or we can consider the layout of the plate as we can choose the downcomer area and that should be 12% of column area. So, downcomer area should be 0.66 meter square. Net area we have already calculated, active area is basically column area minus twice of downcomer area because that you can consider this section only.

So, in this way we can find active area as 0.4203 and next we have to find out the weir length. How I can find it? I have been given 12% as downcomer area.

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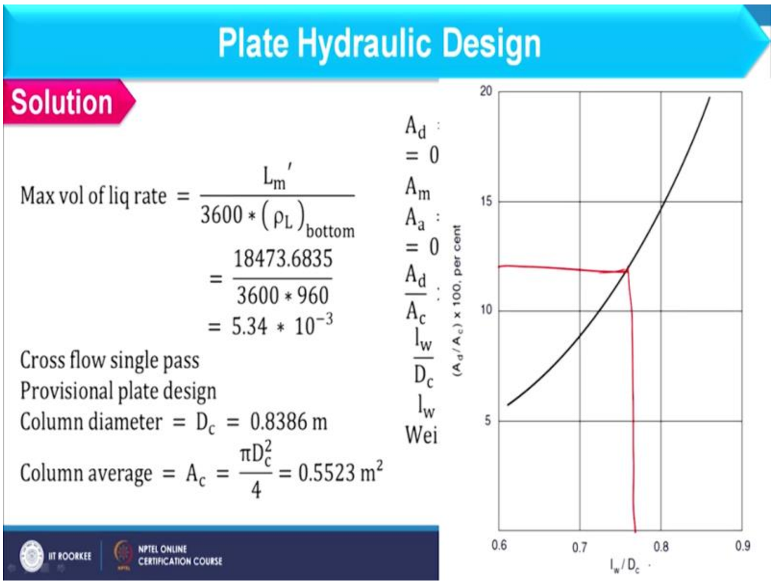

And we can use this graph. So, corresponding to 12% downcomer area if you see the l w / D c value it should come as 0.77. So, from here you can find out the weir length which should come out as 0.64 which is also called as the chord length. So, now we have to decide the weir height hole diameter and plate thickness. So, let us see that.

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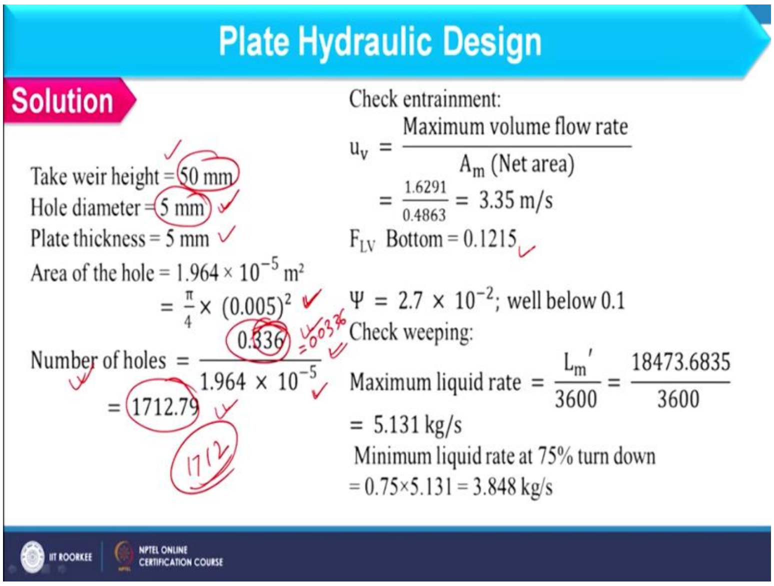

As far as weir height is concerned the most recommended value is 50 mm and for hole diameter it is 5 mm and we can consider plate thickness as 5 mm. So, once I am having the hole diameter I can calculate cross sectional area of 1 hole and we can find out number of holes considering hole area divided by area of one hole. So, this hole area value how I can obtain that this is 8% of active area if you recall the example.

So, this value should be 0.0336 not this. So, consider this value and you can find number of holes as 1712.79 as it cannot be in decimal. So, complete number should be 1712 because area is fixed. So, we have to round off the number of holes. So, if you see the problem what we have to calculate first? We have to check the entrainment as well as weeping condition. So, let us first checking entrainment condition and to find out the entrainment we should consider FLV value which I have already calculated.

And the value of FLV available at bottom that I should consider because I am designing the bottom plate now. And after that I should also consider percentage flooding so that I have consider as 85%. Now, in some cases what we do like whatever column diameter we have calculated just we consider the standard diameter available in the market. So, if that you are considering in that case you have to recheck the value of flooding.

So, that we are considering over here so I have taken 85% as the percentage flooding. So, at the bottom FLV value is given as 0.1215.

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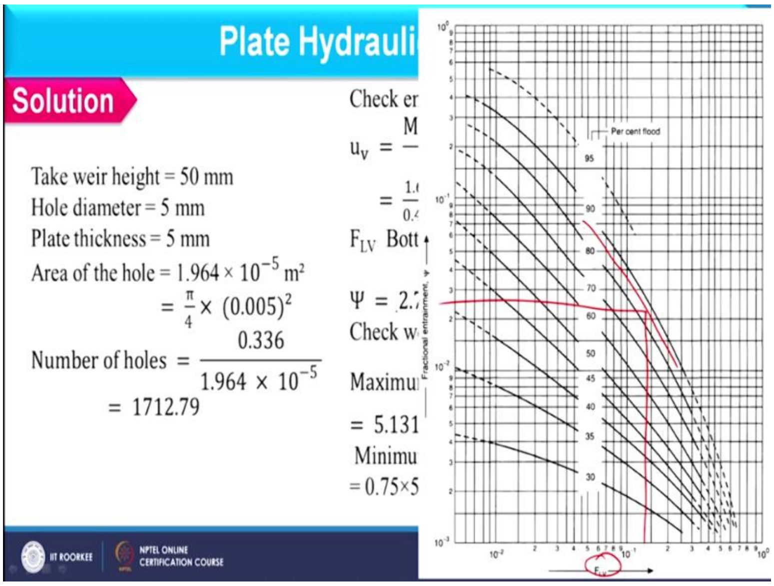

And we can use this graph. So, as FLV value is coming as 0.12 so that value you can obtain somewhere here and that should be corresponding to 85% flooding. So, that line will lie somewhere here. So, considering this we can find out the value and that value will come as 2.7 into 10 is to the power – 2 and it should be less than 0.1. So, here entrainment condition is satisfied if it is not satisfied you have to change the column diameter.

So, for that purpose you can change downcomer section because you cannot play with volumetric flow. Another thing which you can change is the flooding percentage. So, next is we have to check the weeping condition and for weeping condition I have to calculate minimum liquid flow rate. So, if I consider the maximum liquid flow rate so that value is available over here.

This we can obtain by balancing the mass and further we can obtain maximum liquid rate as 5.131 kg per second considering 75% turn down you can find out minimum liquid rate as 3.848 kg per second. And after that I have to calculate the design velocity at which weeping will occur, minimum design velocity. So, let us see that and to calculate that velocity I have to find out K 2 factor.

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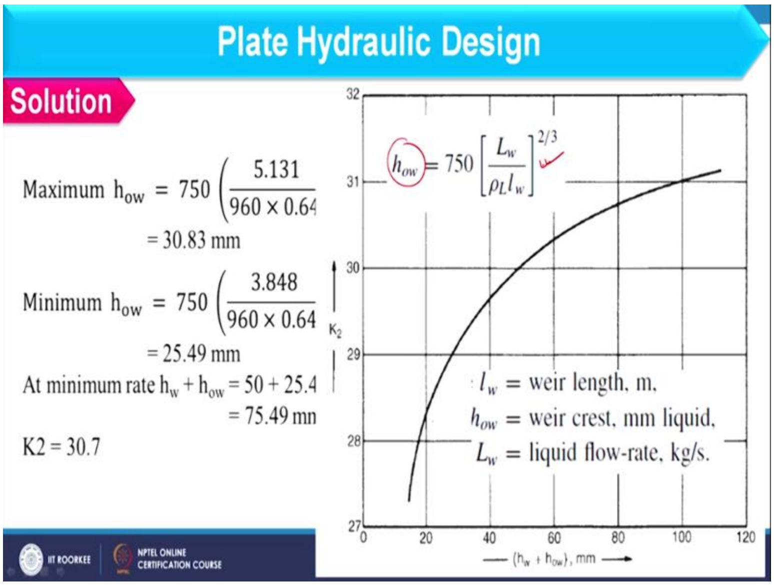

For that I should use this graph where h w v can be obtained using this expression. So, let us obtain that.

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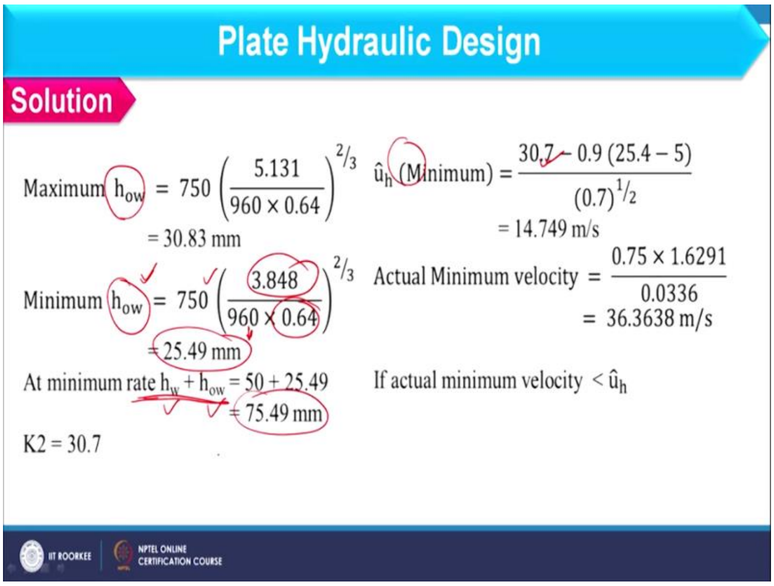

So here I am having maximum how and minimum how as I am focusing on weeping condition I should consider minimum how. So, 750 and here I am having the minimum liquid flow rate which we have seen in the last slide and this is basically the density and 0.64 is the chord length which we have already calculated previously. So, 25.49 mm how is there so at minimum rate how and how can be obtained as 75.49.

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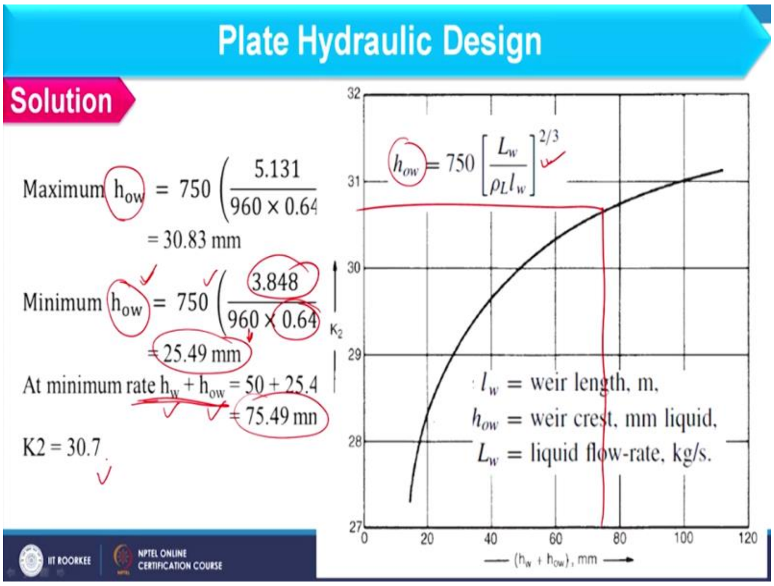

And for that value you can see the value of K 2 like this. So, that K 2 value you can obtain as 30.7. Now, once you have these values you can obtain minimum design velocity at which weeping will occur. So, its value should come out as 14.749 meter per second and in this I have calculated 5 mm hole dia. And further we have to find out the actual vapour velocity. So, this is basically the volumetric flow of the vapour at bottom.

And this is the maximum we consider the minimum value of that because weeping should be corresponding to minimum vapour velocity. So, for that I should consider minimum flow rate as well and that should be divisible by hole area. So, 36.3638 meter per second is the actual vapour velocity and that is the minimum vapour velocity and this is well above then this value.

So at present my condition is satisfied. However, if it is not satisfied what you can change? You cannot change the actual minimum velocity of the vapour because that you can obtained based on the volumetric flow and that is basically based on the mass flow. So, that you cannot change. You can change the minimum design velocity and that is given here. So, you can change different value of hole diameter and decrease this value. So, in this way you should meet the weeping condition.

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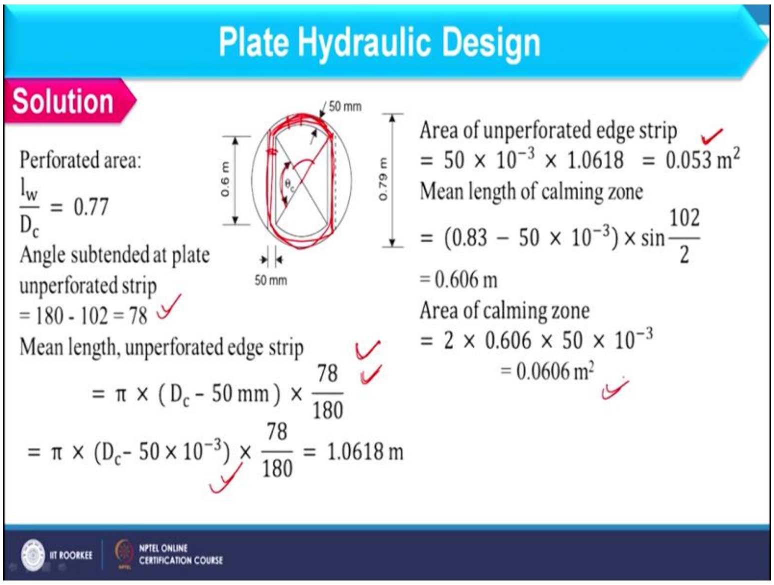

And next we have to find out the perforated area.

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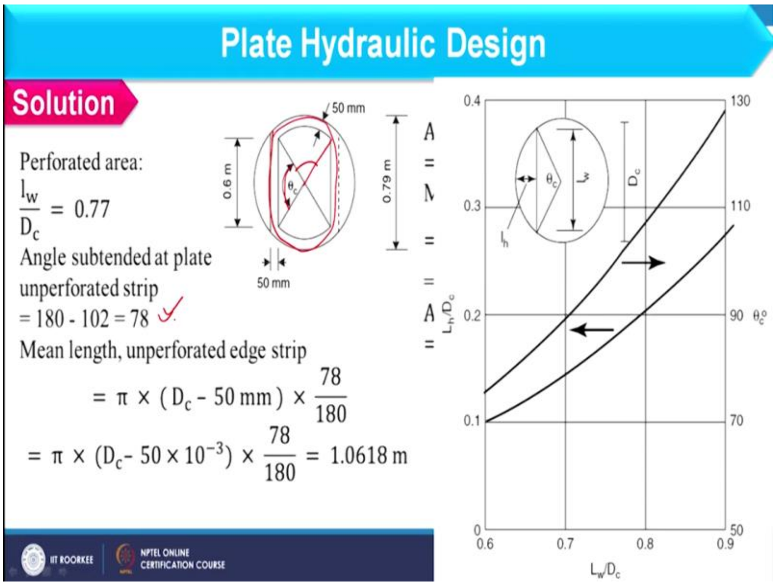

For perforated area we have to find out this theta c value and for that you can use this graph lw / Dc you already know and corresponding to this you can find the value of theta c which is coming as 102 degree this is not the Celsius over here so that is 102 degree only and how I can find the perforated area by reducing the unperforated area which is available over here from the active area.

Now, why I am deducing this area because wherever I am having the calming zone and the support ring you cannot make holes over there. So, we consider different perforated area in comparison to active area. So, this angle you have already seen as 102 so this angle we can consider as 180 – 102 so that is 78. By simple geometry, you can find out this length as well as that can be multiplied by this thickness so you can find out area of this zone into 2 will give the area of this zone also.

Similarly, this periphery you can also find out considering pi D so you can find out like this and when we consider this it should be multiplied by this thickness and twice of that should be considered. So, considering all these we can find out unperforated edge strip as 0.053 this is nothing, but the area of support ring and this is the area of calming zone.

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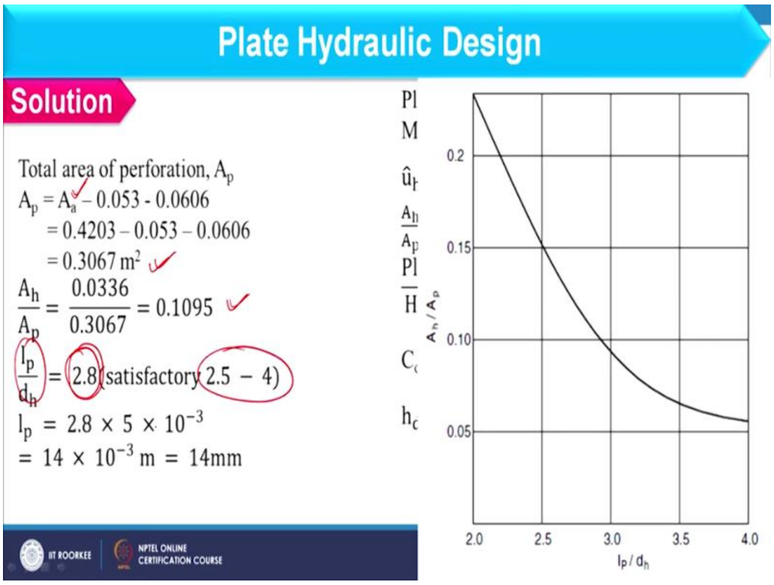

Addition of this should be deduced from active area to find out perforated area. So, A h / A p you can calculate and it should come out as 0.1095 and so you can find out l p / d h so that is 2.8 and which is basically falling within the range that is 2.5 to 4. And next what we have to calculate is the pressure drop in the plate. So, let us see that.

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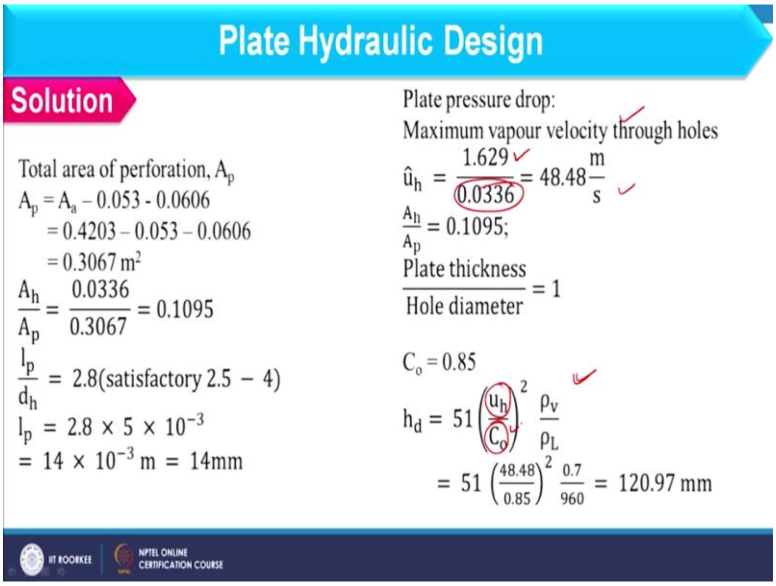

So, to find out pressure drop we have to consider the pressure drop on dry plate that is h d, ho, h w + h o w and hr that is the residual pressure drop. So, let us see how to calculate h d? So, this is the expression for h d where this uh is the maximum vapour velocity through hole and this C 0 is the orifice coefficient. So, maximum vapour velocity we can obtain as volumetric flow of vapour at bottom condition at maximum divided by the hole area. So, you can consider this value as 48.48 and next we have to find out orifice coefficient.

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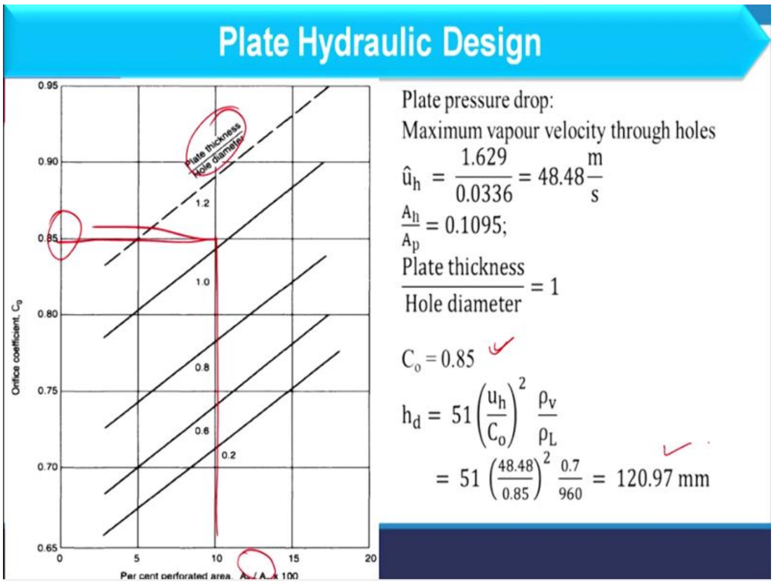

And that we can see from this graph like here A h / A p is given which we have already calculated. Plate thickness and hole diameter we consider as same so 1 will be there. So, if I consider this A h / A p it is coming near to 10 and so you can obtain value of C 0 which is coming as 0.85. If you tally it properly it will come out 0.85. So, considering this h d I can obtain as 120.97 mm.

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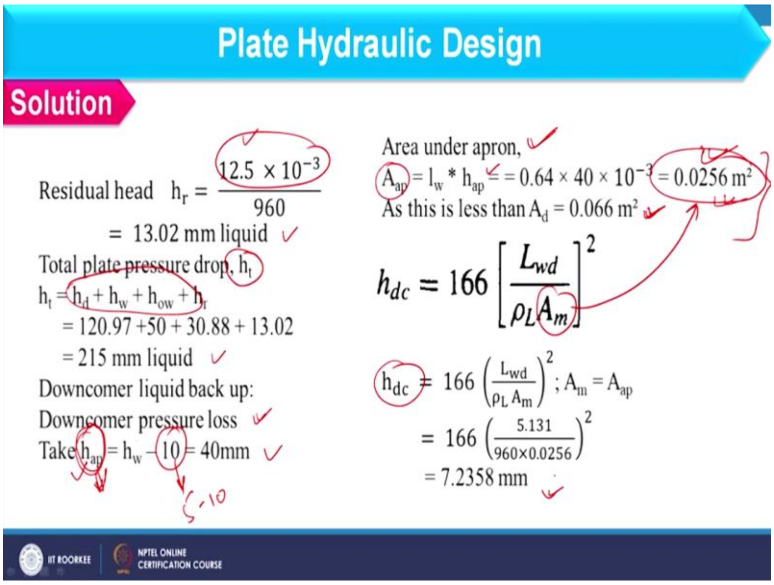

Residual head we can calculate with the constant that is 12.5 mm and its value is coming out as 13.02. So, total pressure drop in the plate is ht which is addition of all these and value we can obtain as 215 mm liquid and finally we have to find out the downcomer liquid backup and for that we should consider the pressure drop in downcomer section and for that hap should be obtained.

And to consider the maximum pressure drop this value should be minimized. So, we consider h w – 10 because this value we can consider between 5 to 10. So, hap we can obtain as 40 mm, area under the apron is A a p and that should be l w into h a p and value we can obtain as 0.0256. We will compare this with the downcomer area which is 0.066 and we consider the minimum area among these two.

So, we will choose this area. So, considering Am as this we can find out h d c and which is coming out as 7.2358 mm.

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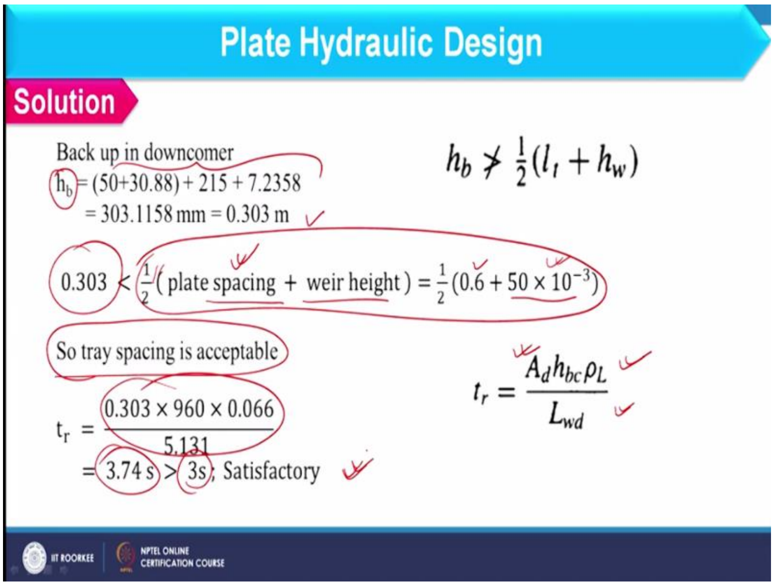

So, let us see the backup in the downcomer and that can be given by h b. We will add all these values and find this h b value as 0.303 meter and that should be lesser than this that is half of plate spacing plus weir height and that should be calculated considering 0.6 because that is the plate spacing and weir height as 50 mm. So, if you calculate this 0.303 will be lesser than half of this.

So, we consider that tray spacing is acceptable otherwise we need to change the tray spacing and then you have to start the calculation again from the column diameter because k 1 factor will be changed which we have consider in flooding velocity. So, accordingly what changes will be there that you have to consider from the beginning. And next we have to find out the residence time in downcomer section.

And this is the expression for that considering values over here because all values you know you can find out residence time in downcomer section as 3.74 which is more than 3 second.

So, here we consider that design of the plate is satisfactory. And wherever the conditions are not met whatever changes you have to do that I have already explained. So, in this way you can design the plate for a distillation column and this plate is basically sieve plate which we have considered.

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And here you can find some of the references to study about the plate design in detail.

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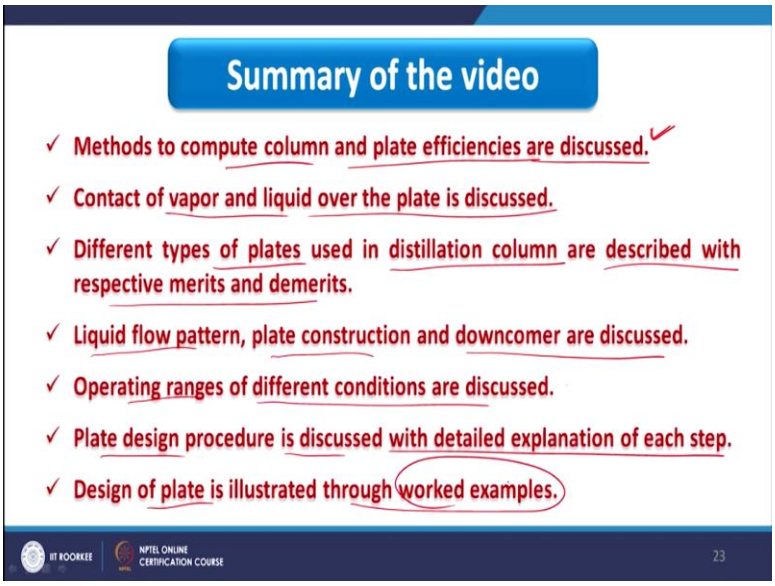

And now we are summarizing the videos and this summary is the video which we have covered in this week. So, summary of all these videos is in these lectures method to compute column as well as plate efficiencies are discussed, contact of vapour and liquid over the plate is discussed, different types of plates used in distillation column are described with respective to its merits and demerits.

After that liquid flow pattern, plate construction and downcomer are discussed and then we have described the operating ranges of different conditions and further plate design procedure is discussed with detailed explanation of each step. And finally we have designed the plate with the help of example. So, in this way you can complete the process design of the distillation column and here I am stopping this lecture. So, that is all for now. Thank you.