Principles and Practices of Process Equipment and Plant Design
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Module - 02
Lecture - 28
Bubble Cap Tray Design (Contd.)

Welcome and good day to you all. Today we are going to do and complete the Bubble Cap Tray Design part. This we have continued from the previous lecture and we moved like this.

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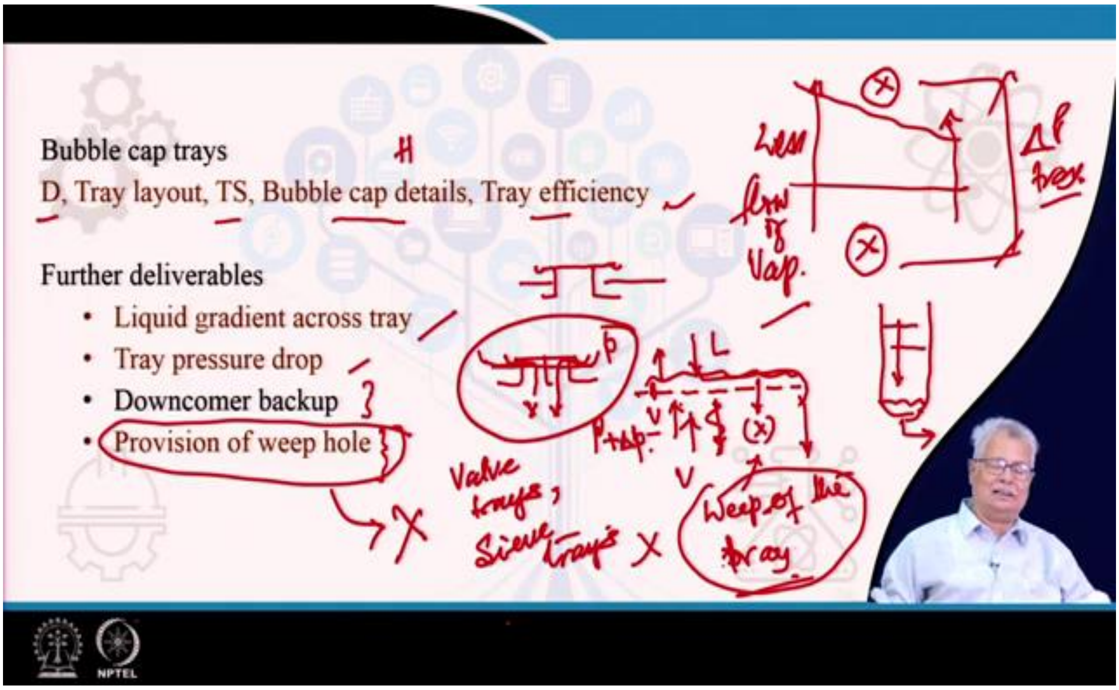

In the last lecture what we have done is, we have found out the diameter of the bubble cap tray or tray plate whatever you may call by two methods; one was Souders Brown method, the other one was Fair and Mathews.

We have decided on the tray spacing. We have been aware of the bubble cap details. We have also gone through the tables which contain these details and we have found out that what our tray layout should be. At the same time, we have talked about the different sections of the tray and how they are to be introduced inside the column itself.

Any tray will have some amount of entrainment and this is going to reduce the murphy tray efficiency of that specific tray and how to estimate the revised murphy tray efficiency that also we have seen. That means, we know at this particular point of time, the diameter definitely, the tray spacing which leads to the total height of the column. The details and the layout of the bubble cap on the tray itself in the active area and the revised efficiency we have recalculated.

To have a complete delivery of the design of the tray, we are also to supply or rather we are also to find out the liquid gradient across the tray. We know very well and we just recapitulate that a liquid gradient across the tray should be as slow as possible to ensure that you have a proper cross-flow. If you have a large gradient of liquid over a tray; in that case wherever you have lower liquid, your flow is going to be more.

And here definitely it will be less; obviously here will be less flow of the vapour, because the resistance to flow will be much more. We have to have an idea about the pressure drop between these two; that means what is the Δp across the tray.

We will try to find out a systematic way of estimating the same. Because we definitely will be having a pressure difference between the column bottom and the top. But we have to ensure that this pressure difference is not large. Because it makes a difference in the volatility at the top and the bottom of the tray.

While designing the sieve tray with a downcomer, the details are how to find out the bank backup in the downcomer and how exactly it affects the performance of a tray that has been told to you. So, we are not going to repeat it. There is another aspect of any tray which is very important.

A tray normally will be having a vapour flow up approaching it. A liquid flows down which is approaching it. The vapour will be leaving and the liquid will be coming down ultimately. That means, you will be having the liquid flow, but it is not across the tray directly. That means it goes like this and then falls.

So, I will just show the liquid flow this way. It comes to the downcomer. But it is also possible and it is necessary at times to have holes; the holes should be on the traits, on the I will just show you where it is. In the case of a sieve tray, there were many holes. So, quite naturally what we wanted was that it should flow across and it should not leak. That means this type of flow is called the weep of the tray.

That means, during the normal operation I do not want any weepy, but during the operation I have a level of liquid. Once my operation of the column stops. What I do not want any liquid to remain up. So, what I want is all the liquid in my tray. All the liquid in my trays should gradually drain down and get accumulated from where I can take it out.

That means, I want this type of weeping to take place only when my column is not in operation. During operation, I do not want my trays to weep. Now, in the case of a sieve tray, you already have holes. It does not weep, because you have a vapour here which is approaching these holes and definitely there is a pressure gradient $p+\Delta p$ and here you have a lower pressure, which is only p.

So, that also holds the liquid. It does not allow weeping through the tray itself. This is to some extent is also true in the case of your valve trays. In your valve trays what do you have? In your valve trays, if you have a hole, you have typically a plate with legs. Now, what is normally done is, the edges of the plate that are upturned at only at certain points.

So, when it rests like this. So, what happens is, there is the possibility of the weeping which can take place this way, so it weeps. So, you do not require the provision of weep holes in case of your valve trays and obviously. You do not need in case of sieve trays. You do not need this. In the case of the other type which is the bubble cap, you definitely will be needing it. Let us go for the simplest thing to tackle, we will tackle the weep hole and its provision first.

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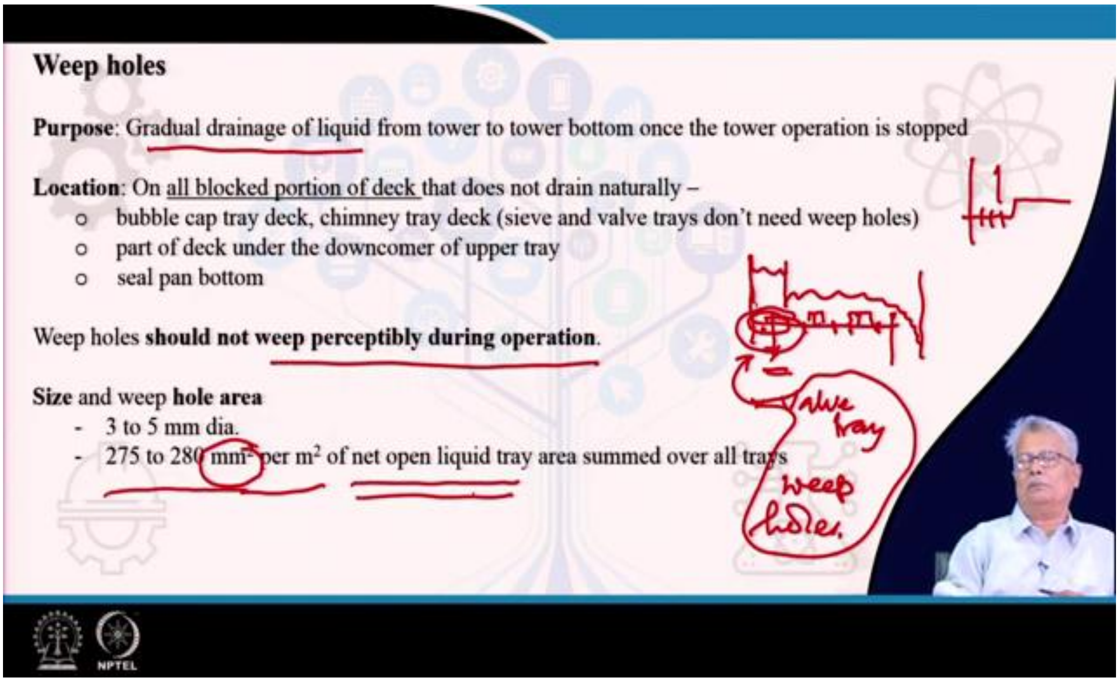

The purpose of a weep hole is gradual drainage; that means when my operation stops from the tray I want everything to come, all the liquid to get collected in the column bottom. And why it happens, we just explain that. Now, this draining will be necessary where? It will be needed on all blocked portions of the deck. That means where it does not drain naturally or freely. What are these places and locations?

Suppose this is a bubble cap tray, I am not showing the bubble cap here. This is the downcomer of the upper tray and this is the downcomer belonging to this tray. So, what you have here; you will have your bubble caps and you have a downcomer back up, the liquid flows this way. This portion of the tray particularly of any type. I mean if it is a sieve tray with a downcomer. Even on the sieve tray or in any other places. You will require this portion to be drained.

So, in case you want, you may be required to provide the weep holes in this part, in case of valve trays. So, in valve trays, you will be having the weep holes only here; but in the case of bubble cap, you have to have it here, you have to have it here, you have to have it here. Because you want your entire tray to be drained. So, the same thing is true in the case of seal pans.

If you have a downcomer sealed pan, if you have a downcomer which is like this and you have a sealed pan which is like this; you must have a set of weep holes here, which will allow draining of this when the column is not in operation. We do not want any weeping to happen perceptively during operation.

Typical weep hole sizes are 3 to 5 mm. It could be punched in most of the cases and drilled in some very rare cases. The typical area provided for weeping per tray per meter square of tray is 275 to 280 mm^2/m^2. You note the unit here, it is mm^2/m^2 of net open liquid area.

Now, the question is, why net open liquid area? Net open liquid area means, wherever you have a liquid level. So, this includes for your tray the downcomer area also and it is to be summed up over all trays. So, anywhere you have a liquid level and its surface area has to be summed up in meter square and you provide 275 to 280 mm^2 of weeping area per m^2 of the area that you have just now determined.

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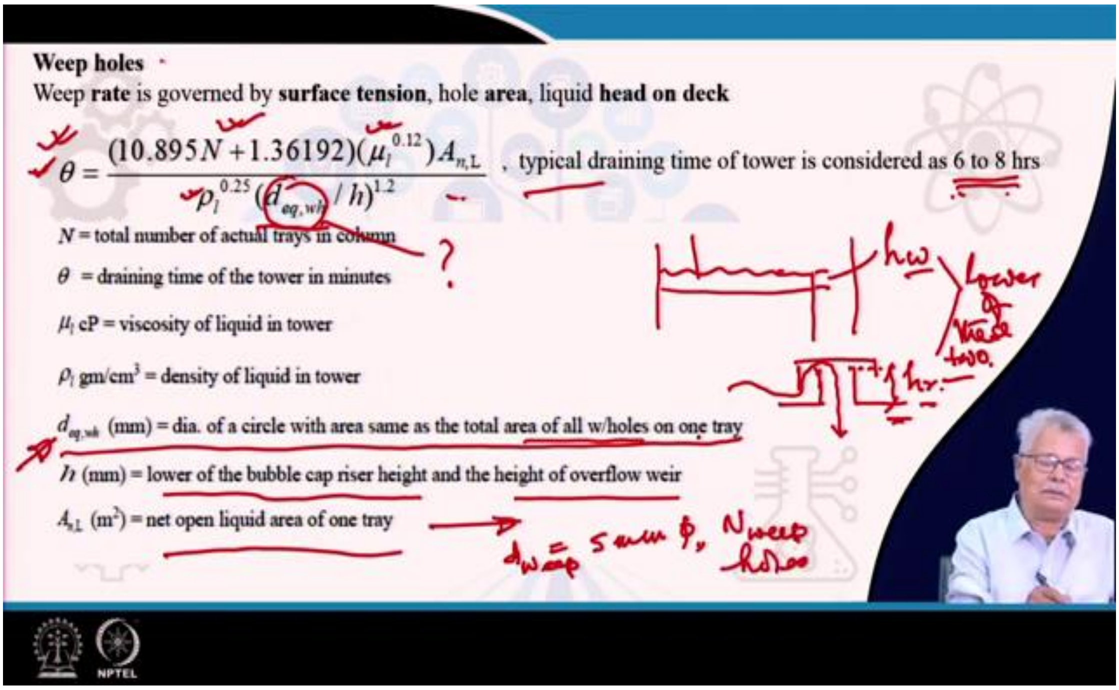

Now, why do we need to have these weeping arrangements? We want that after my operation has stopped. Possibly I will be sending my column for maintenance. The typical time we allow for a column to cool down is roughly about 4 to 6 hours. So, there is an empirical expression which talks about estimating the draining time of the tower in minutes, which is this θ. Theta (θ) is in minutes.

N is the actual number of trays which is provided in your tower. The liquid drains through the weep holes. So, it is viscosity is important. If its viscosity goes up, draining time should go up. So, naturally, it will be involving μ_l as well.

Now heavier the liquid, more will be the static head allowing it to pass through the weep hole. So, quite naturally theta (θ) is inversely related to rho l and rho l appears at the denominator.

Now, what you provide? You provide a weep hole area. The weep hole area here in this case is denoted by a particular dimension d equivalent of weep hole. That means it is basically the area of a circle having the same area as all the weep holes put together. So, you can have its definition here. It is a diameter of a circle whose area is the same as the total area of weep holes on one tray that is the formal definition.

Now, there is one more interesting thing that, how much liquid is to be drained? How much liquid is to be drained is depending on how much liquid was present. So, when you have a tray that is not in an operation. You have an outlet weir that is here.

So, naturally, you are expected to have if there is no draining, this will be your liquid level. It is also possible that when you have a bubble cap, you have which has got a riser over the deck and it goes like this, the riser height here may be h_r. When nothing is there is no air, you know is no gas flow this way. So the liquid is expected to come and get drained automatically up to this.

So, the draining would start normally at the actual tray level. So, the actual tray level is expected to be the lower of these two. That means if my h_r is higher, then I will be saying that h_r is the level. If h_w is higher, sorry the other one is the level.

So, what we have here, is lower the bubble cap riser height and the height of the overflow weir. I believe there is only one more item which is $A_{n,L}$, which is a net open liquid area of one tray. So, that gives us an idea that how much liquid has to be drained from that particular tray.

This is how you estimate. Now, my question is, how do we use it? The typical time for draining is 6 to 8 hours. So we know theta. If you have defined your system that, everything here except this term is known. So, if I set my theta to be either 6 or 8 hours, mind that your theta has to be minutes and in that case, we can find out that d_{eq}.

We know the total area of all holes on one tray. Now, what do we do? We decide whether we are going to have 3 mm, 4 mm or 5 mm holes. Typically it is either 3 or 5. On bigger trays you have 5, on smaller trays, you have 3 and there is one more thing which is also there. It also depends on the viscosity of the material that is being handled and also the surface tension.

Because there is a depending on the surface tension. The liquid whether it will pass naturally through a hole or not that is decided. So, you usually will be using 3 or 5 and based on that you fix up the number of holes.

So, your number of the hole is basically determined. Once you have decided the weep hole diameter to be say maybe 5 mm. In that case, you find the number of weep holes. So, this is how you find the weep holes and in fact, there is the simplest part of it.

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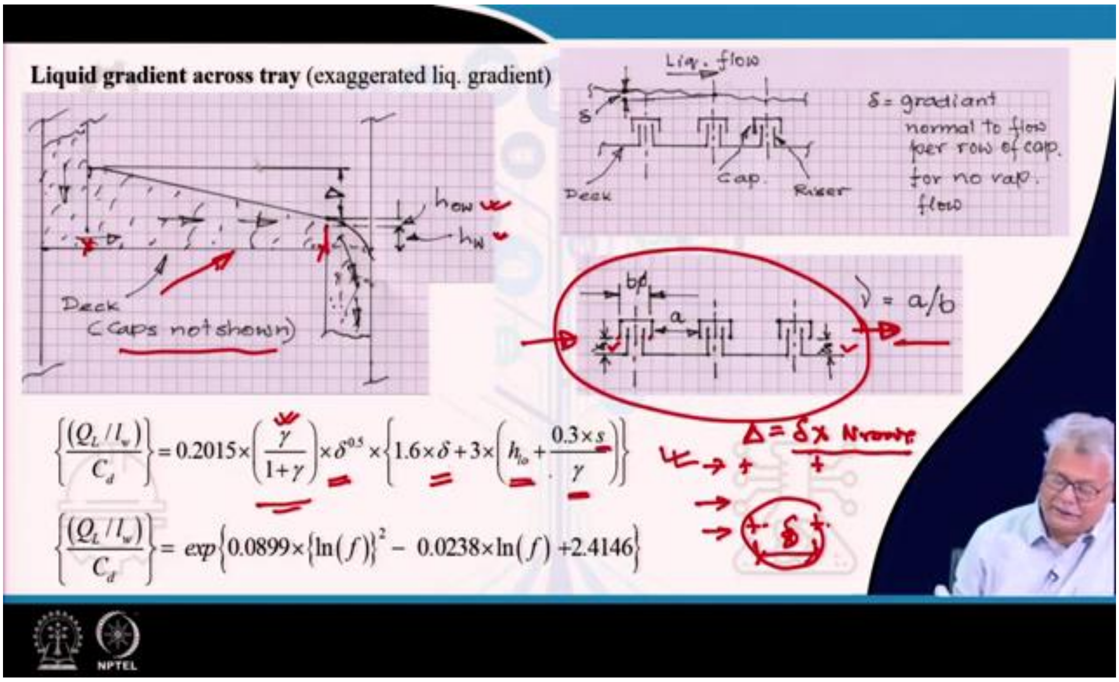

If my tray has to operate smoothly and without any channelling of that vapour going through that inner layer of liquid, we must have as low a difference in the level of liquid over the tray.

Here we have a schematic of the tray again. Here is my deck, this is my deck and the caps are not shown here. We have also exaggerated the level difference. What you will find here is something very interesting. You will definitely have an outlet where with a height h_w. When it flows over this, you require a minimum of 6 to 10 mm of the liquid level above this which is basically h_{ow}.

So, while designing, you must have considered h_{ow} anything between 6 and 10. If it is below 6, normally the passage of liquid over the weir is non-uniform. So, that you have to avoid. Now, what you have to do is basically; you have a look at the bubble caps, the bubble cap which is mounted here. Offers resistance to the liquid flow.

Let us see what all things affect this resistance. One is I have the riser here and I have my clearance below the cap, which is basically clearance below the shroud which is small s and this is also small s. If we have we can have or rather we will have a specific gap between the caps and the caps will have a diameter b. So, quite naturally if I have this a small, my resistance will be more. If I have b large, it is going to affect my resistance of flow to my liquid.

So, these are the points which is going to decide, what exactly is going to be the pressure drop of the liquid is flowing from this point to this point. So, the basic equation here you have is, Q_L is a flow of liquid. l_w is a length of the weir. C_d is a coefficient of it is something very very much similar to the coefficient of discharge. It is a basically a frictional coefficient, is related to this particular geometry which is defined by the term gamma is equal to a/b.

So, here you have a gamma term. Delta is what? Delta is the difference of level. See if you have your caps oriented this way and if you have your flow of liquid this way, the head difference between these consecutive rows is basically a small delta. Quite naturally if this is per row. If you have n number of rows, n rows; then your total difference is going to be this delta (δ) multiplied by the number of rows.

So, that we are going to use it later on. But the way delta is related to the other parameters is given here. So, this is a delta and here you have a another delta. So, you find that this is not an explicit expression in delta, but it has got delta in the implicit form. Now, what you have? You have s, you have gamma and you have h_{lo}. We will see this in the next slide.

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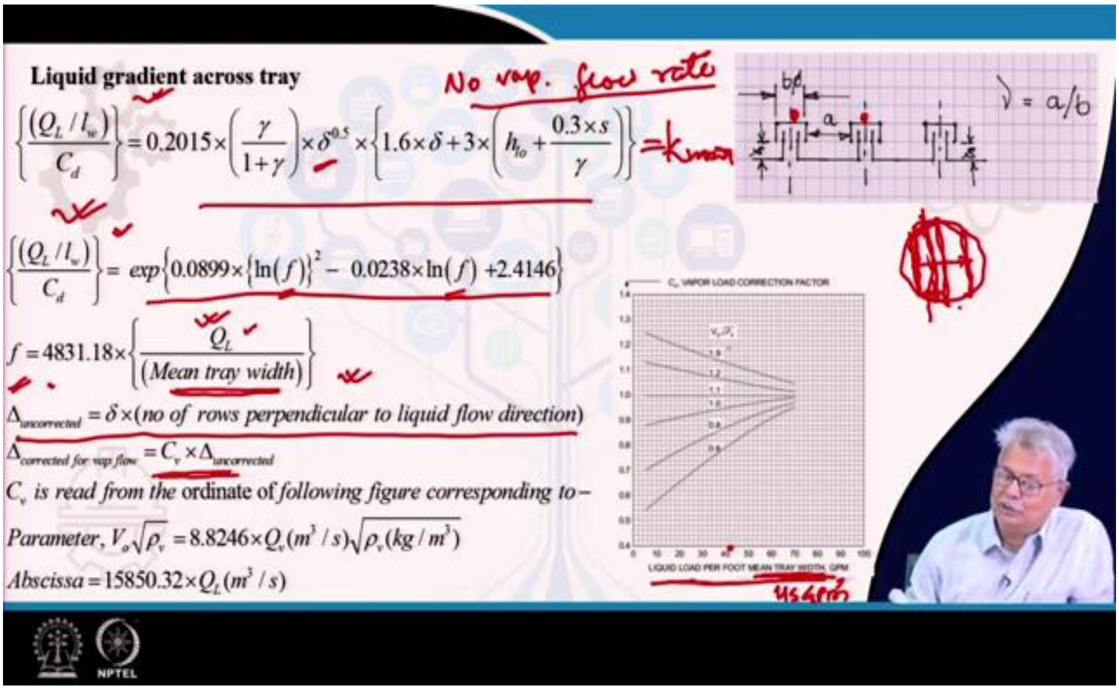

Now, you have here is basically h, what is h_{lo} at a height of liquid over the weir? So, all these are here. There is another way to express or find out the same term in using another expression, which uses a parameter small f. The small f is related to the frictional drop. Q_L is the flow rate of liquid across the tray and you have a mean tray width.

For example, if you have a tray that looks like this. It has got the upper tray downcomer. The downcomer which is blank and this tray downcomer is here, the path length is here. The width of the path starts from here, goes to a maximum value and ends here. So, what you take is an approximate average, which is the midway of these. It is basically a trapezoid that is taken and you take this particular gap as the mean tray width.

Now, this mean tray width at the denominator and the numerator if you have Q_L. You know the value of small f. So, once you know the value of small f, it is possible for you to evaluate this and you know this value. So, this point at this point of time I will say this is a known value; while you are designing, you definitely know your Q_L. You already have gone for your layout of the tray.

So, you have, you are very much aware of the numerical value of the mean tray width or as well. Now, this delta refers to no vapour flow rate, this refers to no vapour flow rate.

So, if I solve this particular expression by trial; I will be getting a difference between the level on this and this, when there is no vapour flow rate.

So, we got to correct it for the vapour flow rate now. The total delta as I have already said is delta multiplied by the number of rows perpendicular to the liquid flow direction, which is small n, that I have already said. You have to have a correction for this now, which is C_v.

C_v is read from a graph. The graph is here. C_v here what let us have a look; this graph is typically in the x axis is in GPM, which is the liquid load per foot mean tray width. That means, if you have a tray width of l_w in foot. The flow rate of liquid in gallons per minute US gallons per minute, in fact this is US GPM.

In that case, you will be knowing what exactly is going to be your liquid load per foot mean tray width. So, sorry I made a mistake, because I possibly made had said l_w. It is not the l_w. But, basically, it is the mean tray width that has to be used here. So, we know the x coordinate now; there is a parameter in this particular graph that is $V_0\sqrt{\rho_v}$.

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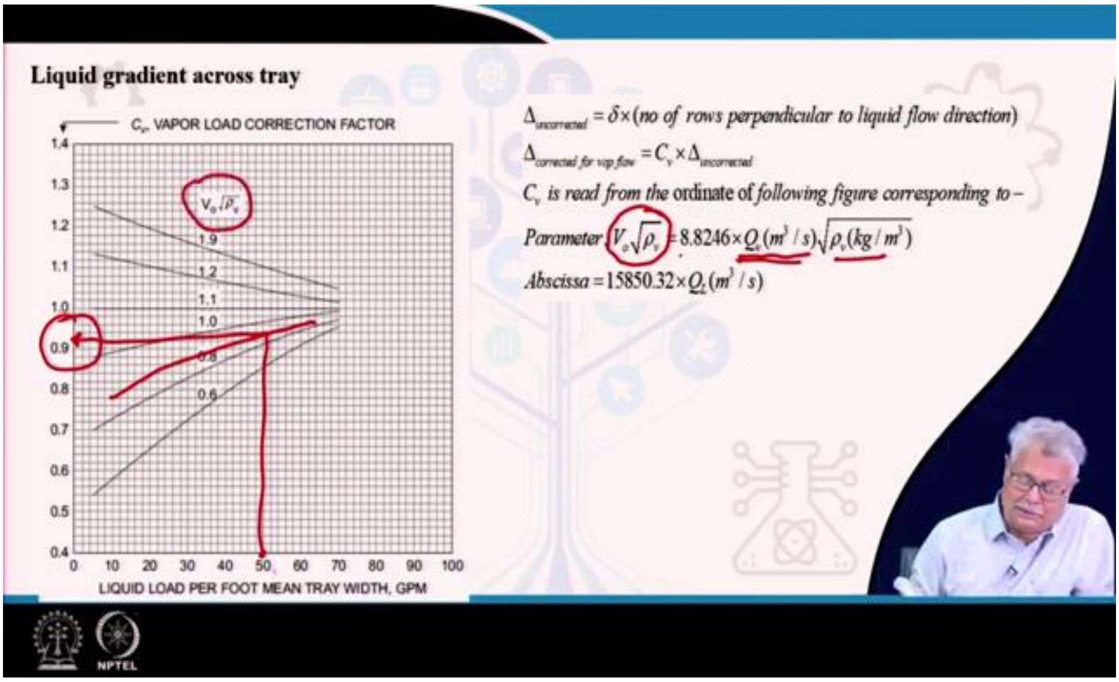

I have redrawn the same thing here. The $V_0\sqrt{\rho_v}$ is what? The $V_0\sqrt{\rho_v}$ is basically the volumetric flow rate multiplied by rho v and I have already converted the constant so that you have this particular parameter in the unit of your whatever is the parameter here which is basically in FPS units.

So, once I know my $V_0\sqrt{\rho_v}$ possibly if it is 0.85 or something like this. I will have a curve like this. If I have my x-axis, I will be taking this and I will be coming here and possibly I will be reading my C_v value to be 0.92. So, this is how you generate that Δp connected for the vapour flow. You will notice one thing here; it involves both the vapour flow rate as well as the liquid load.

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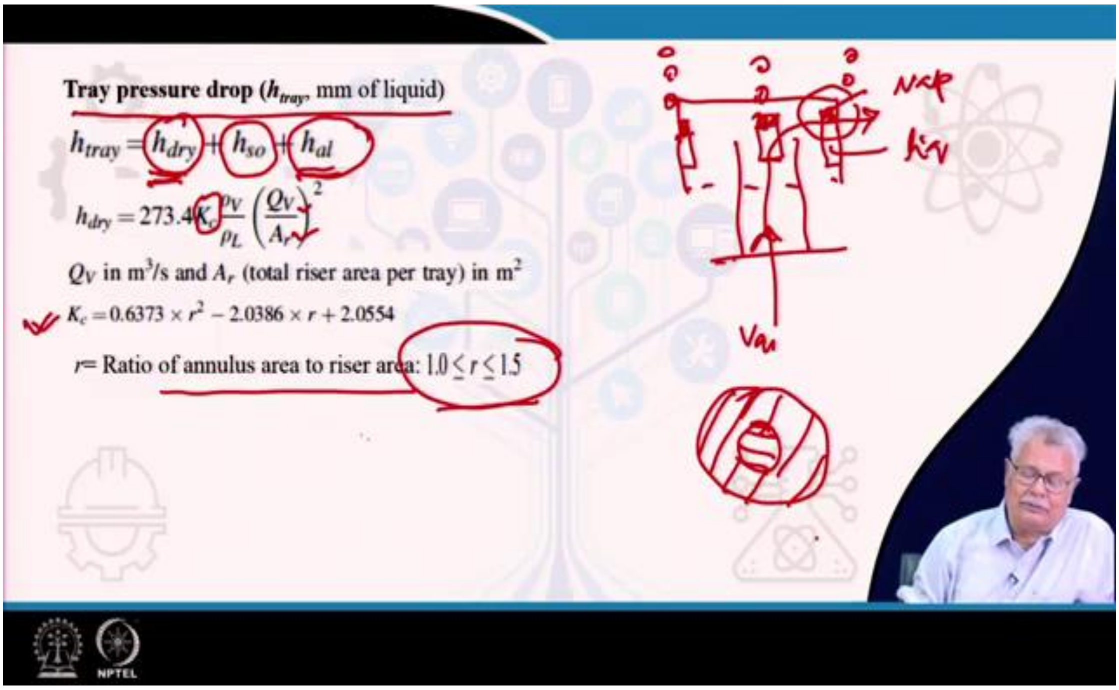

Remember this is a technique I mean this technique is valid only for bubble cap trays. This particular correlation. The third part that we are going to deal with is the tray pressure drop, which is h tray, which is going to be expressed finally in the mm of the liquid which is there on the tray itself.

If you look at the tray and the tray pressure drop will find that. If my tray is dry; there is no liquid on it and I am passing the same amount of vapour through it. There will be a particular pressure drop.

Quite naturally if this pressure drop itself is high; when my performing tray I am talking about that will also be high. So, it is said that it is a total of three components the dry tray pressure drop, which will estimate somehow using certain other things. Then what do we add? We add the pressure drop in my aerated liquid. My bubble cap is surrounded by what? My bubble cap is surrounded by liquid; in fact, it is aerated liquid.

So, what I have to add here is the pressure drop due to the aerated liquid which is present on the tray itself. Now, what else is left? What I have said is about the dry pressure drop. That means if I have my cap like this and my riser ends here. I will also have here slots. I will have my slots here which are the openings.

Now, what happens is, whenever there is a flow of vapour; the vapour has to come out through the slots. While doing it; it has to displace the upper portion of it with vapour and this portion of it will be the liquid and the upper portion will be the vapour, which will come out and form bubbles.

Now, what we do is, to remove the liquid from its front. There will be an additional component of pressure drop, the slot opening pressure drop. So, the total pressure drop on a tray is found out by the sum total of all these. The dry pressure drop is found out from an empirical expression, which is related to naturally the riser area and the riser velocity.

So, the riser velocity is the vapour flow rate divided by the total riser area and it is related to $\frac{\rho_V}{\rho_L}$. Because we would like to convert the total pressure drop in terms of the liquid. Now, this K_c is an empirical term that is found out from a correlation, which relates to the annulus area to the riser area. What is the annulus area? If I look at my bubble cap, I have my riser at the central; so this is going to be my annulus area and my riser area is this part.

The ratio of these two types should be between 1 and 1.5 and this is what is used in evaluating the K_c value. Which is used in estimating the dry tray pressure drop.

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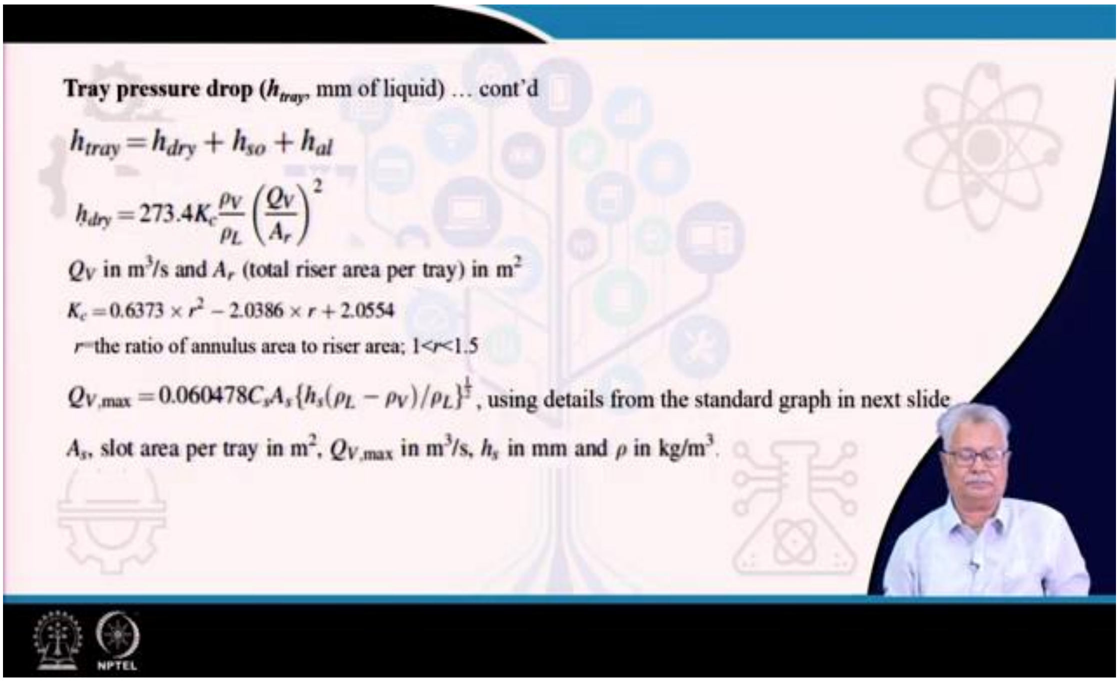

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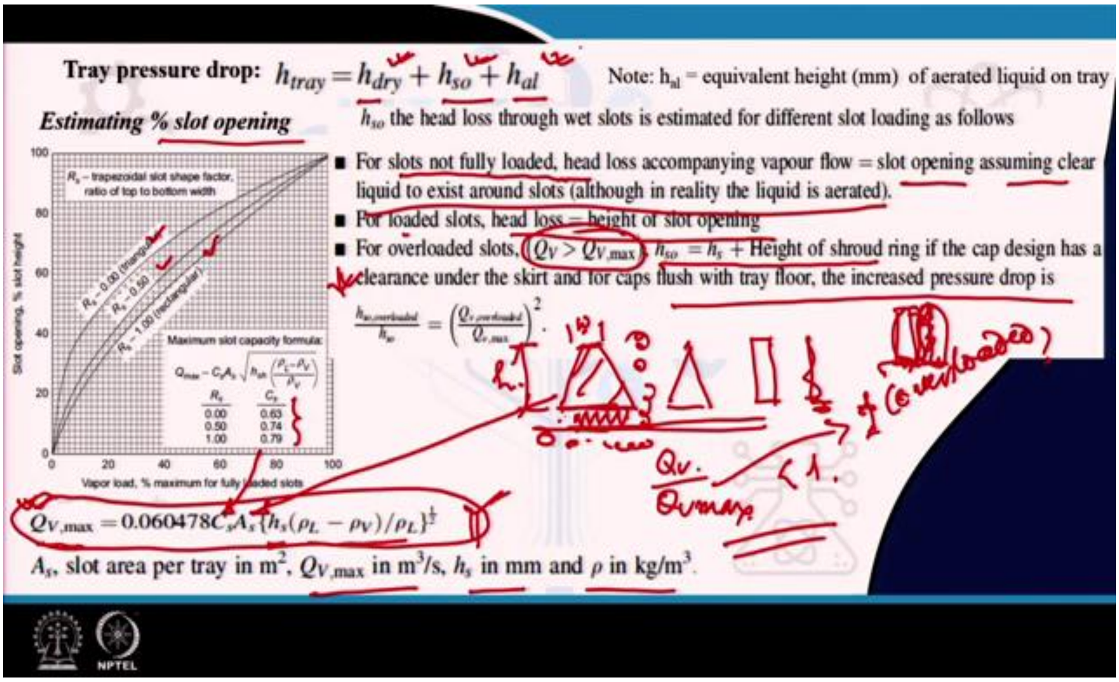

Next what we do is basically, the same thing we have to estimate now the percentage of the slot opening; because the pressure drop which is encountered at the slot outlet as the vapour comes out will depend on how much opening it is present there.

This is found out again with a graph. The geometry of the slot is definitely very important. The slot can have a rectangular shape or it could also have a tapered geometry. So, all these three are combined in a very interesting way. If this is given called h and this is called w.

When my w/h=0, which is nothing but my Rs. This is basically what, it is a triangular slot. When Rs is 0.5. typically it is a trapezoidal slot; because conventionally the trapezoidal slot that is used, they have their width half their base length.

You can have anything in between also and you can interpolate. But that is the most standard trapezoidal slot that is used. You could also have a rectangular slot. When your w becomes equal to the base length and so, this is a cut for that.

Depending on these, you have a factor defined, the factor is here. That is $Q_{V,max}$. The max that means when the entire slot is open; because there is a large amount of vapour which is trying to come out. You will have naturally the maximum vapour flow rate.

Empirically it will be related to the area of the slot which is my A_s. It will also be related to the pressure drop across the slot itself and it will also be depend depending on the vapour and the liquid densities. So, this gives us the maximum vapour velocity that can happen. A_s is the number of slot area per tray in meter square and $Q_{V,max}$ is in meter cube per second, h_s is in mm and ρ is in kg per meter cube.

Now, what I do here is basically, I stop at but this particular point. Because with this you can estimate the maximum vapour velocity. Based on this, you have to first check whether your vapour slots are overloaded. If they are overloaded, this is the way you evaluate your slot pressure drop.

For which the slots which are if they are not fully loaded, basically what you find your basically $Q_V/Q_{V,max}$, if it is less than 1. It is not fully loaded, which means you have a partial opening of your slot. So, basically, what is happening here is the slot opening assuming clear liquid. So you find out what is going to be a pressure drop in this particular case.

For loaded slot, it is the head loss is equivalent to the slot opening. It is as if you have a like a level of liquid here. This is the level of liquid that you had. It is being pushed here and it gets removed and this is the additional pressure drop that you have. In the case of overloaded slots, it can always happen that your slots are fully open and you are still pushing more; that means this, in this case, is greater than it is greater than 1, which means it is overloaded.

In that case what you do is, add the how the height of the shroud ring. Because what happens is, in case of an overloaded slot. The shroud ring is immediately below this portion is your shroud ring. So, naturally, you will have your bubbles coming out from below the shroud ring as well and so that gets added.

So, this is how you estimate, you find out the different components of the h tray, which is the dry tray pressure drop, the slot opening pressure drop, and the aerated liquid pressure drop in case of bubble caps. With this I think if you are supposed to design a bubble cap tray. Your steps will be finding out the diameter. Find out the tray spacing. Find out the total height of your column. Finding out the slope or the gradient of liquid on your tray.

Before that, you have to find out what will be your layout and you have to go into the details of your layout. Beyond that what you will do is, you will find out you're the tray pressure drop exactly the way we have discussed. I think this will complete our topic here today and after this, we will start the design of packed columns.

Thank you all.