Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 25
Sieve Tray Design (Contd.)

Hello everybody. So, today we will be continuing our discussions on Sieve Tray distillation columns primarily and they can be used for absorbers as well. So, we have mainly covered the major portions of the sieve tray in the last class. We had discussed the limiting operations and after that how to calculate the diameter, calculation of the tower height by you by calculating the number of theoretical stages, using McCabe Thiele method.

Then incorporating efficiency and calculating the actual number of trays and then taking to account the tray spacing and for individual, between individual trays and also the specific tray spacings at the feed tray or the rather just above the feed tray at the top of the column, at the bottom of the column; taking all these spaces into account, how to calculate the tower height that has also been discussed with you.

So, at the moment you know how to calculate the tower height. You know how to calculate the tower diameter. After the diameter was calculated, we also know how to check about the entrainment level, whether the entrainment level is within limits and it is not going to cause flooding by entrainment.

So, till this much we have already done. I had given you a specific problem from where you found out that, what are the typical inputs which are there and what are the things which you are generally supposed to estimate or evaluate for a complete design of the column.

Most of the things that have been mentioned are common to all types of tray columns. There are certain specific differences, definitely, the sieve tray is the simplest which we are going to. Which we are discussing at the moment, there will be certain specific additional features for the bubble cap tray, which will be taken up when the bubble cap tray design will be discussed with you.

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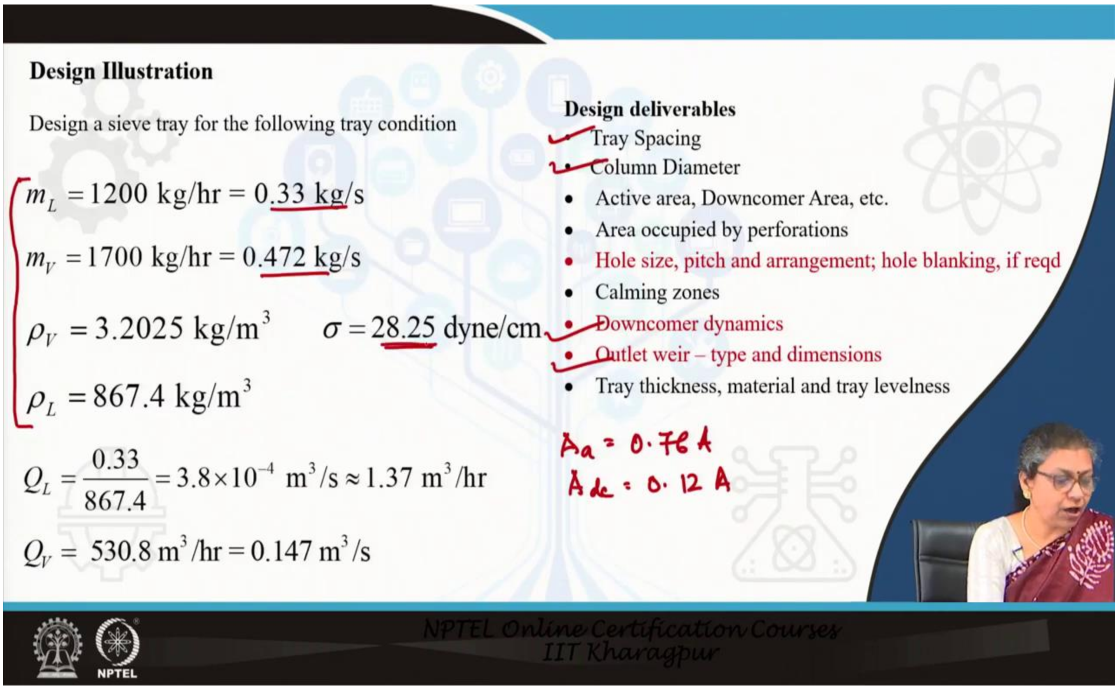

Now, just to recollect, this was the design illustration and out of the design illustration, more or less how to calculate the tray spacing, and the column diameter were already done. More or less what should be these particular ratios that was also mentioned to you. Normally, A_a=0.76A, then downcomer area A_{dc}=0.12A. It is around point tentative.

Now, after the design is formed up, we may change these little ones depending on convenience. But these are the tentative things. As I had already mentioned the tray comprises two calming zones. One is at the inlet of the liquid, and another is at the exit of the liquid and the remaining area can comprise of the active area.

Now, today what we will be doing is, once we have decided the tray diameter, now the tray layout. What the tray has? We know that that there will be some space left out for the downcomer and the remaining portion is the active area.

So, in the active area, we need to layout the holes. Now, for that what are the things we need? We need to find out the diameter of the holes and the arrangement. Remember mostly in sieve trays, the arrangement is a triangular pitch. In bubble cap trays, we use both square and triangular pitches. But, conventionally in a sieve tray, we use triangular pitch.

So, we need to decide the pitch, we need to decide the hole diameter, we need to decide the number of holes and then we need to fit the number of holes in the active tray. Keep in mind that certain portions of the active tray are also not available for the punching of holes, because there will be blanking strips if required, otherwise they will be backing strips as well.

So, therefore, we have decided on the tray layout, next comes the downcomer dynamics and the outlet weir dimensions etc. It is usually a V notch weir. Conventionally, it is taken. So, we will take this specific problem and we will go step by step in the design. In the course of designing for this particular specific problem, we will be understanding how to decide upon the tray layout, downcomer dynamics, outlet weir and then definitely certain checks, which we need to do to define that the design.

Checks are very evident to you, one check is the entrainment check which we have already discussed in the last class. The other thing is we assume some sort of an approach to flooding. Yesterday, I have told you we have we assume around 80 to 85 % of flooding. Finally, after the design is there, you just need to see that the flooding limit has not been exceeded. If it is less than what we have decided, it is fine. we can go ahead with it.

But after the design, if we find that we have approached closer to flooding, then definitely the diameter has to be changed and the design has to be reworked. The other very important thing for the sieve tray is to check for weeping. So, these are the three checks that we need and after the tray layout has been designed. The tray pressure drop has to be checked, which gives you a check for the weeping.

Again you remember in the downcomer dynamics. It is very important to check up the holdup in the downcomer. It has to be at least less than half of the tray spacing. So that by any chance flooding by downcomer choke flooding does not take place.

At the same time, the downcomer backup should be sufficient such that no vapour circuiting should take place. These things were discussed. Today through the design, we are going to find out or rather we will see how we can exactly estimate these particular parameters.

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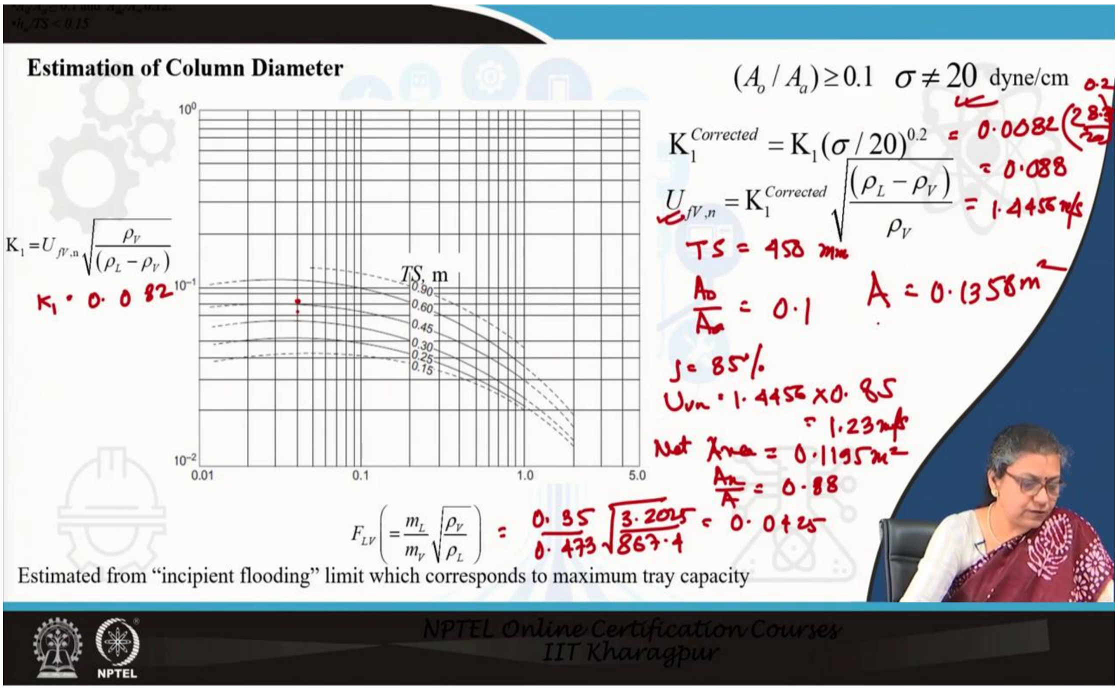

So, with what do we start? We start with the diameter. You are aware of this particular graph which was shown to you. The graph is based on which we are going to find out the diameter. So, the data are already given to you. The liquid flow rate, the vapour flow rate, the vapour and liquid densities are given. I have already calculated the volumetric flow rates for your convenience.

So, now let us proceed in this case. We start with assuming TS=450 mm. So, once TS is assumed, we are in a position to find out F_{LV}. For our case what is F_{LV} based on our liquid flow rate and the vapour flow rates? I will just put down the values so that in case you have done anything wrong, you can check it up also.

So, therefore, this gives you something like 0.0425. Now, from here if you can find out 0, 1, 1, 2, 3, 4; so you can go up, we have taken the tray spacing as something 1, 2, 3, 4. So, it should be somewhere here. So, it should be somewhere here. From there you can find out what is K_1 equals to; from here if you go straight, roughly you will find K_1 will be equal to roughly 0.0082.

Now, once you have found out K_1, then, in that case, we can calculate this. But we have to remember the sigma(σ) was 28.25. Now, I would like to remind you that this particular whole thing. This was, rather this graph it is based on sigma(σ) equals to 20 dyne/cm. So, therefore, if and we assume for our purpose that A_0/A_a, this is going to be 0.1.

So, therefore, we need to correct K_1 just for the correction of sigma(σ). We will not introduce any correction for A_0/A_a. So, therefore, once we have found out K 1; from there we can find out $K_1^{corrected}$, this is simply $0.082\left(\frac{28.25}{20}\right)^{0.2}$. So, this gives you roughly about 0.088.

So, therefore, we get the $K_1^{corrected}$ as 0.088. Now, once we have got it; then using this particular equation you can make the substitutions and from there you will get $U_{fV,n}$ to be around 1.4456 m/S.

Now, here we can assume J the approach to flooding to be 85 % as I have told you. So, once we have assumed that, we can find out U_{vn}. It will just be from that particular basis, it is going to 1.4456 into 0.85, which is going to give you as 1.23 m/S.

So, from there you can find out the net area. The net area is going to be around say $0.1195 m^2$. U_{vn} was equal to 1.23.

Now, we know that $A_n/A=0.88$. So, from there you can find out A. I can do it here also, we can find out A. Now, this A we find it out, this is going to be around $0.1358\ m^2$. Now, based on this, we can find out the diameter.

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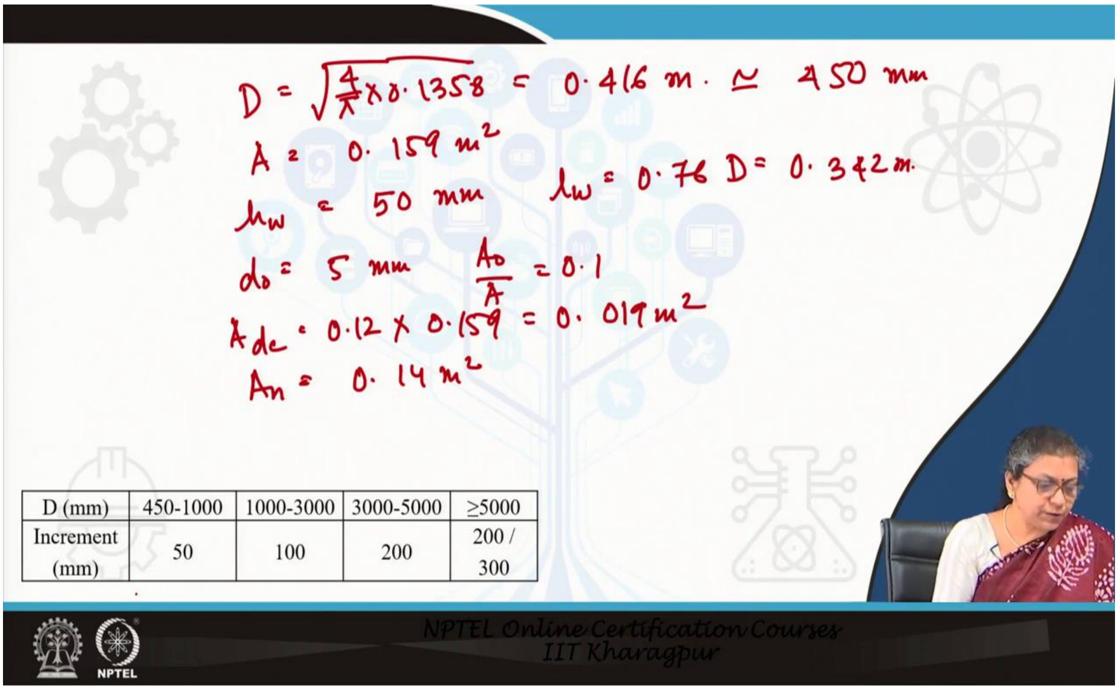

D (mm)	450-1000	1000-3000	3000-5000	≥5000
Increment (mm)	50	100	200	200 / 300

So, therefore, if we can find out the diameter in this particular case. More or less we get the diameter as 0.416 m. Now, if we refer to the standards, we find that roughly their diameter for this particular range, it is taken off to the next higher value for a proper rounding referring to the codes.

So, therefore, we assume the diameter to be 450 mm. It does not matter the diameters a little more, vapour velocity will be slightly less. If weeping is respected, we have no problems with this. So, therefore, we take the diameter, once the diameter is selected, you once more recalculate A and get A to be 1.59 m^2. From here more or less the weir height, it is always taken as typically a 2-inch weir we assume.

So, h_w=50 mm, l_w =0.76 D. So, therefore, l_w is 0.342 m. We to start with I have told you, we assume the diameter of the perforation (d_0) to be 5 mm. We assume A_o/A=0.1.

So, from there let us find out the other distributions. So, therefore, based on this diameter, the A_{dc} it is going to be 0.12 into 0.159, which gives as 0.019 m^2. The net area we need to recalculate once more, comes to 0.14 m^2. So, therefore, we have calculated more or less these things.

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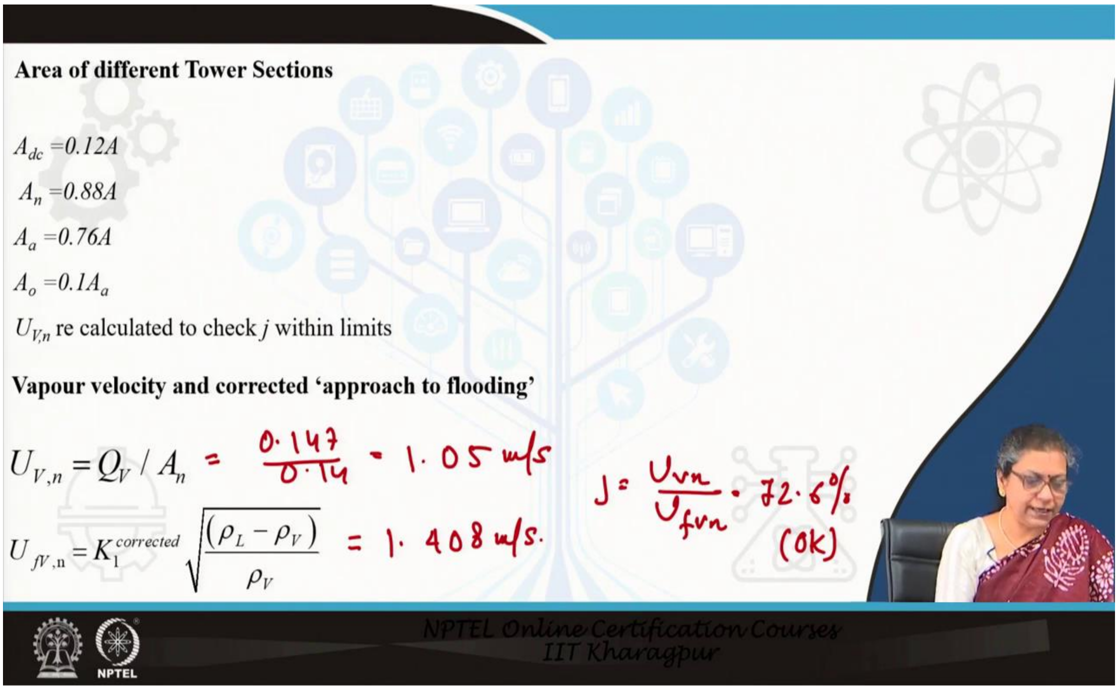

Now, once these are calculated; with this particular thing, let us find out the corrected approaches. So, therefore, all these things more or less we have calculated and we have kept. What is the next thing that we will do? See the diameter was rounded off. So, with everything we need to check up the corrected vapour velocity and whether the approach to flooding is fine or not.

So, therefore, for this particular part, we know what is $U_{v,n} = \frac{0.147}{0.14} = 1.05\ m/S$. We already know that our $U_{fv,n}$ =1.408 m/s. So, from there we find that J, which is the approach to flooding $\frac{U_{vn}}{U_{fvn}}$ =72.6 %. Slightly less, but anyhow it is ok. It is more or less far removed from flooding.

So, therefore, we are fine with this. Now, after this what is the next thing that we would like to do? We would like to check for entrainment.

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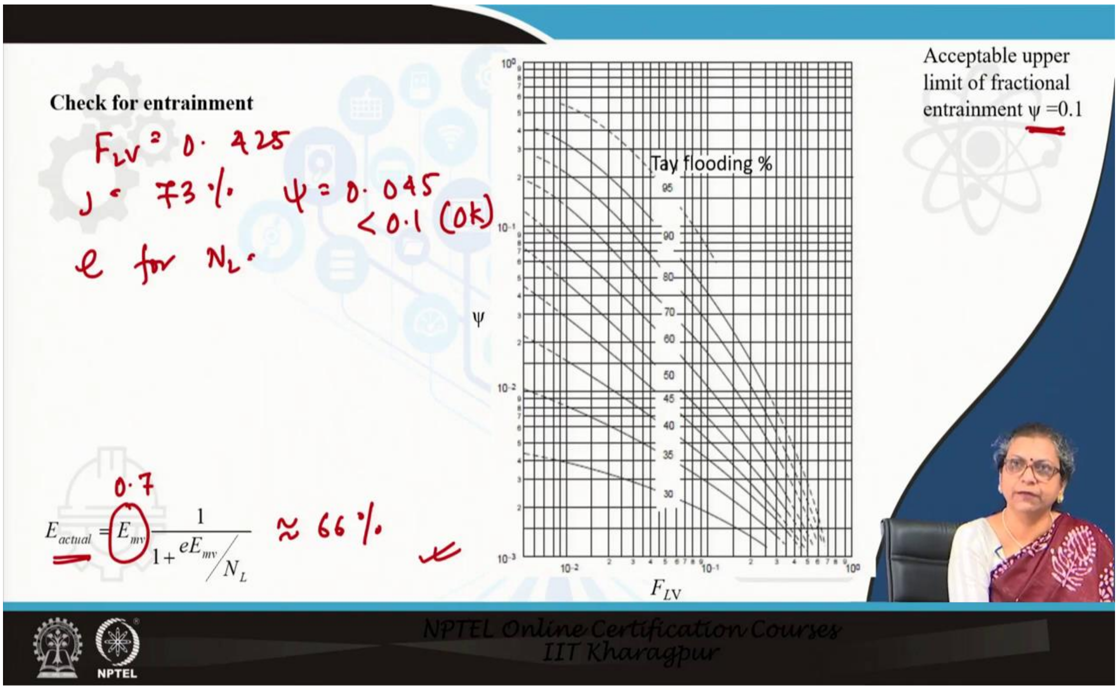

If you remember that this was the graph that we had taken up for entrainment. We have already calculated F_{LV}=0.425, J=73%. So, from here if you take it up 0.425 and around 73% flooding. In that particular case, you can just check it up, you will get ψ is equal to 0.045. The acceptable limit is given here. So, therefore, this is less than 0.1. So, definitely, we can proceed with this particular design, this is fine for us.

The additional information we would like to find out is the total amount entrained, which means the total amount entrained for say N_L equals to the moles of the liquid. So, what is the total amount entrained? If you want to find roughly, you can find out that the total amount entrained and then you can find out by how much the Murphree tray efficiency has been influenced.

To start with you can assume the Murphree tray efficiency to be something around 0.7 or 70 % and you can calculate the actual. You will find this roughly to be around 66 or 65 %. So, it is not very far removed from the Murphree efficiency that you have assumed. If for your tray you can assume a higher Murphree efficiency. You will get higher E_{actual}. We find that these two are not much removed. So, therefore, this design is ok as far as entrainment is concerned.

So, after entrainment, we have the diameter, we have everything. So now we will go for the tray layout.

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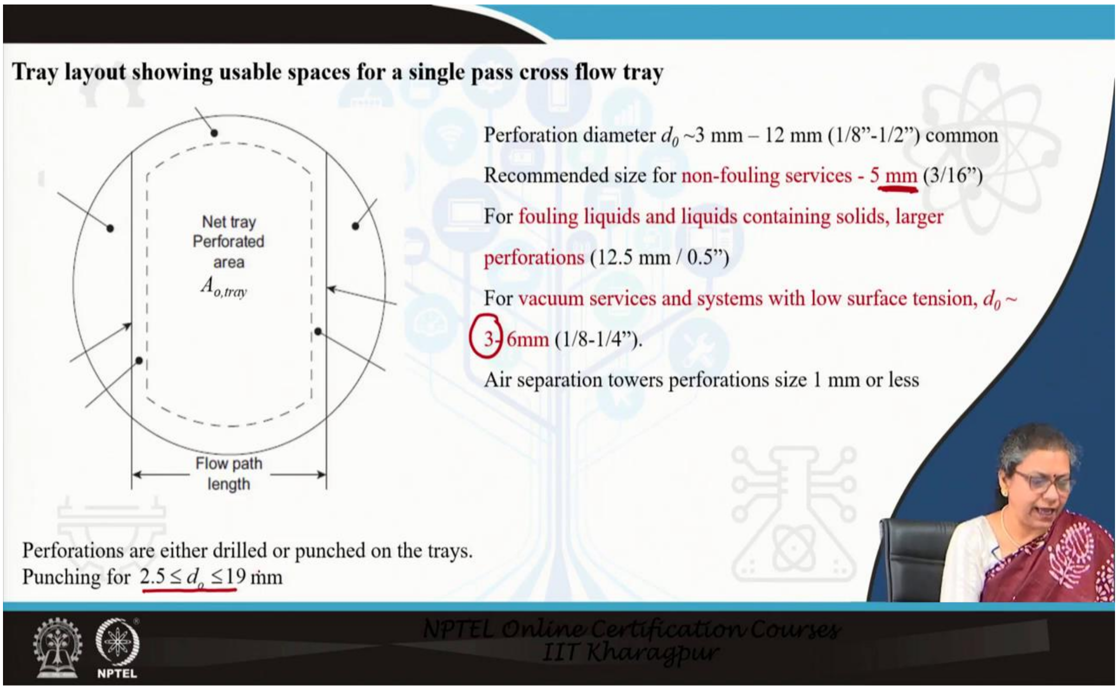

Now, there are certain thumb rules which are usually followed for the tray layout. I have already told you that since ours is a non-fouling service; we have already assumed the perforation diameter to be 5 mm. Just for you to remember, suppose we have a fouling liquid or suppose we have a liquid which are containing solids. In that case, there is a chance of the perforations getting clogged. Under those particular situations, we would prefer to go for a higher perforation diameter.

Again, if we are having vacuum services or we are having systems with low surface tension. Then we would be adopting instead of 5 mm. We can go for a 3 mm column. For air separation towers etcetera, the perforations can be much less. But for our purpose, we will go for 5 mm diameter perforations. Remember one thing that, these perforations are either made by drilling or they are made by punching. Normally punching is used if the diameter varies between 2.5 and 19 mm.

When we are making the holes through punching, then the dimension is often decided by the diameter of the punching die.

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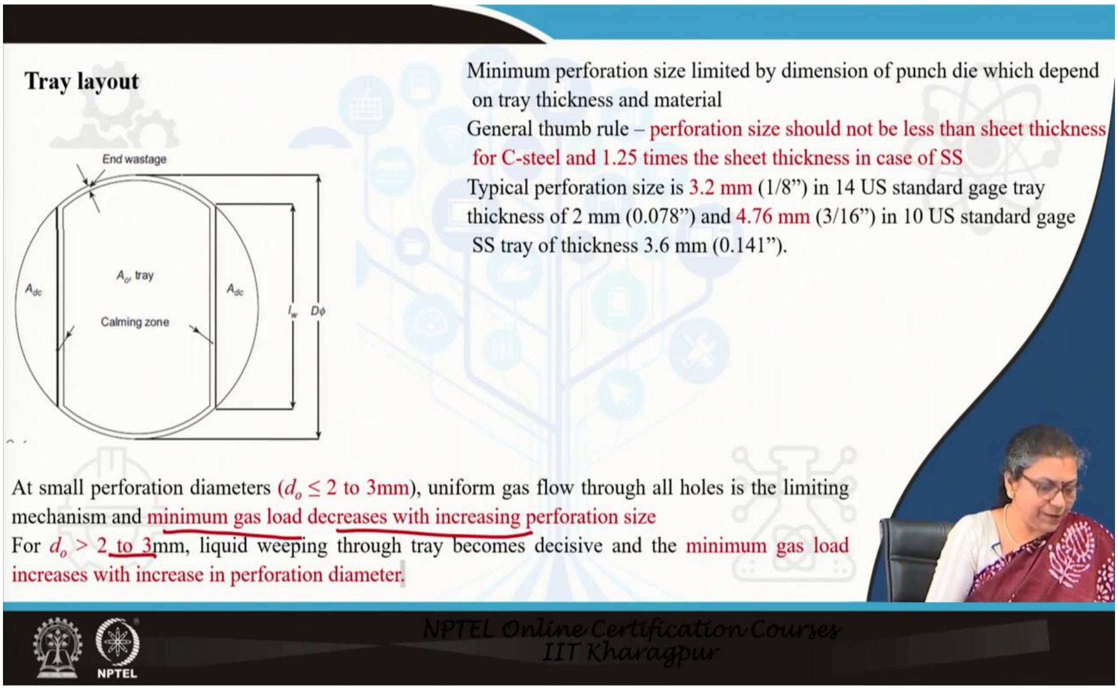

Just it is for you to keep in mind that the minimum perforation size under that case is limited by the dimension of the punching die that depends upon the tray material and the tray thickness. Normally, we adopt either carbon steel or stainless steel materials.

So, therefore, there are certain thumb rules, like the size of the perforation should not be less than sheet thickness for carbon steel. 1.25 times the sheet thickness applicable for stainless steel. Based on this, the typical perforation size for your stainless steel for different thicknesses, are all given 3.2 mm in 14 US standard gauges. The thickness of 2 mm, 4.76 mm for 10 US standard gauge. A SS tray thickness of 3.6 mm etc.

So, based on that also tray, your perforation diameter can be selected. Depending upon the problem, you will be selecting the perforation size. But conventionally to start with, we start with a perforation size of 5 mm. Now, something is interesting I would like to tell you before I proceed further.

If we go for a perforation size less than 2 to 3 mm. We find what is the limiting operation. The uniform gas flow rate through all the holes, because then it is a challenge to see to ensure that all the holes, the gas is bubbling out uniformly.

So, under such a condition we find that the minimum gas loading decreases as you increase the perforation size. But if you go for larger perforation sizes say greater than 2 to 3 mm. Then under that condition, the uniformity of gas flow through all the holes is not a deciding factor. On the other hand, liquid weeping becomes the decisive factor.

So, therefore, under that condition, we find that the minimum gas load increases with an increase in perforation diameter. So, these are the small things that you need to keep in mind.

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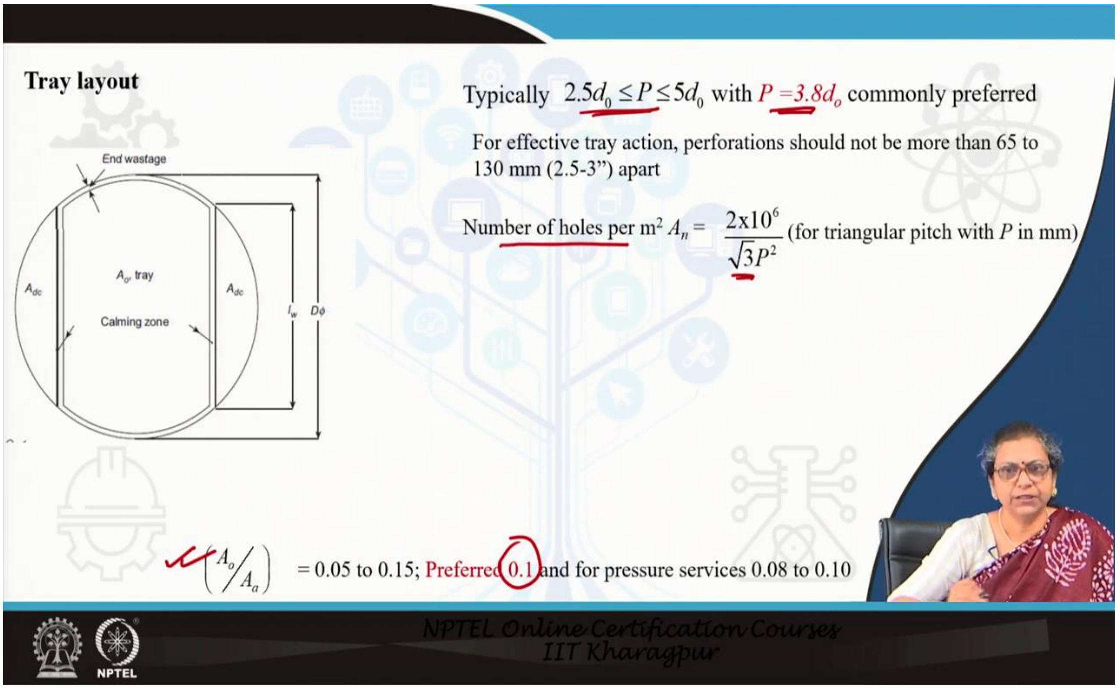

Along with that, once the hole diameter has been fixed, then next we come to fix the pitch. Now, the pitch conventionally again to start with, you can use this particular pitch and once the pitch and diameter are fixed, we would we can fix the number of holes per meter square of the net active area.

When it is a triangular pitch, then from geometry, we know that this is the total number of holes. Now, you can do one thing, you can decide their perforation size, you can decide on the pitch and then you can calculate the number of holes and try to accommodate the number of holes. We can also go a little different; we know that A_o/A we have assumed it to be 0.1.

So, that the total number of, the total area occupied by all the holes, you can easily find out from this A_o. Now, once you know this, you know the area of each hole, from here you can find the number of holes.

Once you have found the number of holes, then from this formula you can find out the P. Then you see whether the P is falling, more or less it is falling within this particular range or it is closely obeying this particular range. If that is admissible, we can proceed with it or else we have to go for a lower pitch or higher pitch and we have to adjust accordingly.

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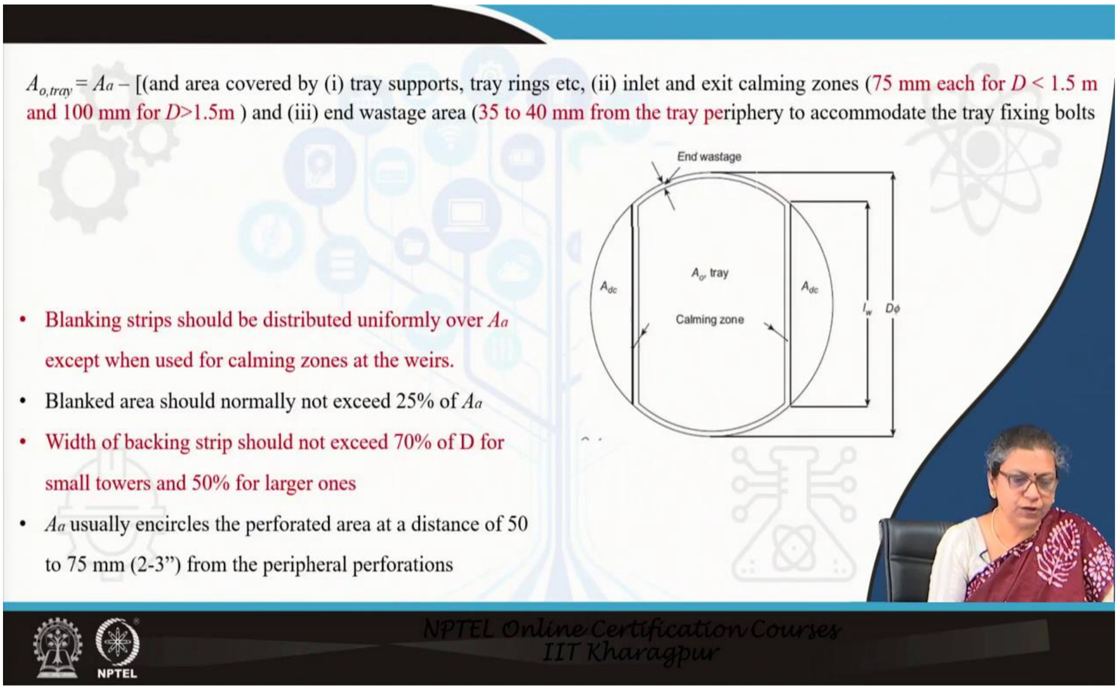

So, let us see if we go around with the tray layout.

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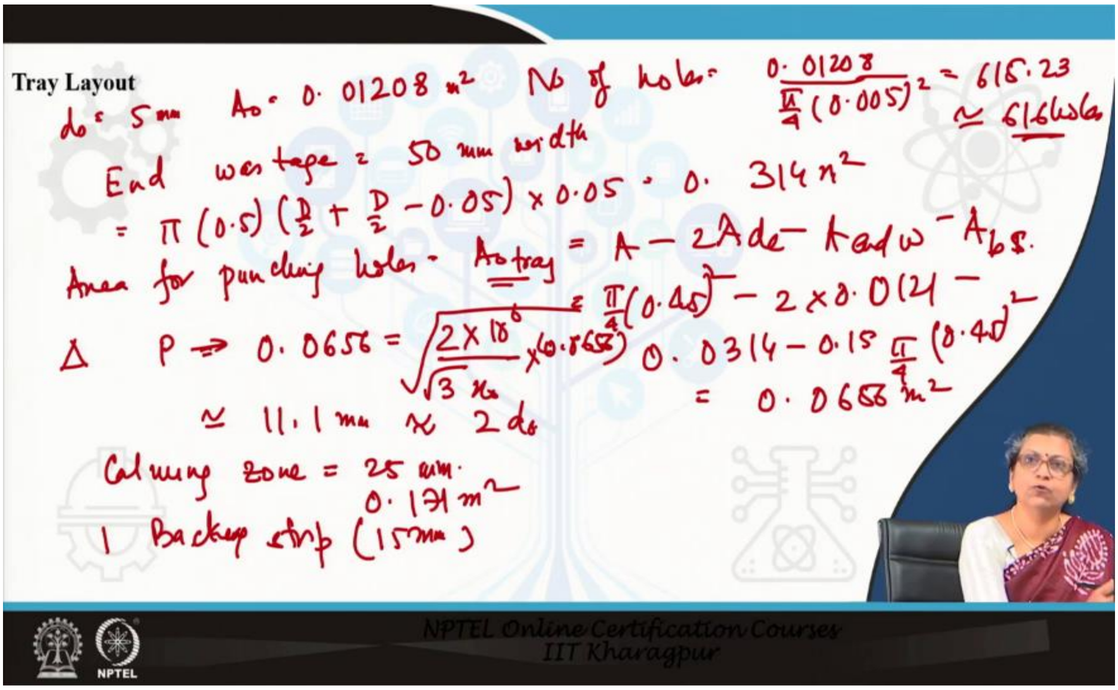

Then in that case for what do we have in this particular case, d_o=5 mm, A_o, we have already calculated this is 0.01208 m^2. So, from here you can calculate the number of holes. What will be the number of holes from here you get? It is nothing, but $\frac{0.01208}{\frac{\pi}{4}(0.005)^2}$.

One thing you need to remember, consistency of units; this is where the students often in a hurry they make a mistake and then the problem starts. So, from here you get something like 615.23, we take it as 616 holes. We know what is the end wastage area, I have already told you it is around 50 to 100 mm. So, therefore, let us start with the minimum, so that we have the maximum amount of the active area.

So, this is 50 mm in width. So, you can find the end wastage area. This is going to be $\pi(0.5)\left(\frac{D}{2}+\frac{D}{2}-0.05\right)\times 0.05 = 0.314\ m^2$. Therefore, what is the total area for punching holes? So, what is this particular area, which is nothing, but $A_{o,tray}$?

If you remember this ($A_{o,tray}$) equal to $A - 2A_{de} - A_{endw} - A_{bs}$. So, therefore, you can keep on substituting all of these. This is $\frac{\pi}{4}(0.045)^2 - 2\times 0.0121 - 0.0314 - 0.15\times \frac{\pi}{4}(0.45)^2 = 0.0656\ m^2$. The backing strips, I had told you in the last class, more or less I think 75 mm to 50 mm width of the backing strip if we take.

So, if we consider a triangular pitch, then in that case we find that what will be the pitch for corresponding to this particular $A_{o,tray}$. If you calculate this out, you will be getting this is 0.0656 using the formula that I have shown you. This will be $\sqrt{\frac{2\times10^6\times0.0656}{\sqrt{3}\times616}}$.

So, therefore, from here we get the pitch is roughly equal to 11.1 mm, which is almost equal to 2 d_o. So, therefore, we take this up and we find that this is fine.

Now, we can take up the calming zone of 25 mm. So, therefore, we get the total calming zone. We consider one particular backing strip. So, we have considered, in this particular case, we consider a calming zone of 25 mm. So, therefore, you can find out the total area of the calming zone will be around 0.0171 m^2.

This will be the total coming zone in one particular tray. You can consider one particular backing strip and which is 15 mm wide. I have shown you and accordingly, we have done it. So, in total what do we have here? We are having 616 holes and this has been accommodated in a triangular pitch, where the pitch is twice the diameter.

Once this is done, then we will be going for calculating the tray pressure drop.

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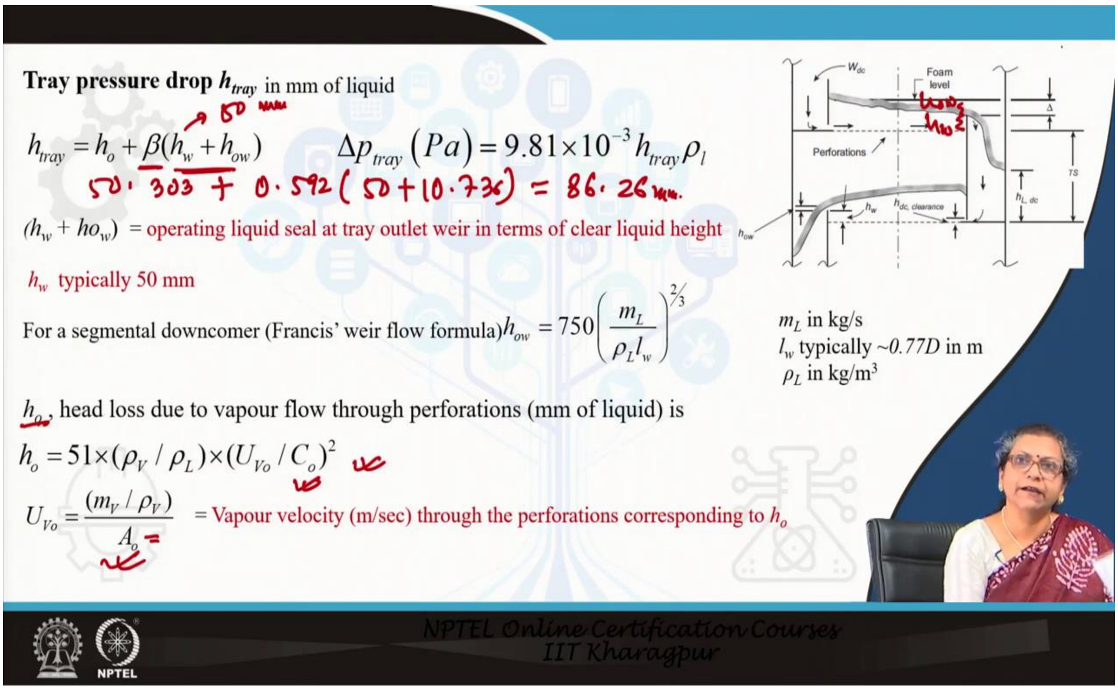

What will be the tray pressure drop? On the tray what is there, there is a liquid level. What is the liquid level? It will naturally be equal to the height here h_w plus the height over the weir which is equals to h_{ow}. Along with that what will be there? There will be some particular head loss as the vapour is flowing through these particular perforations.

Now, we have to remember that the liquid which is flowing over h_w and h_{ow}, that is aerated; it is not an unaerated fuel liquid mixture. So, therefore, the equivalent height if you find, will be the total liquid height multiplied or corrected with an aeration factor (β).

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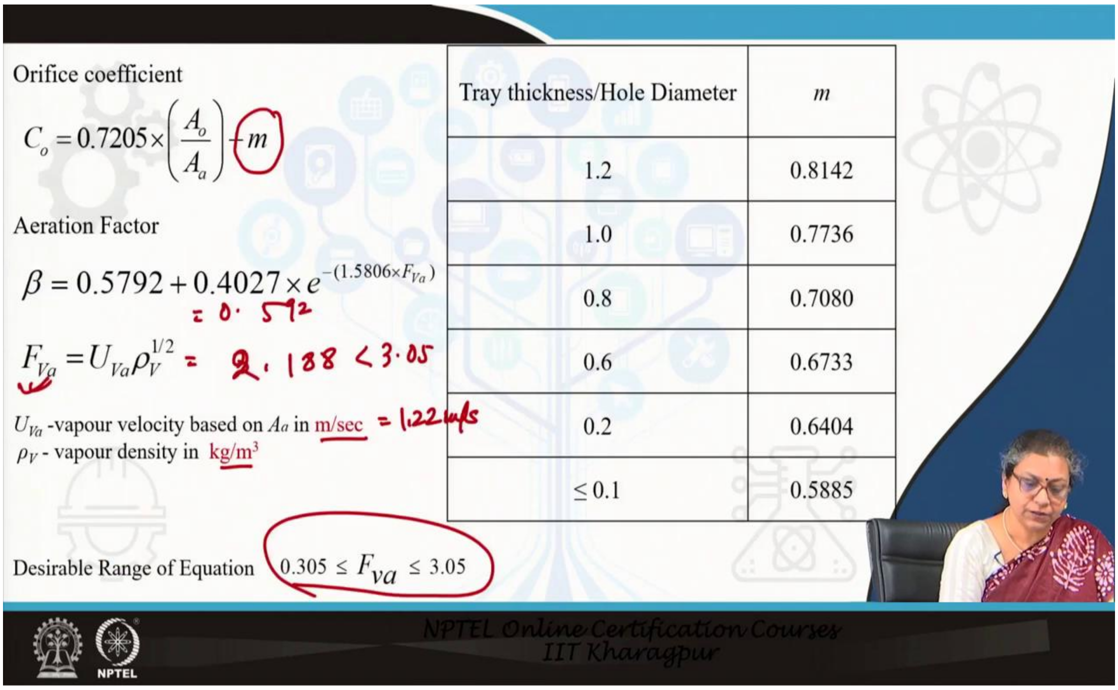

Now, this particular aeration factor, normally it is given by an empirical correlation in terms of the vapour factor based on the active area.

So, therefore, remember one thing that, whenever you are using such correlations; these correlations are derived from experiments or standard practices. you must keep the units in mind. So, therefore, if you can calculate β in this particular case and then you know h_w, you know h_{ow}. So, therefore, you can calculate the total operating liquid seal at the tray outlet, in terms of the clear liquid height.

To calculate the head loss, again there is an empirical formula. In this formula you find that the head loss naturally will be depending upon the vapour flow through the perforations. All these heads are given in mm of liquid. You need to remember. So, to find out h_o, you need to find out the vapour velocity through the perforations corresponding to h_o.

So, this gives you the vapour velocity (U_{vo}). You know how to find out A_o. So, therefore, if you substitute all of these; then you can find out, you will be in a position to find out h_o and all this h_o, h_w, h_{ow}. h_w is typically 50 mm. For finding out h_o, you need U_{vo} which is there. You also need C_o, which is sort often, it is equivalent to an orifice coefficient.

C o is again given by this particular empirical correlation, where the factor m can be obtained if you know the tray thickness to hole diameter ratio. So, with all this, we find that we are in a position to find out the that the at the tray pressure drop. Just certain checks you have to do, when you are we are calculating F_{va}. It is important to find out that F_{va} lies in this particular range. Because based on this the relationship for β has been done.

So, you can start these particular things and you will find that the value of U_{va}. That you get will be equal to 1.22 m^2/S. F_{va} will be getting as something like 2.188, which is it is less than 3.05.

So, therefore, you can use up this particular β here. This β if you calculate from here, then you will be getting the β as something like 0.592. From where you can find out the tray pressure drop. This particular tray pressure drop, $h_{tray} = h_0 + \beta(h_w + h_{ow})$ can be calculated by using the formula. $h_{tray} = 50.303 + 0.592(50 + 10.736) = 86.26\, mm$

Once this is done, the next thing that we will be doing is that we need to check for weeping.

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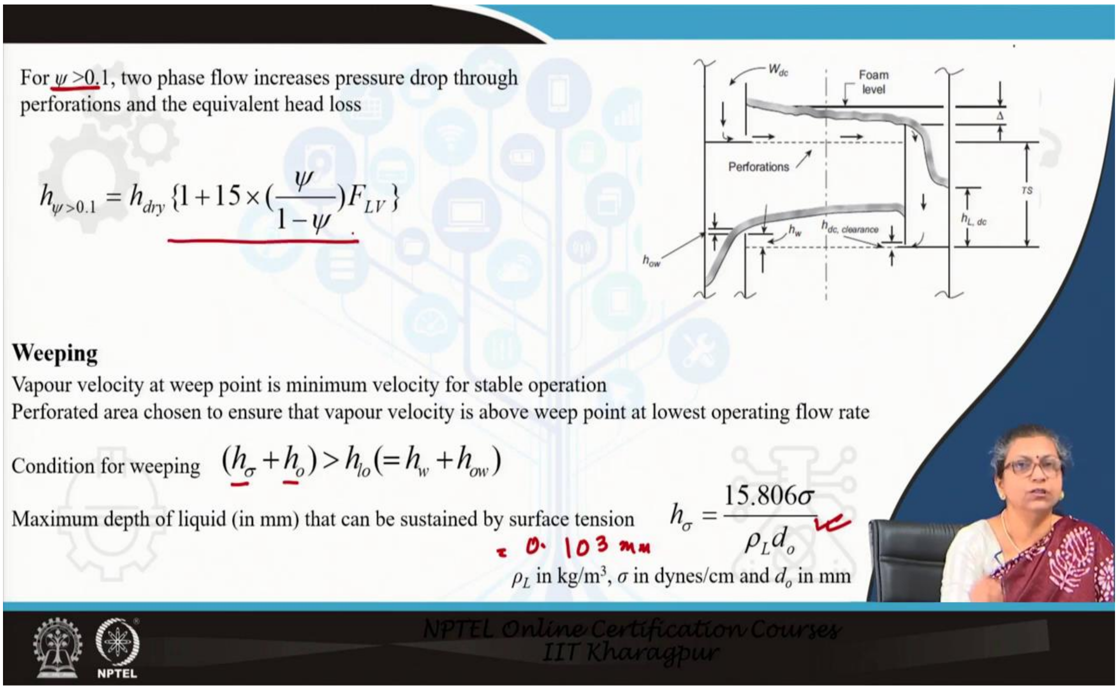

Now, you tell me, under what conditions you will be getting weeping? Naturally, you will be getting weeping. When you find that the vapour velocity is much less as compared to the liquid velocity or in other words, the head loss due to vapour plus the force due to the liquid surface tension that has to be greater than this particular situation, only under that, when this is satisfied, then weeping does not occur.

How to calculate the maximum liquid depth that can be sustained by surface tension? You can get this from this particular equation.

You can calculate and you can find out that this particular h_σ. The h_σ value can be calculated. This will be something around 0.103 mm. You can check it out and h_o. We have already calculated. So, therefore, most of the values are calculated here. If you can just substitute them. Then you will find that more or less your particular condition is satisfied.

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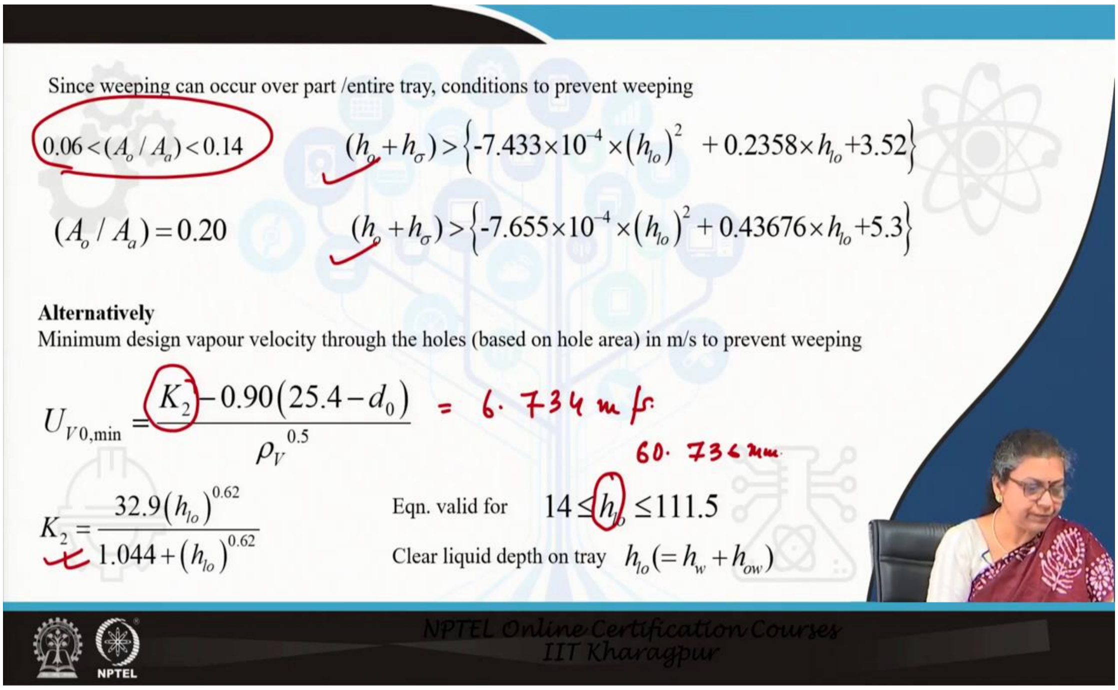

So, therefore, from here, you can find out the condition of weeping. Now, when you are finding the condition of weeping; certain things are important for you to know. Firstly, weeping need not occur over the entire tray at one time. It can occur at certain sections of the tray. So, therefore, the condition of weeping is obtained by this equation or this equation, depending upon A_o/A_a. So, in our case, this is the applicable thing.

So, therefore, what you need to know; based on whatever data we have calculated. You need to find out, you need to use this equation and you will find that this equation will be satisfied for your particular case. The other thing that we need to find out is, either you have to find out whether the head is sufficient to hold the liquid or else you can find out the minimum design vapour velocity from the holes to prevent weeping and find whether your actual vapour velocity is higher than the minimum.

The minimum vapour velocity can be found out again from some empirical equations. Where we find that this is expressed in terms of a constant K_2, where K_2 can be obtained from here.

Again there are certain criteria for which, by which you can find out K_2 when h_{lo} confirms to certain conditions. Well, so, therefore, if you check it up, you will find that h_{lo} here. You just check up this will be 60.736 mm. So, therefore, it is obeying here. From there if you find out $U_{vo,\,min}$. We will find this is equal to 6.734 m/S.

Well, and so from there if you find, you will find that more or less this complies to your case. Now, after this what is left after this you tell me?

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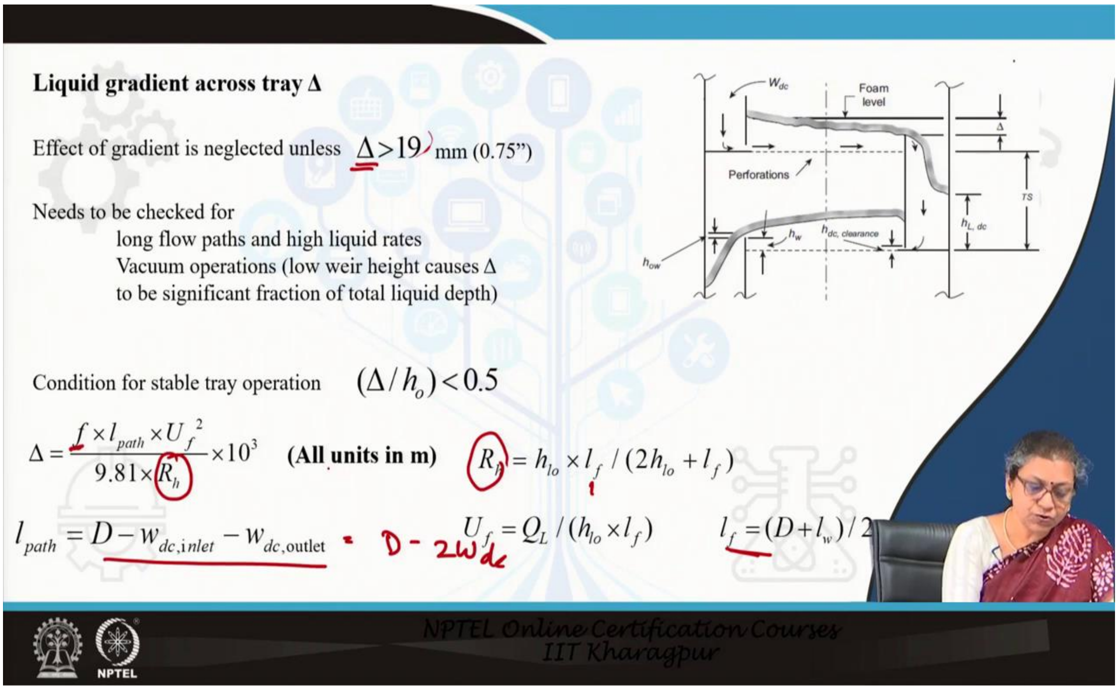

The next thing which is left is the liquid gradient across the tray. You know that the liquid gradient should not be too high. Now, this liquid gradient poses a greater problem for the bubble cap tray. In this particular case, you just need to check, if the gradient if it is less than 19 mm or 0.75 inches.

Only if it is greater than this, then only it has to be, it has to be taken into consideration. Generally, for sieve tray columns, we do not have this. So, how to calculate this delta? For calculating the delta, this is the standard formula, where this is the friction factor (f). l_{path} is the total path of the liquid. All these formulas are laid down. You just need to substitute the values and you have to do. $l_{path} = D - w_{dc,inlet} - w_{dc,outlet} = D - 2w_{dc}$

The width of the downcomer is the same for both cases. So, for U it is D minus 2 w d c and then this is the hydraulic radius of the liquid path. For here also you know all the things. l_f is given by this equation. h_{lo} have already found out. So,therefore, you can find out R_h in this particular case. Remember one thing; here all units are in meters.

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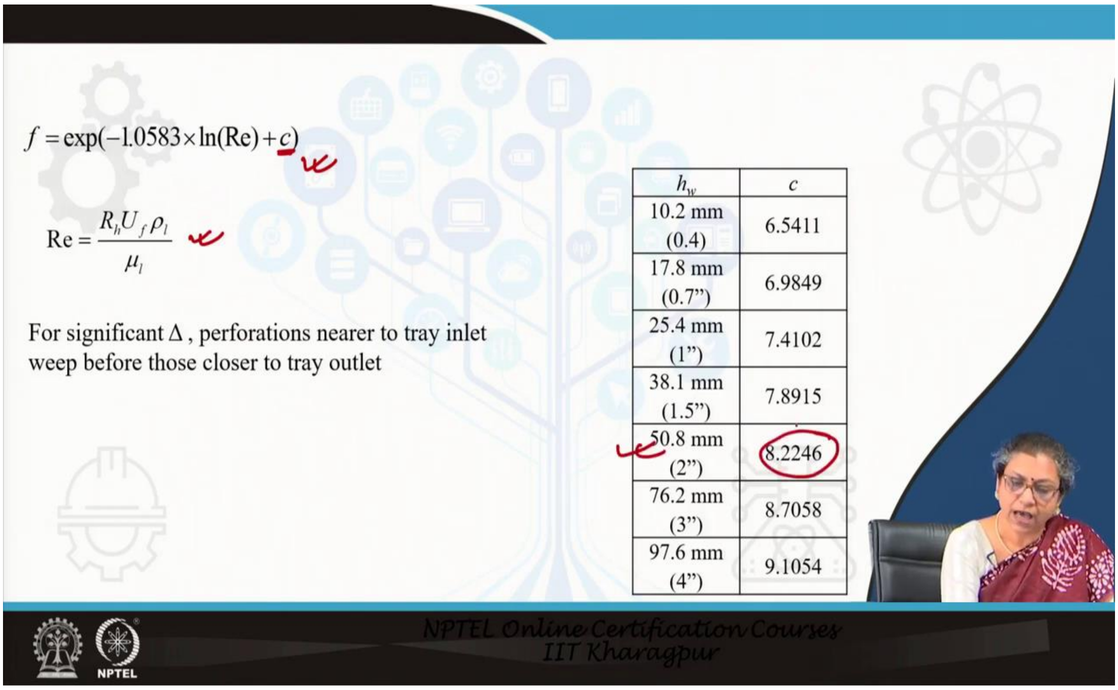

So, therefore, you can find out the friction factor as a function of Reynolds number, just like you do in other different fluid flow problems. Reynolds number can be found out from this equation and here in this particular factor, you have got a term c. This term c can be obtained as a function of the height over the weir. We have taken this, to for us c is this.

So, once all these things are substituted and you are supposed to check delta. Do it for yourself, for your case we will find delta is about some millimeter 7, 8 millimeters or something even lesser. In case, it would not have been, it would have been greater. Then what we do? We would have tried to see that certain holes could have been blanked.

One small thing I had missed, I would just like to mention that, if suppose your entrainment factor would have been greater than 0.1; then, in that case, the pressure drop which you have, the head loss due to vapour flow that you are calculating, this was just for vapour flow.

But if the ψ is higher; then in that case a liquid-vapour mixture would come and for that case, your h_o should have been calculated from this formula, for your case that is not required at all.

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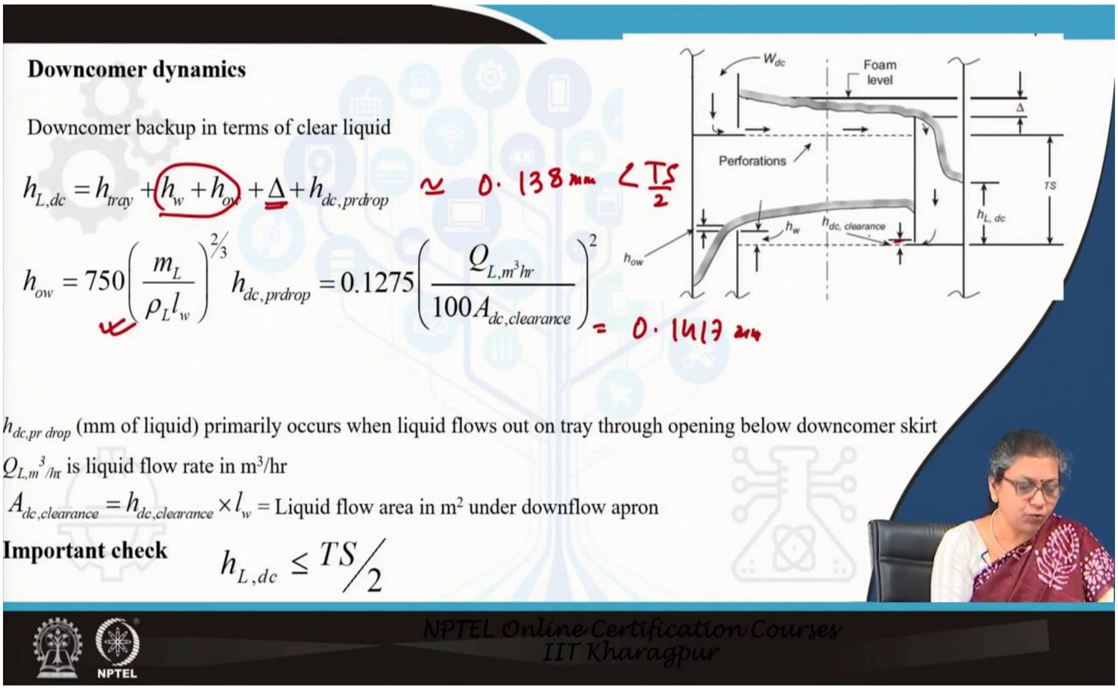

So, next what we have, the downcomer dynamics. This is similar to for all tray columns. What are the things in the downcomer that you need you to tell me? First thing you need to find out about this particular backup.

What are these backup equals to? It will be the h tray here and plus the height of the weir as well as the height of the liquid over the weir plus the delta plus the pressure drop which the liquid encounters, when it tries to flow through this opening and enter this particular tray.

Now, from here what is the height of liquid over the weir? This we can find out from something like the Francis formula. Here in this particular case if you find out; you will find that h_{ow} for your particular case, this is given as; let me just see where I have calculated this particular h o w yeah, from here I have just find out the h_{ow}, it will be around, I believe it should not be more than 10.736 or some mm, just check it up.

The h_{dc} pressure drop you can find it out from here. Where the h_{dc} pressure drop, it is primarily due to your Q_L /1000 A_{dc}.

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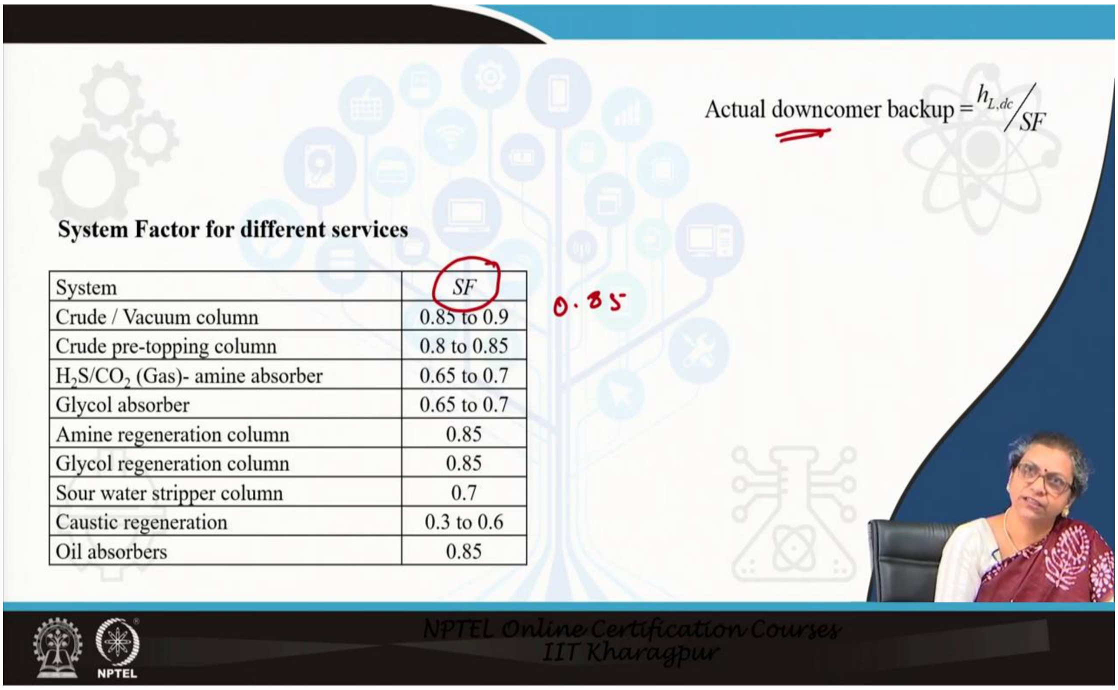

Where have I put it? You know it is here itself. So, therefore, yeah this one. So, therefore, the h_{dc} pressure drop you can calculate. You will be getting this as 0.1417 mm and these are all known to you, delta also you have calculated. So, you can substitute all of these, more or less you will be getting something like about 0.138 mm or 0.137 mm something, which is less than your half of tray spacing, so therefore it is fine for you.

The next thing, one thing you need to remember here that, more or less from here the h_{Ldc} you have calculated. The actual downcomer backup will be something more than that. Why because in reality in the downcomer a frothy mixer comes. So, if there is a lot of froth; then to calculate the actual downcomer backup. You need to consider these particular system factors.

For our case, more or less we can consider SF to be around 0.85 and calculate the actual downcomer backup. Anyhow that we will find that, that will also be less than half of the tray spacing.

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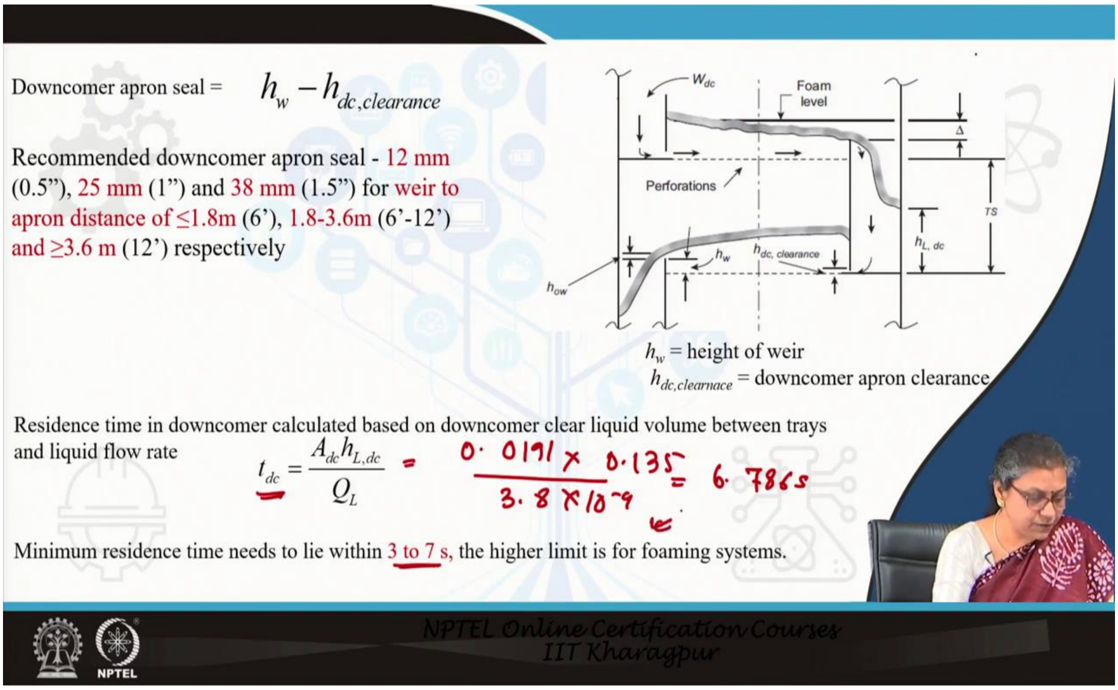

So, once we have calculated those things, the next thing is the residence time in the downcomer. Now, it is important to see that the residence time lies between 3 to 7 seconds. So, for the residence time (t_{dc}), you can calculate, you can find this will be equal to 0.135; this is for the h_{Ldc} that I have got 3.8 into 10 to the power minus 4, more or less you get this as 6.786 seconds. So, therefore, this lies between 3 to 7 seconds. So, therefore, this is fine for us.

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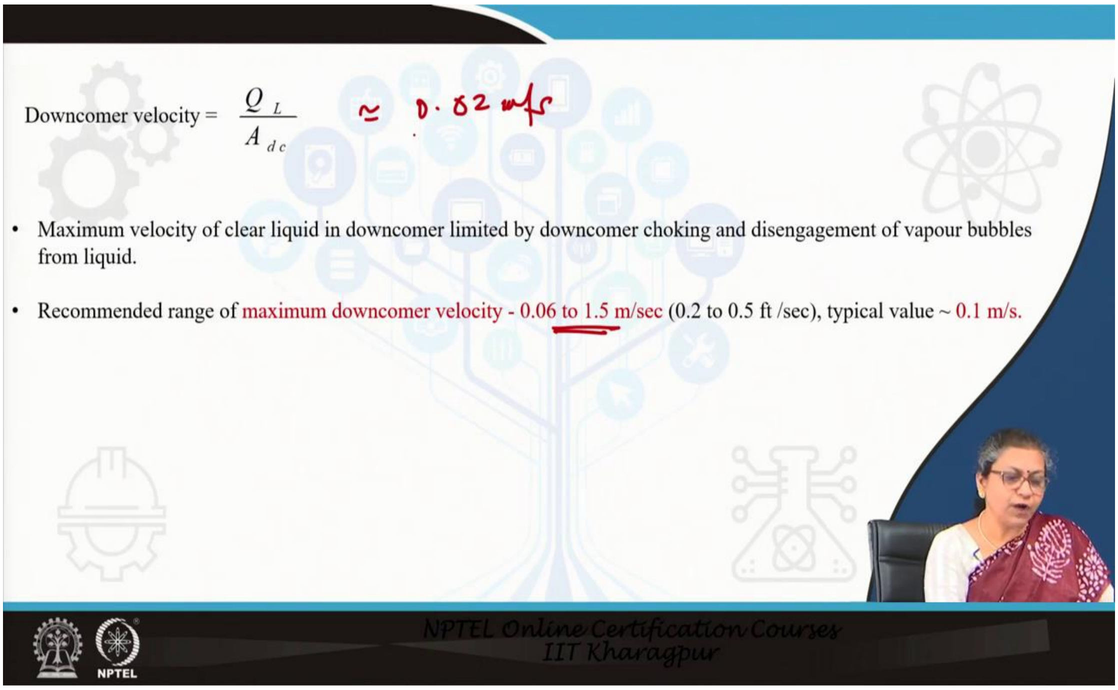

The next thing is the downcomer velocity. The downcomer velocity also you calculate, more or less you will be getting this roughly around 0.02 m/S.

Therefore, the recommended range of velocities is this. So, more or less we find that this is close. So, therefore, we can comply with this, it is sufficiently below the choking level.

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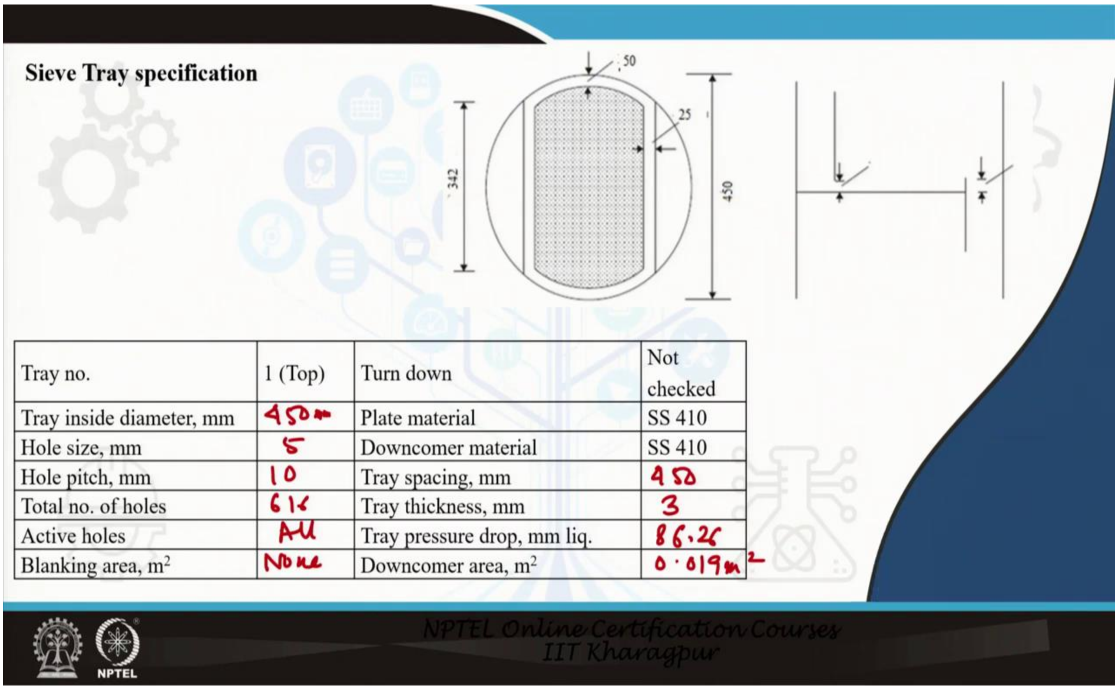

So, once everything has been calculated, then in that case generally show the layout in the way I have shown you. Here you need and you need to fill up all the relevant dimensions. The tray inside dimension was said 450 mm, hole size 5 mm, pitch was taken around 10 mm, number of holes was 616, we assume that all the holes were active.

We did not have to blank anything. The plate material downcomer material we have selected; the tray spacing was 450 mm, the tray thickness was 3 mm, roughly the tray pressure drop was around 86, 87 mm, the downcomer area was roughly around 0.019 m^2. So, this is how a sieve tray, complete sieve tray design is specified.

So, with this we complete the design of the sieve tray; we have discussed how to find out the diameter, the tray layout, the downcomer dynamics and the checks are to check that, we have sufficient downcomer liquid backup. We have checked against flooding, weeping and flooding with entrainment flooding as well as downcomer choke flooding.

So, with this we have completed, you can try out the problem yourself and see whether the values are tallying with it. Only thing that you need to do is to keep the units in mind because most of the equations and relations that we have used are empirical.

Thank you so much.