Process Equipment Design
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Lecture –54
Distillation Column – 7

Hello everyone. I welcome you all in this lecture which is 54th lecture of the course Process Equipment Design and here we are going to discuss distillation column. If you remember the last lecture we have started discussion on plate hydraulic design that is how to design a plate for a distillation column or for absorption column. So, in that lecture we have discussed how to calculate the column diameter and how to decide liquid flow pattern along with the entrainment condition. And in this lecture we are continuing that design.

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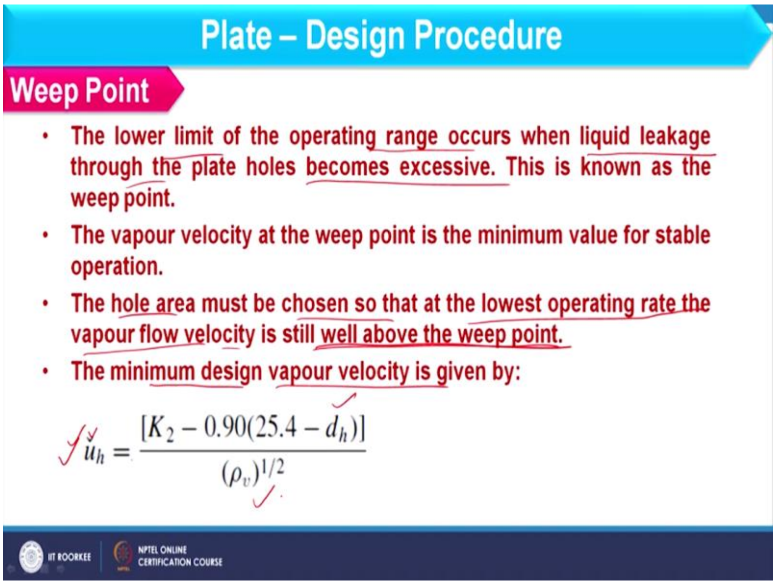

And further we will focus on weeping condition. So, as far as weeping condition is considered first of all we should understand what is the weep point? So, as far as weep is concerned I guess you understand that when liquid flow rate is very low it will start coming from the holes which are available for vapour to move up. So, in this way what we can say that if vapour velocity is low enough it will not able to hold the liquid over the plate.

And so the liquid will start falling from the holes and that condition we call as the weeping condition and that point where the velocity of vapour allows that we consider that as weep point. So, the lower limit of the operating range occurs when liquid leakage through the holes becomes excessive and this we consider as weep point as we have already discussed. So, what is the main concern over here?

Main concern is to decide the vapour velocity accordingly and for that hole area must be chosen so that at lowest operating rate the vapour flow velocity is still well above the weep point. So, we consider the hole area or we can say that hole area should be chosen in such a way so that vapour velocity should be more than the velocity at which weeping will occur. So, let us see how to find out the velocity where weeping will occur.

So, minimum design vapour velocity considering weeping condition can be calculated by this expression where I am having uh and that should be equal to K 2 – 0.9 25.4 – d h divided by rho v power 0.5. So, this is the expression we should use to find out the minimum vapour velocity. And we should chose the hole diameter in such a way so that the vapour velocity which is existing actually in this system should be more than that.

And as far as this design parameters are concerned you should understand that whatever flow rate of liquid and vapour is given that you cannot play with. You have to design in such a way so that considering those flow rates of liquid and vapour my all condition should be satisfied whether it is entrainment whether it is weeping and whether it is any other like pressure drop or so.

So, in that way here I am having the minimum design vapour velocity and that we should compare with actual vapour velocity. However, to find out minimum vapour velocity we should find out K 2 factor value.

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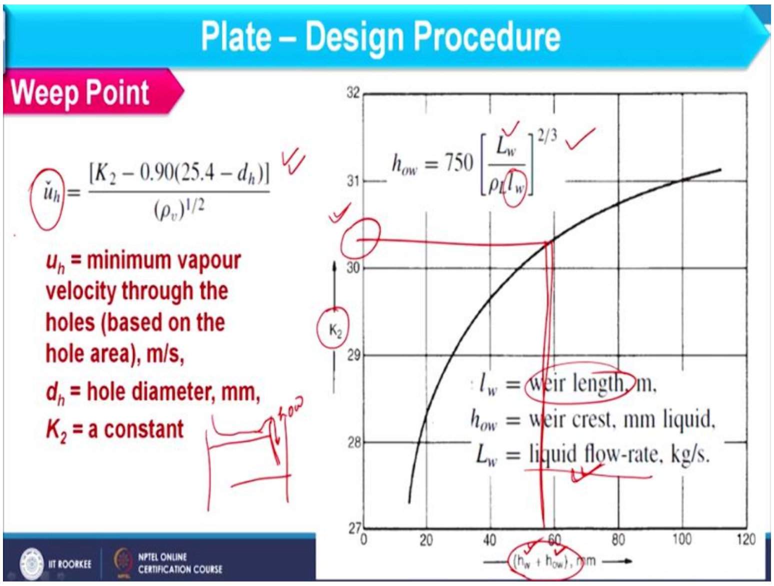

So that you can calculate from this graph here I am having K 2 on y axis on x axis we have hw + how. So, what is this hw this is nothing, but the weir height. What is how? This is basically the crest height over the weir. So, what is the crest height? Let us say if I am having this much height of the weir and liquid will move over this so whatever height of the liquid layer will make over the weir height that we consider as crest or we consider as crest or we consider that as weir crest.

Let us say if I am having this column and this is one plate, this is another plate and here I am having the weir. So, whatever liquid is coming it is obviously moving up and then through the downcomer. So, whatever this height is that we consider as weir crust. So, that we can calculate using this expression where L w and small l w are liquid flow rate and small l w is weir length.

Liquid flow rate means minimum liquid flow rate because weeping condition we should check for the minimum flow rate and accordingly we should find out the actual vapour flow rate. So, once you have these value you can draw the line like this and then you can see the value of K 2 I think graph you all are able to see. So, accordingly K 2 value you can obtain and then you can use this expression to find out minimum vapour design velocity. Here dh is the hole diameter and that you can choose.

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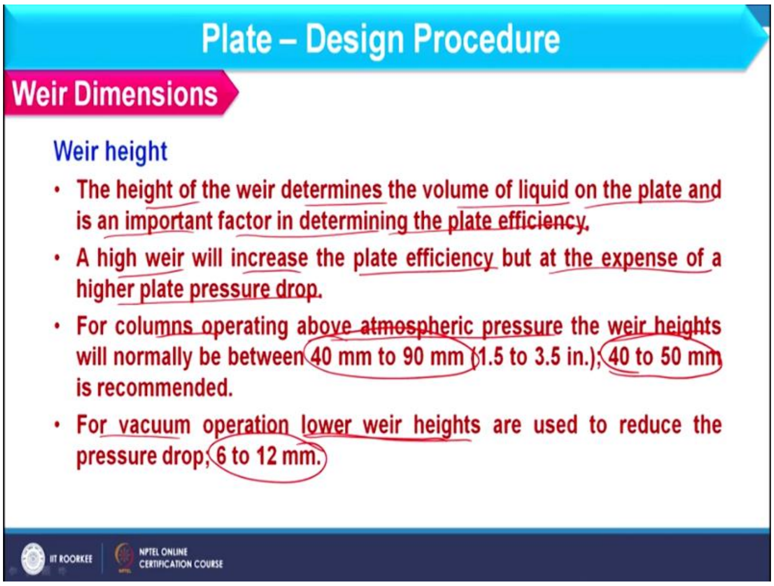

Now, let us see how to find out weir dimensions and as far as weir dimensions are concerned we should consider first the weir height. So, the height of the weir determines the volume of the liquid on the plate and it is an important factor in determining the plate efficiency. So, whatever volume is available over the plate and when the vapour will contact with that so that volume basically decides the plate efficiency because based on that mass transfer will take place over the plate.

So, a high weir will increase the plate efficiency, but obviously at the expense of high pressure drop on the plate. When we consider columns which are operating above atmospheric pressure weir height should be between 40 mm to 90 mm. So, this is the hole range. However, 40 to 50 mm is the recommended value. So, you can choose the weir height accordingly.

So, as initial guess we usually consider 50 mm as the weir height and in case of vacuum condition we usually consider lower weir heights and that is basically 6 to 12 mm. So, in this way you can choose the weir height.

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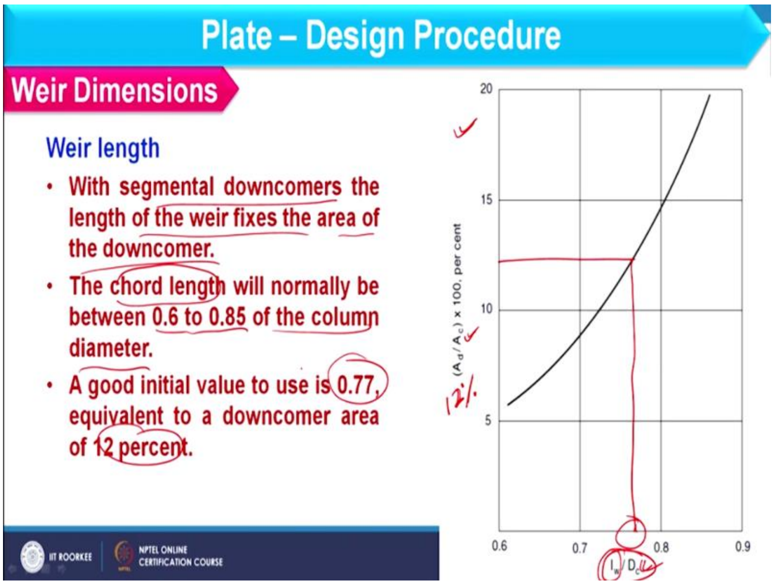

And now we will see how to find out weir length and what is weir length? If I am considering the cross sectional view of column then this is basically the weir length this we represent as small l w. So, that will depend on the downcomer area. So, with segmental downcomer the length of weir fixes the area of the downcomer. So, usually we consider this graph where A d / A c is there it means downcomer area percentage with respect to column area is given over here.

So, usually we consider this downcomer area as 12% to column area. So, if I consider that you can see that l w / D c value should be around this that is 0.77 and so you can chose l w value because diameter you already know. So, in this way we can select the weir length however the recommended length of the weir or we consider that as the chord length it is normally between 0.6 to 0.85 of the column diameter.

And according to 12% downcomer area we can choose l w / D c as 0.77 and this point we have already discussed. So, in this way you can find out the weir length or the chord length.

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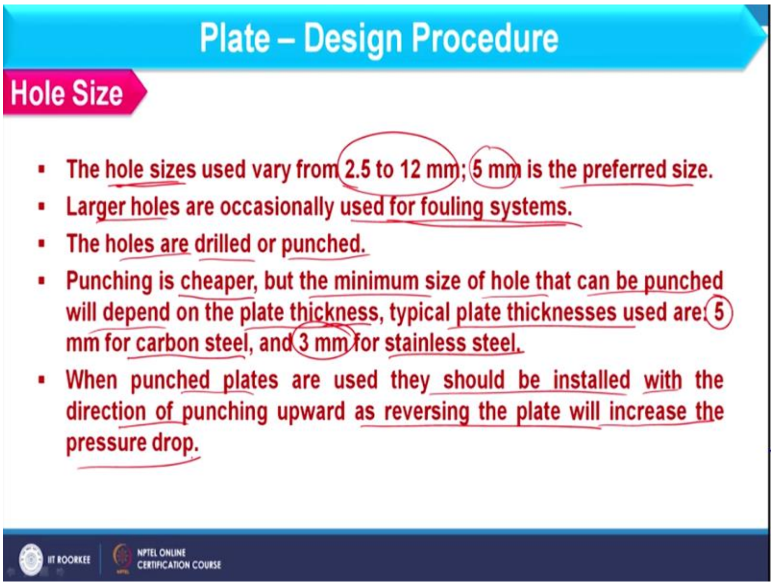

Next, we should consider the hole size and as far as complete range of hole sizes is concerned this varies from 2.5 mm to 12 mm. However, 5 mm is the preferable value. So, initial guess of hole size should be 5 mm and then depending upon the weeping condition you can vary this value in a given range. So, larger holes we usually consider when I am dealing with the fouling system with the obvious reasons.

And holes are basically prepared with drilling or punched. So, when we punch it usually punching is cheaper, but the minimum size of hole that can be punch will depend on the plate thickness. If plate thickness is 5 mm for carbon steel we can punch it otherwise if I am considering stainless steel minimum thickness should be 3 mm. Further, if punched plate are considered they should be installed with the direction of punching upward as reverse the plate will increase the pressure drop.

When we punch it obviously at one side some non uniformity will be there so that side should be kept upward because vapour is moving from bottom. So, vapour flow rate should not be hindered. However, if I reverse the plate so it will give more pressure drop because of more friction. So, in this way we have to choose the hole size and place the plate. Now, if I ask you that how we place the plate in the distillation column.

So, if you consider that we usually have support ring at the inner periphery of the column. So, over that support ring plate sits and then plate can be attach with bolts. So, in this way plates are usually arranged or connected with the inner section of the distillation column at the given spacing. So, in that case support ring is very support.

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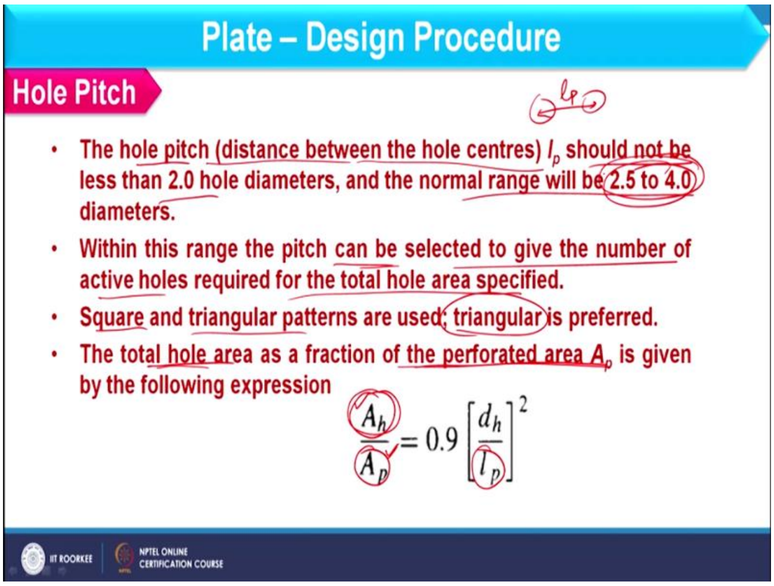

And next parameter in plate design is the hole pitch. So, let us see how to decide that and first of all we will focus on what is hole pitch that you understand it is the distance between hole centers like holes are there. So, this is basically the hole pitch which is denoted by small l into p. So, l p should not be less than 2 hole diameter and the normal range is 2.5 to 4 diameters and this condition we should also check in designing.

So, within this range pitch can be selected to give the number of active holes required for the total hole area specified. Usually, we arrange the holes like square as well as triangular pattern as we discuss in heat exchangers also when we arrange the tubes in tube sheet. So, usually triangular pitch is preferred or triangular pattern is preferred. Further, the total area as a function of perforated area is given as this A h is basically the hole area.

How we find it? When we calculate the column diameter there we consider the factor K 1 and K 1 will depend on the hole area. So, there we consider the hole to active area ratio and if you know the active area you can find the hole area also and here I am having the perforated area so what is this area that we will discuss? So, that should be equal to 0.9 d h / l p power 2. So, in this way you can find this l p value and that should fall within this range.

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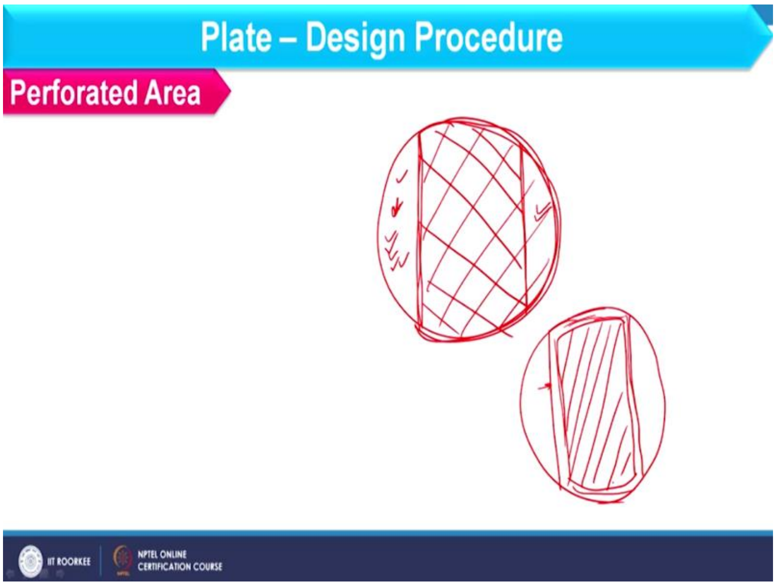

Now, next is what is perforated area? Actually as far as this plate design is concerned we have different areas so let us first discuss that if I am having this cross sectional view of the column this is basically the inlet downcomer and here I am having the exit weir. So, this is the downcomer section and this is also the downcomer section. If I consider this particular section where I am having only one downcomer and usually plate is this much size only.

This section is basically removed from the plate. So, if I consider this particular section it is called as net area. When I consider downcomer at inlet as well as outlet weir this particular section we call as active area because in this area only we can make the holes. And further if I focus on this as well as this so this is nothing, but the downcomer area it is this you know already and we can have other point also.

Let us say if I am considering this as the column diameter. This is the exit weir and this complete section I consider as the active area. Now, if I focus on this now what is this? When the liquid will come in from the upper plate it will not only come in contact directly with the holes where vapour is available because in this section we have the support ring in this section also we have the support ring.

Here we consider some sections which are consider as the calming zone. So, this area which is in between this we call as the perforated area where we make the holes. So, active area is different, perforated area is different, net area is different and column area is different. So, all these you should understand with respect to a plate and now we will focus on the perforated area calculations. So, let us start that.

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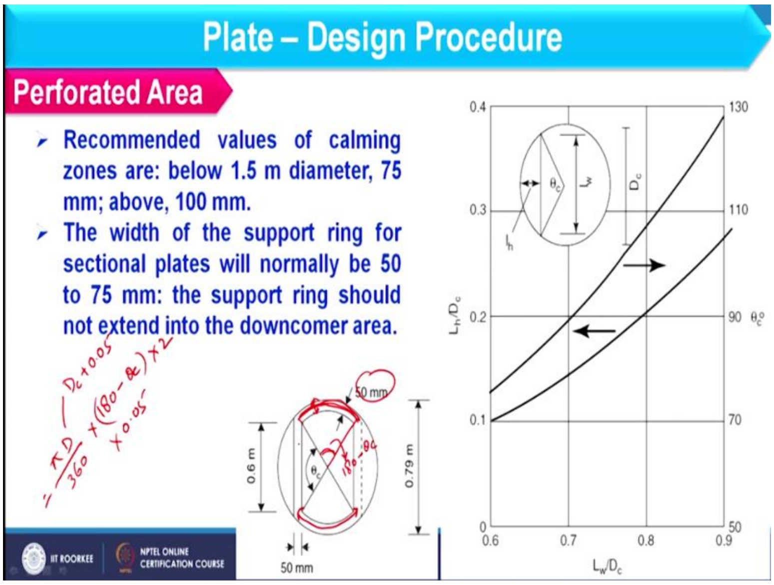

So, to decide the perforated area we have to deduct the area which are covered by the support ring as well as calming zone. So, first of all we will decide the thickness of calming zone as well as the support ring and as far as support ring is concerned it is only available where the plate is there. It means it is not extended to the downcomer section because if ring will be available and plate is not available because that is the empty section.

So, it will hinder the flow of the liquid. So, when I consider the calming zone its thickness should be 75 mm if column diameter is less than 1.5 meter and above 1.5 meter 100 mm thickness of the calming zone should be considered. Further, the width of the support ring vary from 50 to 75 mm. The support ring should not be extended to downcomer area so that point we have already discussed.

However, thickness you can choose from 50 to 75 mm. Let us say if I focus on this schematic here I am having this net area. And inside this we consider the support plate thickness as 50 mm as well as calming zone thickness as 50 mm. So, active area I already know to find out the perforated area which is basically this area. You have to deduct the area by this support plate as well as this calming zone from the active area.

So, how to find that let us see that? So, to find out the perforated area we should find the theta value which is the angle which is made by the chord with the center of the plate. So, that angle is basically theta c and that we can see from this graph. You see here I am having L w /

D c that is basically the chord length by D c. This value we can already fixed when I have fixed the weir length depending upon the downcomer area.

So, you can see here I am having the theta c value for which upper graph is available. So, whatever would be the value of L w / D c accordingly you can find the value of theta c. So, if I am having this theta c how I have to find out this area. If I consider this particular section and if I consider the middle point of this because I have to consider the mean length. So, that length I can obtain by column diameter - 0.05 that is the thickness of this section.

So, this divided by 2 will be d dash and if you see here I am having this d dash value. And if I have to find out this length I can consider this as theta c / 2. So, how I can find this length that should be d dash sin theta c / 2 into 2 because I have to consider this into 2 because this also I have to consider into 0.05 because this thickness is 50 mm. In this way, you can find out the area of calming zone.

However, how you can find out the area covered by this support ring. To understand that we should consider this angle and that should be 180 – theta c. So, I have to find this periphery so if I consider pi D that should be for 360 degree and this D should be the mean diameter. So, D c + 0.05 because its thickness is given as 50 mm. So, this pi D / 360 into 180 – theta c for this angle.

So, that is basically this length into 2 because here it is also available into 0.05. So, in this way you can find out the area of this support plate as well as calming zone we have already discussed. So, addition of support ring area plus the calming zone area when we deduct the total area from the active area we can find the perforated area that Ap value so that you can consider in last equation where we have fixed the hole pitch.

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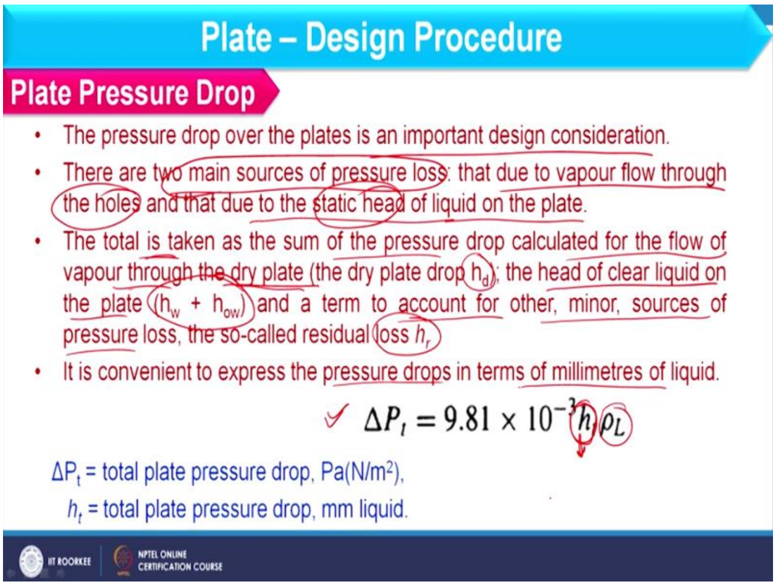

Now, once we have all dimensions of the plate we should consider plate pressure drop and as far as plate pressure drop is concerned this is basically an important design consideration. Here I am having two sources of pressure drop. First is due to vapour which flows through the holes and second is due to availability of the liquid on the plate which will cause static head.

So, here I am having two condition. First is because of the movement of the vapour and second is because of the liquid hold up over the plate. So, let us see how to account these in pressure drop calculation. So, the total is taken as sum of the pressure drop calculated for the flow of vapour through dry plate that is hd. So, when I am considering dry plate pressure drop it means I am not considering liquid holdup on the plate.

I am only considering that vapour is moving through the hole. So, pressure drop due to that will be counted as h d. Further, head of the clear liquid on the plate that we can consider this will give the static head so that should be h w + how. And a term to account other minor sources of pressure losses and this we consider as the residual loss h r. So, it is convenient to express the pressure drop in terms of millimeter of the liquid.

And so we can consider that total pressure drop on the plate is basically rho gh and rho corresponds to the liquid we are handling and this ht should be in mm and this ht is the total head loss over the plate. So, we will see how to find this.

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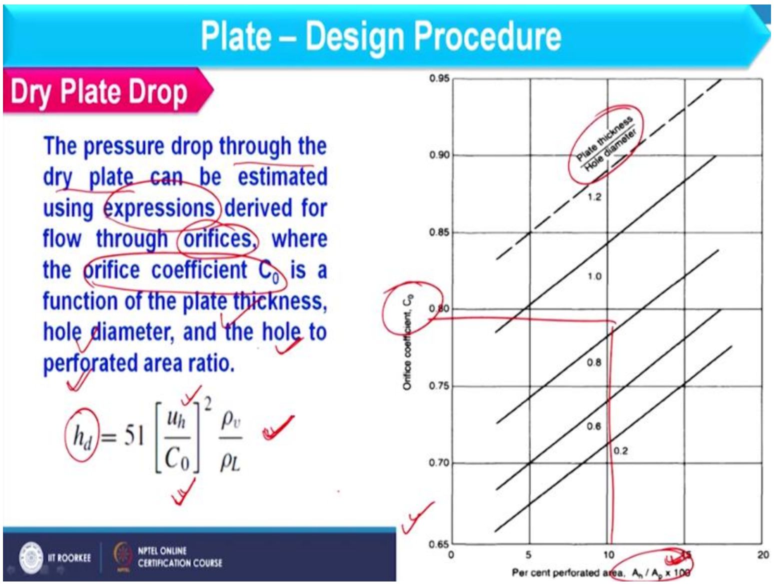

So, if you see what parameters we can account in ht calculation. First is h d which is the dry plate pressure drop second the static head and third is the residual loss h r. So, let us see first of all how to find out dry plate pressure drop that is h d. To find the h d pressure drop through the dry plate can be consider with the expression which is given over here. In this expression we basically consider that flow occurs through orifice.

And therefore orifice coefficient should be calculated first and it will depend on the plate thickness as well as hole diameter and it will also depend on the hole to perforated area ratio. So, when we consider the opening in the plate it is basically the orifice we are considering because it is similar to that design only. So, we can use this graph to see the value of orifice coefficient. So, here I am having the ratio of hole area to perforated area.

These value we have already calculated, plate thickness to hole diameter that you can decide. So, depending upon the value you can choose the C 0 value and so you can calculate h d value. It will depend on u h which is nothing, but the vapour velocity through holes. So, vapour volumetric flow you already know so that should be divided by the hole area and hole area value is like 10%, 8% or 6% of active area that you know already. So, in this way we can find out h d value.

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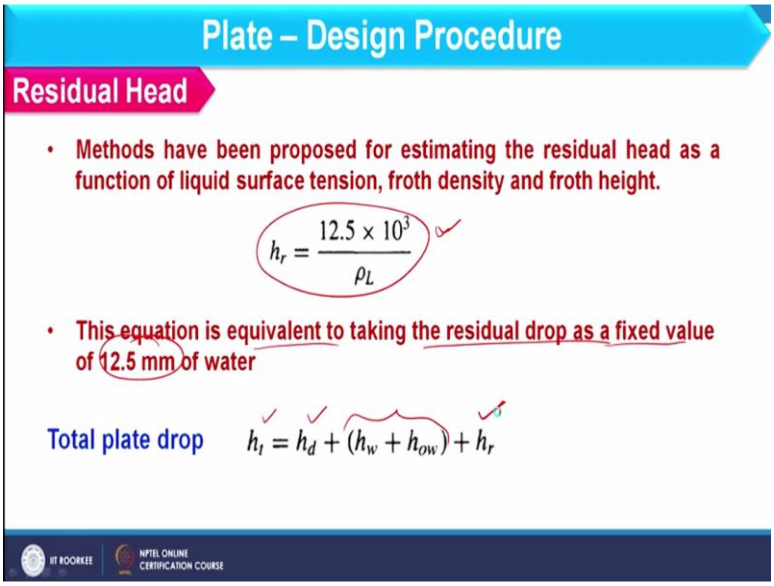

Next, is the residual head. Residual head is usually consider with the fixed value and that should be 12.5 into 10 is to the power 3 divided by rho L. So, this equation is equivalent to taking the residual drop as a fixed value of 12.5 mm of water. So, the total pressure drop is basically ht which is equal to h d h w + h o w that is static head and this is addition and here we have the residual loss.

So, once I am having the pressure drop calculation over the plate we can design the downcomer.

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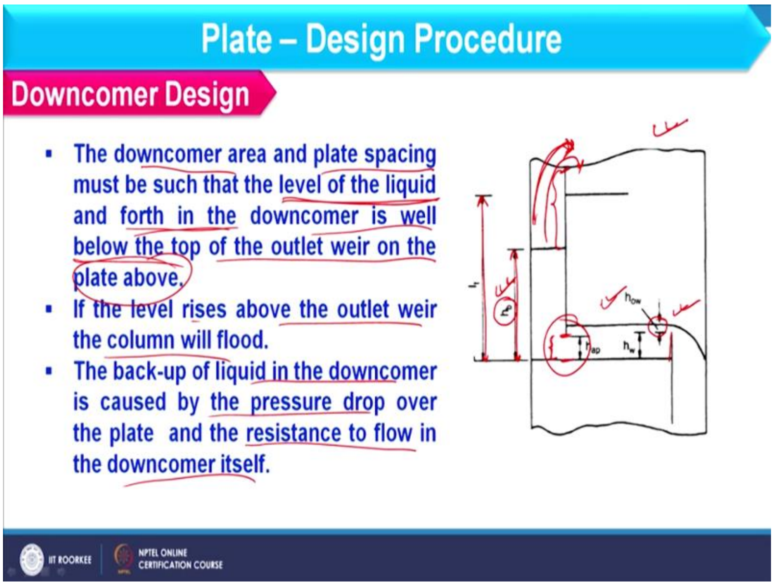

So, you can consider this schematic this Lt is basically the plate spacing and in this plate spacing this h b is the height of liquid available in downcomer section. So, if I have to design the downcomer properly this h b should be within the limit otherwise if this h b exceeds from the permissible limit we consider that liquid backup is taking place in downcomer section and that is really unacceptable condition as flooding will be next to that.

And this section is basically the opening for liquid to enter into the plate and here I am having this weir height and you can visualize how clearly in this image. So, this hap is basically the area between inlet downcomer as well as plate. So, let us see the downcomer design. So, as far as downcomer area is concerned this area as well as plate spacing should be selected in such a way so that liquid level and froth in downcomer is well below the top of the outlet weir of plate above.

It means this point so this h b should be well below to this. Further, if the level rises above the outlet weir the column will flood because in this way liquid will move in this direction So, the backup liquid in downcomer is caused by the pressure drop over the plate and the resistance to flow in the downcomer itself. So, we have to focus on this particular section as well as plate pressure drop.

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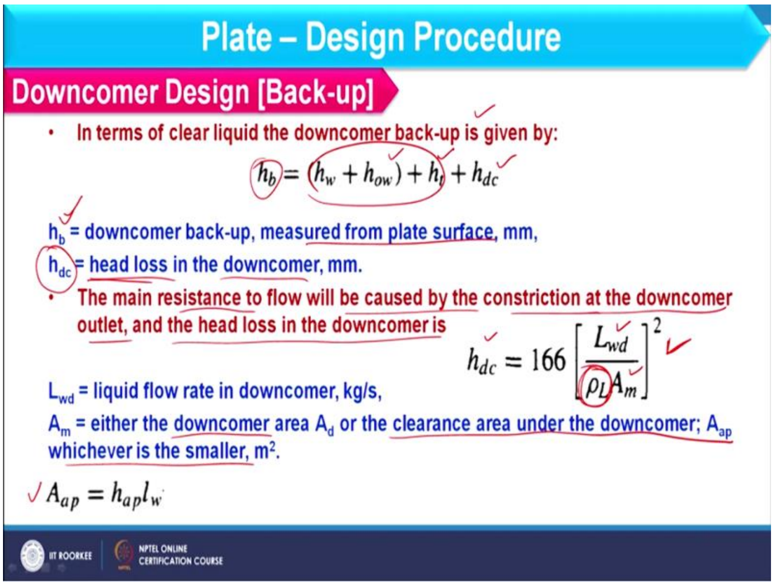

So, let us consider the downcomer design that we also call as the backup. So, in terms of clear liquid downcomer backup can be considered using this equation where h b should be equal to h w + h o w + ht that is the total pressure drop over the plate + h d c. So, let us see these parameters h t, h w and how we have already calculated h b here is basically the downcomer backup.

And it is measured from the plate surface as we have discussed in the figure which is shown in last slide. So, further we have to found that h d c that is basically the head loss in downcomer. So, the main resistance to flow will cause by the constriction at downcomer outlet and the head loss in downcomer is we can calculate h d c by this equation and here I have L w d that is the highest flow rate of the liquid available in downcomer.

So, further we have to focus on this Am because this property you already know. So, A m is either the downcomer area or the clearance area under downcomer A a p whichever is smaller because when we consider the smaller area it will cause more pressure drop. So, we have to design for extreme condition. So, let us see how to find out A a p value. A a p is nothing, but h a p into L w.

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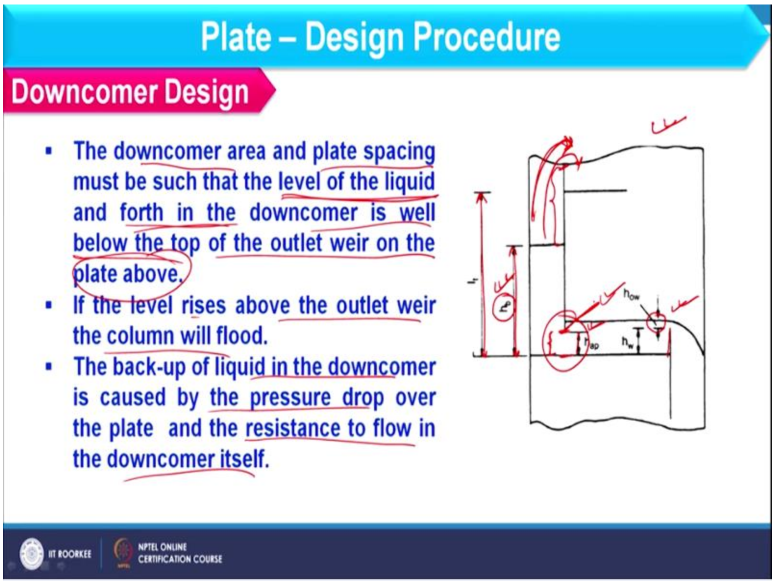

If you focus on this section so here I am having hap and this is available throughout the weir length or the chord of the weir. So, in that case we can consider the area as hap into L w which is the chord length as shown over here and how to decide hap that should be hw – 5 to 10 mm. So, for extreme condition we consider 10 mm deduction from h w. So, based on all these we can find h d c value and so h b value.

And h b value here should be compared with l t that is the plate spacing + h w because here we should consider that backup should be considered when the liquid will move from upper weir to upper plate. So, complete distance should be l t + h w and half of it and h b value should not exceed half of this complete value. So, in that we can design the downcomer section.

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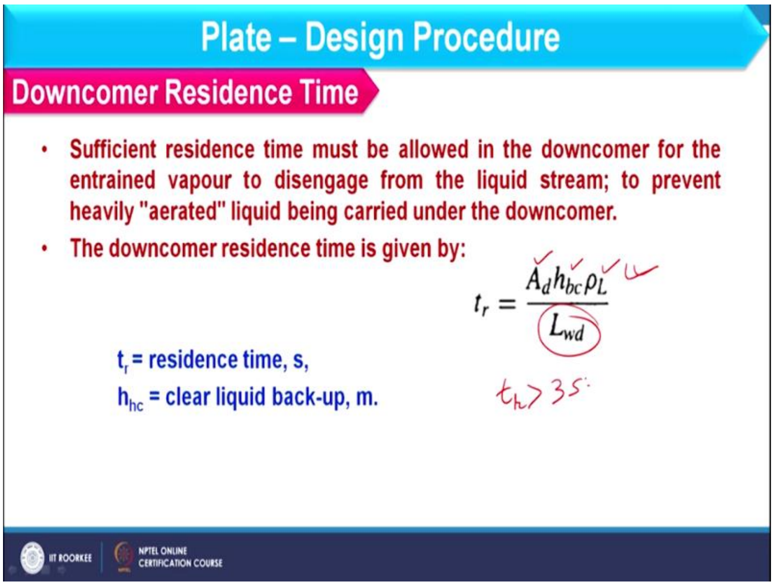

And finally we have downcomer residence time because sufficient residence time is required for downcomer for entrainment of vapour to disengage from the liquid stream and this is required to prevent the heavily aerated liquid which is being carried with the vapour in downcomer section. So, in this way we can find out the downcomer residence time and that can be calculated using this tr.

Ad downcomer area you know already h b c we already have calculated, rho L and L w d all these parameters are known to you and this t r should be more than 3 second. So, at least 3 second residence time should be required when the liquid is available in downcomer. So, in this way we complete the design of plate and whatever conditions will not satisfy what we have to do that we will discuss with the help of one example and that will be covered in next lecture. So, that is all for now. Thank you.