Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 27
Bubble Cap Tray Design (Contd.)

Hello all, I will be continuing with the Bubble Cap Tray Design and this is the 2nd class on the same topic. What we had concluded at the end of the last class was this; we require additional checks for entrainment.

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Slot opening, liquid gradient on tray, downcomer backup, pressure drop across tray and outlet length outlet weir length and height. Definitely, we have to finalize the tray layout; that means, where to place the vapour disperses.

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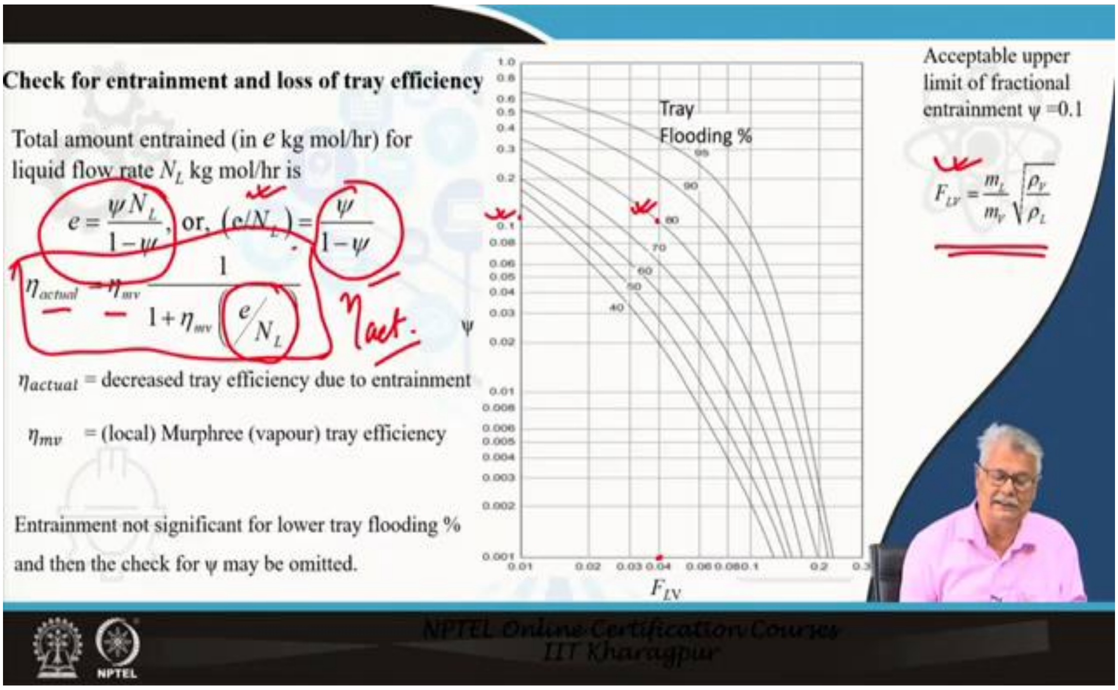

To start with we talk about entrainment. This entrainment check is also very similar to what we have seen. It is practically the same as what you find in the case of your sieve trays. It is the same plot. The same F_{LV} factor is used which is the ratio of mass velocity of liquid to mass velocity of vapour. Then you have the $\frac{\rho_V}{\rho_L}$. So we know the value of F_{LV}.

So, if we know the fact, the x-axis parameter and we have decided on a Murphree tray efficiency. For the tray, to maybe 75 % or rather 80 % and in case I have an F_{LV} factor of this. The corresponding value here for my ψ will be 0.12 or 0.13 something like this.

I know this particular expression. The entrainment quantity e in moles per hour and the moles of liquid flowing across the tray if it is N_L. The relationship in this particular case is given by this i.e. $e/N_L = \frac{\psi}{1-\psi}$. We have just found the value of ψ which is noted from here. So, it is possible for me to know or rather I know at this particular point the value of e/N_L.

The efficiency actual will be different from whatever has been there in this particular value which is 80 and a change will be related by this particular expression. So, I have known the quantity which is here. I put it here. I recalculate my η_{actual}. That means, we find here that due to entrainment my actual efficiency is going to be lower than what I had assumed initially. As long as it is within the limit, it is fine. Say, if you have assumed 80 and if you get some value like 75 or 76 it is usually ok.

It is obvious that we need not emphasize that with increasing ψ the efficiency fall will be more. When will the efficiency fall be more? When will you have a higher value of ψ? When you have a lower value of F_{LV}? When will you have a lower value of F_{LV}? When you have a lower L and a high m_v. It is obvious with a higher vapour flow rate, the chance of liquid being blown off is more. So, that is why you can relate and you can interpret the result that you will be getting from here.

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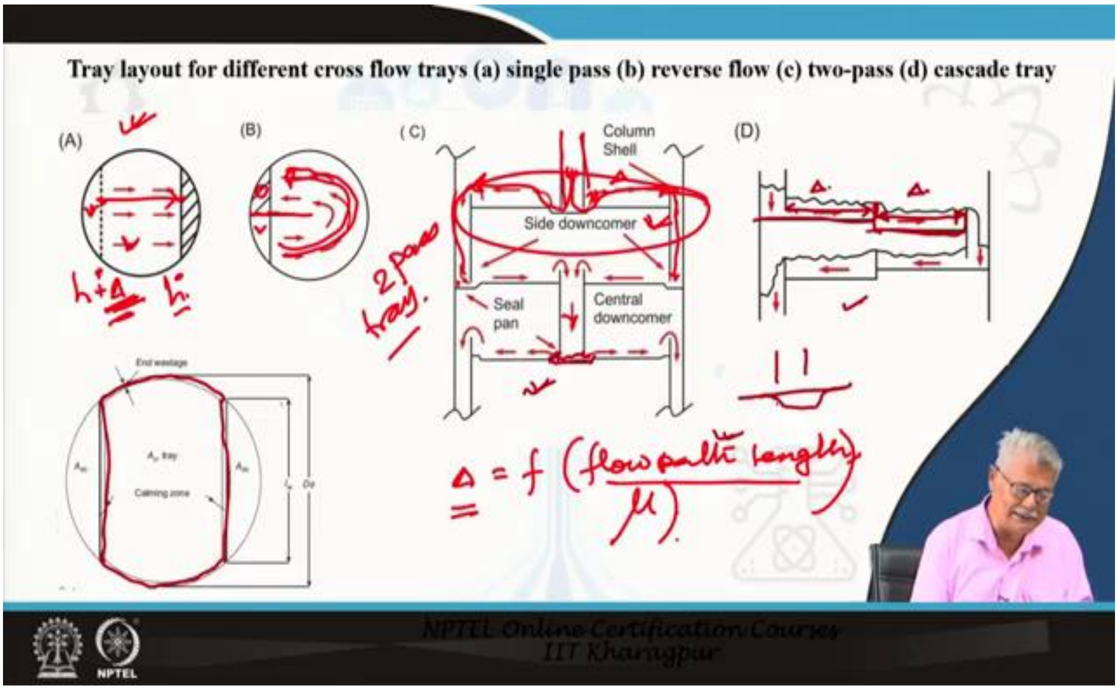

Now, we can have various types of layouts on my tray. This is the simplest. We have a single downcomer and a single pass. The flow path length is from here to here, it goes like this. We have a gradient of liquid level at this point and this point. It flows by gravity. So, naturally, the h here will be h + Δ and if my h is here. This Δ is a driving force for the liquid from this point to this point.

Now, what is this? This is the gradient of liquid. When is it is expected to be high? When the frictional drop is expected to be large your Δ will be high. Suppose, you are dealing with a liquid that has got very low viscosity. Like liquid air in a cryogenic plant, you will have a very low value of delta. So what is done, to give a longer residence time you use a reverse flow tray. You will note here, that instead of having the downcomer of the upper tray discharging it is liquid here, it discharges here.

The liquid from this tray goes to the tray below through this particular point or this section of your downcomer and quite naturally you have a partition here and you have a baffle that allows the liquid only to come from the right side to its left like this way.

Now, there are other ways of reducing this Δ. This delta (Δ) depends on what? This depends on the flow path length. We also know that it depends on the viscosity. So, what we do is, to reduce this Δ we can split the flow into 2. Here what you have is a 2 pass tray where you have the downcomer of the upper tray discharging here the liquid getting split into 2 streams. The tower diameter is if it is D, the path of each liquid in this case is half of D. So, your flow path length has come down.

Quite naturally the Δ is from this point to this point. Not only the path length has come down the flow rate has also been halved. So, quite naturally as compared to a configuration like this, this is going to give you a much smaller delta. Now, once you have come once the liquid has come here to the extremities, they are collected and they go back this way with a central downcomer.

We note here is something. We have a tray with a side downcomer and the next tray is with a central downcomer. You will notice here something quite interesting. You will notice here that if you will just get the pen back. You will notice here that there is a small recess. That means it is not a flat it is there is a recess in which it discharges.

So, this is done. So that you have a seal here in a better fashion. You can also split the flow path in a large diameter tower into 2 continued sections. In that case, what will we have we will have the first weir here then a stepped portion of the same tray this is the first step. This is the second step and a second weir here.

So, what you have here is the delta in this has to drive only this much of length and the delta here drives only this much of length. This allows reducing the flow path length keeping the flow rate the same. So, quite naturally what you can have is either this or this depending on your choice. We in the industry are not only limited to 2 pass trays. We have 4 pass and higher pass trays also. But more common is a 2 pass. Sometimes 4 pass trays.

Like in any vapour dispersers mounted on a tray, there will be end wastage that is mentioned here. There has to be a calming zone both upstream and downstream of the flow path length and this is the length of the weir and this is your tower diameter.

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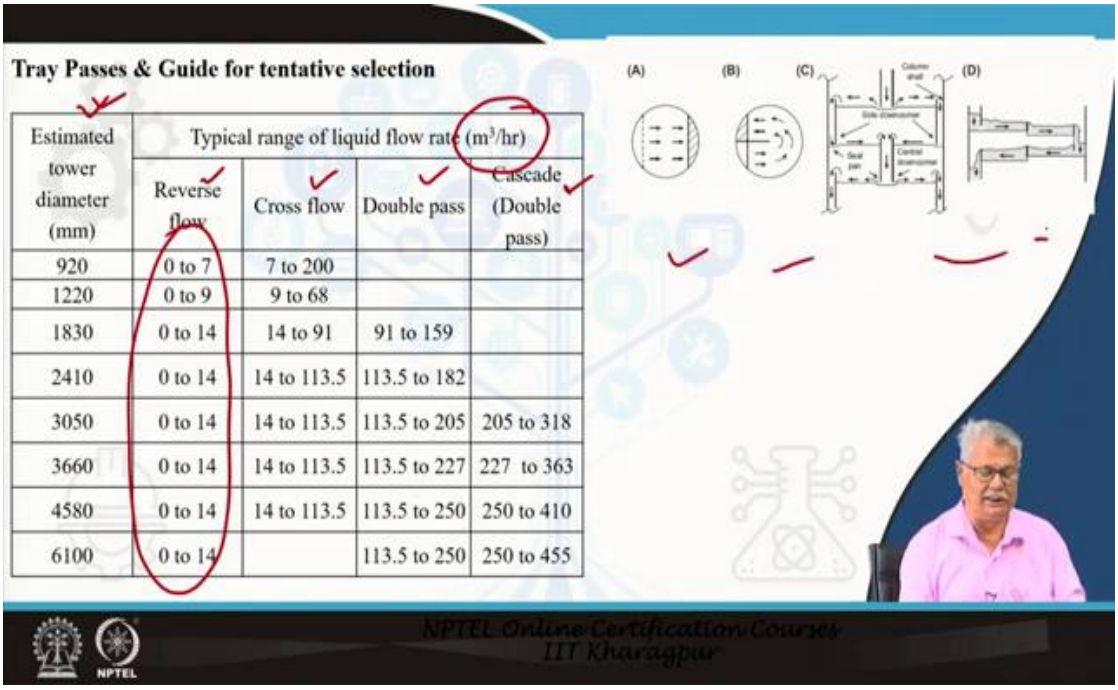

Estimated tower diameter (mm)	Typical range of liquid flow rate (m^3/hr)			
	Reverse flow	Cross flow	Double pass	Cascade (Double pass)
920	0 to 7	7 to 200		
1220	0 to 9	9 to 68		
1830	0 to 14	14 to 91	91 to 159	
2410	0 to 14	14 to 113.5	113.5 to 182	
3050	0 to 14	14 to 113.5	113.5 to 205	205 to 318
3660	0 to 14	14 to 113.5	113.5 to 227	227 to 363
4580	0 to 14	14 to 113.5	113.5 to 250	250 to 410
6100	0 to 14		113.5 to 250	250 to 455

Depending on what type of velocity or rather what flow rate of the liquid we have, the tray selection has to be made. Here, what we do is, we know that we have made some estimated tower diameter. What we have done is based on the tray spacing and the diameter, we have a cross idea of the size of the tower itself.

Now, depending on the flow rate of liquid what we do is, we choose whether we are going to have a reverse flow or a cross-flow or a double pass or a cascade double pass. You will notice one thing, we go for a reverse flow only when my liquid flow rate is small. That means, your delta is expectedly when my flow rate is expectedly very small.

Similarly, we go for the other types when we have higher flow rates and these are the different configurations.

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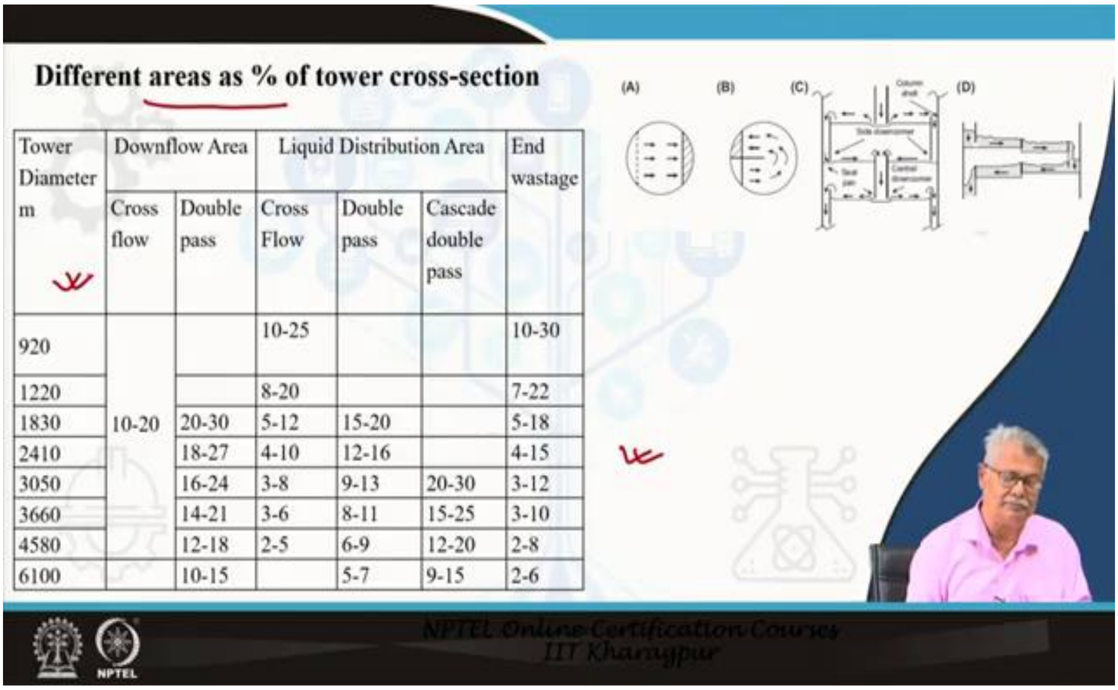

Tower Diameter m	Downflow Area: Cross flow	Downflow Area: Double pass	Liquid Distribution Area: Cross Flow	Liquid Distribution Area: Double pass	Liquid Distribution Area: Cascade double pass	End wastage
920			10-25			10-30
1220			8-20			7-22
1830	10-20	20-30	5-12	15-20		5-18
2410		18-27	4-10	12-16		4-15
3050		16-24	3-8	9-13	20-30	3-12
3660		14-21	3-6	8-11	15-25	3-10
4580		12-18	2-5	6-9	12-20	2-8
6100		10-15		5-7	9-15	2-6

But, depending on the type of configuration that we have chosen, there are certain guidelines about the different areas as the percentage of the total tower cross-section which is $\frac{\pi}{4}D^2$.

So, this is just a table to give you an idea and you should have a look at these and have an idea about the standard typical tower dimensions which is here.

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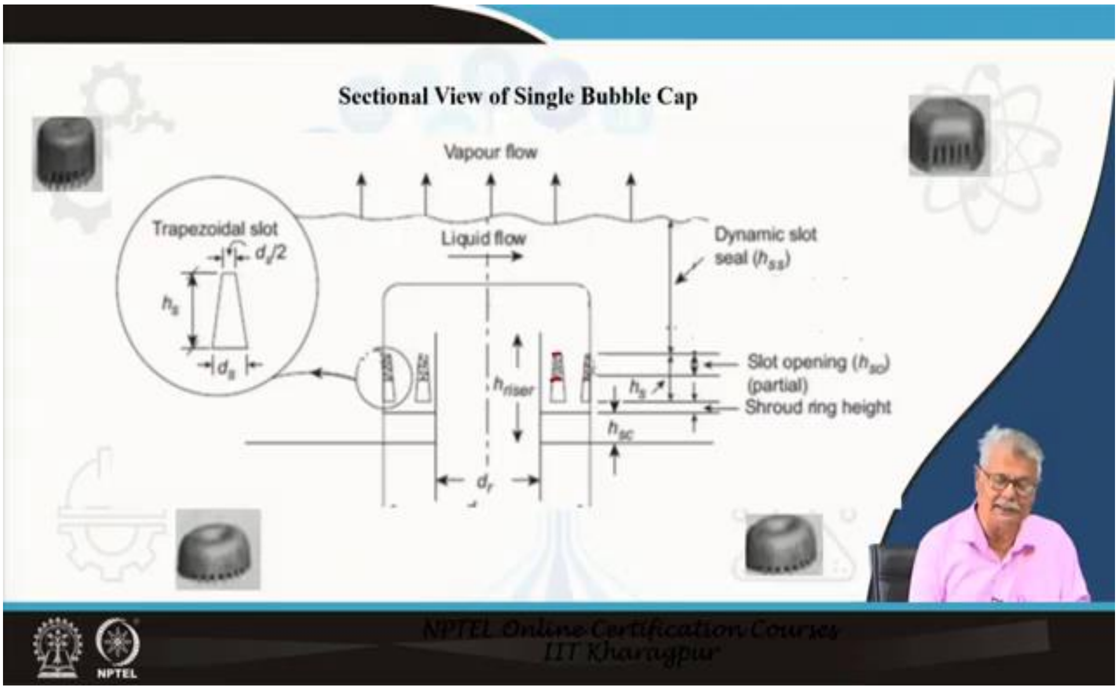

Now, what we do is, we look at the view of a double bubble cap and it is the same thing which we have here and all during our design. We are supposed to find out the slot opening. That means when it operates by how much will the liquid level here in the slot get depressed. We definitely will have to check this and we move on with this.

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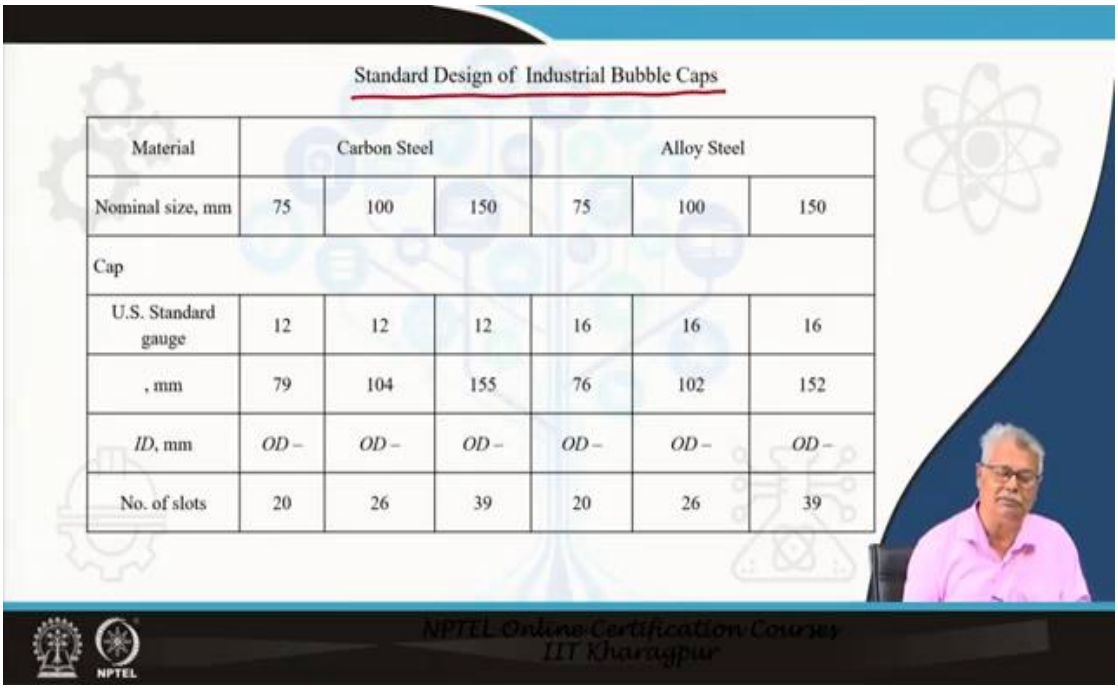

Standard Design of Industrial Bubble Caps

Material	Carbon Steel			Alloy Steel		
Nominal size, mm	75	100	150	75	100	150
Cap						
U.S. Standard gauge	12	12	12	16	16	16
, mm	79	104	155	76	102	152
ID, mm	*OD* –	*OD* –	*OD* –	*OD* –	*OD* –	*OD* –
No. of slots	20	26	39	20	26	39

We have here a few slides that give the standard design of industrial bubble caps. Normally there are typical vendors like glitch who will be supplying you the bubble caps that you require. If they will also be redesigning the tower for you if you use their caps.

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Material	Carbon Steel			Alloy Steel		
Slot shape	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal	Trapezoidal
Slot width						
Bottom, mm	8.5	8.5	8.5	8.5	8.5	8.5
Top, mm	4.2	4.2	4.2	4.2	4.2	4.2
Slot Height, mm	25	32	38	25	32	38
Height of Shroud ring, mm	6	6	6	6	6	6

It is also possible for you to make your cap, but it is not done very commonly until and unless it is a small plant. Regarding the slot shape, I have said there are 3 shapes possible. One thing could be trapezoidal, sometimes you have triangular which is uncommon and you can have a rectangular slot also. When it is trapezoidal this is b/2 if this distance is b. The dimensions and the slot widths are given here at the top bottom the slot height and the shroud ring. The shroud ring typically is always 6 mm i.e. one-fourth inch.

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Standard Design of Industrial Bubble Caps (Contd.)

Material	Carbon Steel			Alloy Steel		
U.S. Standard gauge	12	12	12	16	16	16
OD, mm	53	69	104	51	67	102
ID, mm	*OD* –	*OD* –	*OD* –	*OD* –	*OD* –	*OD* –
Cap standard heights, mm						
13 mm skirt height	57	2.5	63.5	57	2.5	63.5
25 mm skirt height	70	76	83	70	76	83
38 mm skirt height	83	89	95	83	89	95

The standard designs are here again for the carbon steel and alloy steel valves.

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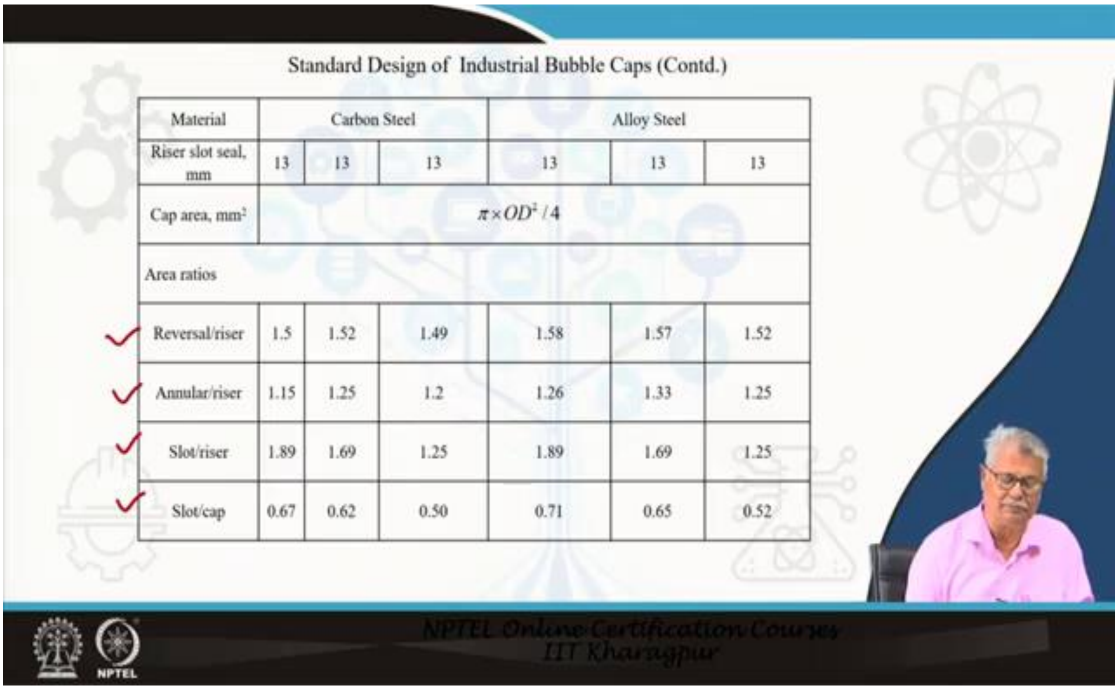

Standard Design of Industrial Bubble Caps (Contd.)

Material	Carbon Steel			Alloy Steel		
Riser slot seal, mm	13	13	13	13	13	13
Cap area, mm²	$\pi \times OD^2/4$					
Area ratios						
Reversal/riser	1.5	1.52	1.49	1.58	1.57	1.52
Annular/riser	1.15	1.25	1.2	1.26	1.33	1.25
Slot/riser	1.89	1.69	1.25	1.89	1.69	1.25
Slot/cap	0.67	0.62	0.50	0.71	0.65	0.52

These are the other details which is given here and the different area ratios are there. Because this area ratio are required when you go for your design and you need to calculate your other parameters regarding the flow hydrodynamics around your bubble cap.

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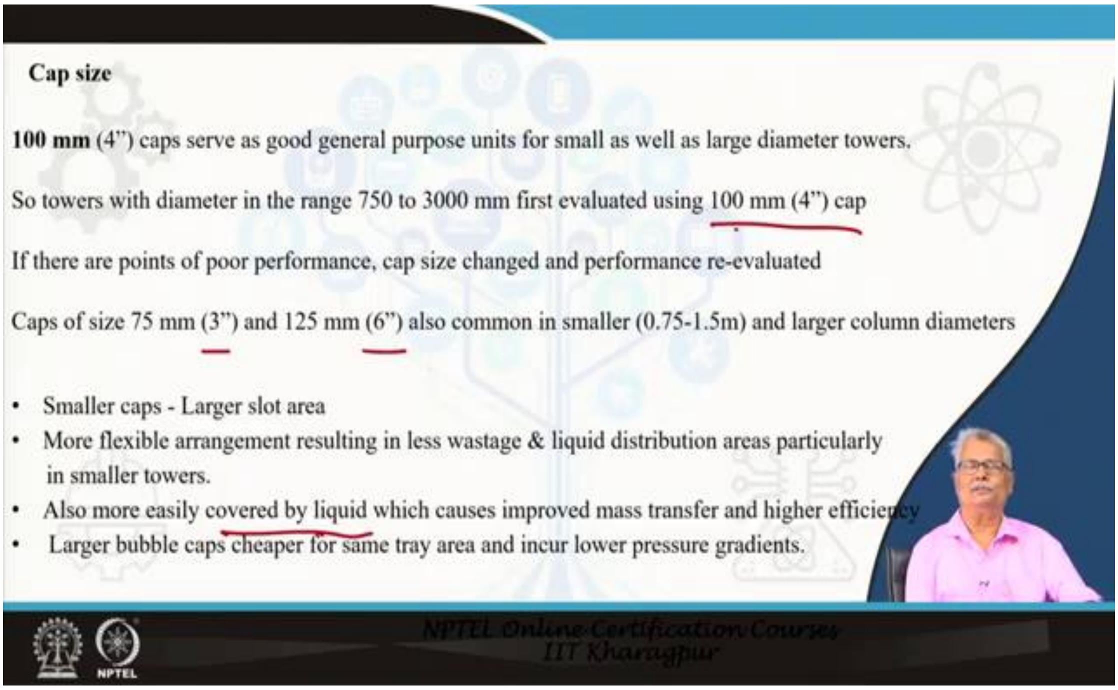

The most common industrial capsize is 4 inches, 100 mm. It is usually the most popular type and it is used in small towers as well as large towers. Normally, if you are going to expect that the diameter of your tower is going to be slightly less than a meter to around 3 m. You can try by checking with the 4-inch caps first.

If you find that due to some reason or the other if you are having poor performance; that means, your efficiency is not up to the mark. You definitely will be required to re-evaluate or redesign. Smaller caps and bigger caps are also in use in the smaller and larger diameters.

If you have a smaller cap, in proportion to the capsize it will have a larger amount of slot area. If you are using smaller caps you will be having a more flexible arrangement of laying it out on your tray, but you will require a more number of caps. Now, smaller caps are also more easily covered by the liquid, which is something desirable because it helps mass transfer and leads to higher efficiencies.

But, in the case of large caps, normally you have a lower pressure gradient. That means, you choose what size of cap you are going to use. You normally will be starting with 4 inch caps unless you are working with a very large tower or a very small tower.

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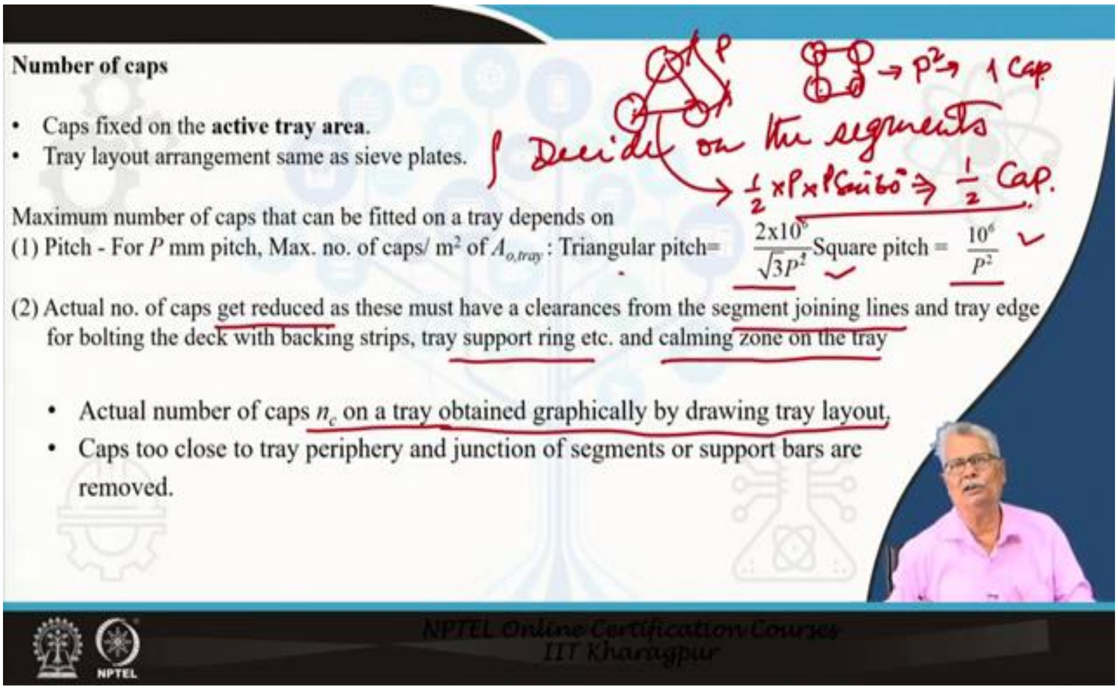

Next comes the question of the number of caps. The caps have to be located on the active tray area and within the active tray area also you do not have everywhere where you can locate your vapour disperses. So, basically what you have to do is, you have to do your tray layout arrangement. The first thing that you do is decide on the segments; the tray segments.

So, you know now wherever you have the joints you have to have the backing string and you cannot put your vapour dispersers there. You also have decided have to tentatively decide, you must have decided by now what is the downcomer location and the downcomer length and that those dimensions are already known to you. It is time for you to decide on a pitch for P mm pitch naturally you can have it either on a triangular pitch, which is the center to center distance or we could also have it on a squared pitch.

So, if in this case an area of P square can contain how many caps? It can contain one-fourth one-fourth one-fourth one-fourth it contains 1 cap and in this case the area of the triangle is half base is P into altitude is P sin 60 degree which is root 3 by 2. This is equal this. This contains how many caps?

This contains one-third this is one-sixth one-sixth one-sixth; that means, half a cap. So, the formula of the triangular pitch number of caps per meter square and the square pitch caps per meter square is derived from this geometric analysis.

The actual caps actually I have already said that will get reduced because you require clearance from the edge, clearance from the segment joining lines and tray support ring fixing wherever you have and naturally in the calming zone on the tray you cannot have your vapour dispersers located. So, this is usually done by trial manually with some drafting help of course, but it is primarily a manual procedure.

Now, this is what I have meant here by saying that n_c which is a number of caps is obtained graphically by drawing the tray layout. Usually what you do is, you put as many caps as you can and then you start removing the caps which are inadmissible to be placed there because of fawning with something else.

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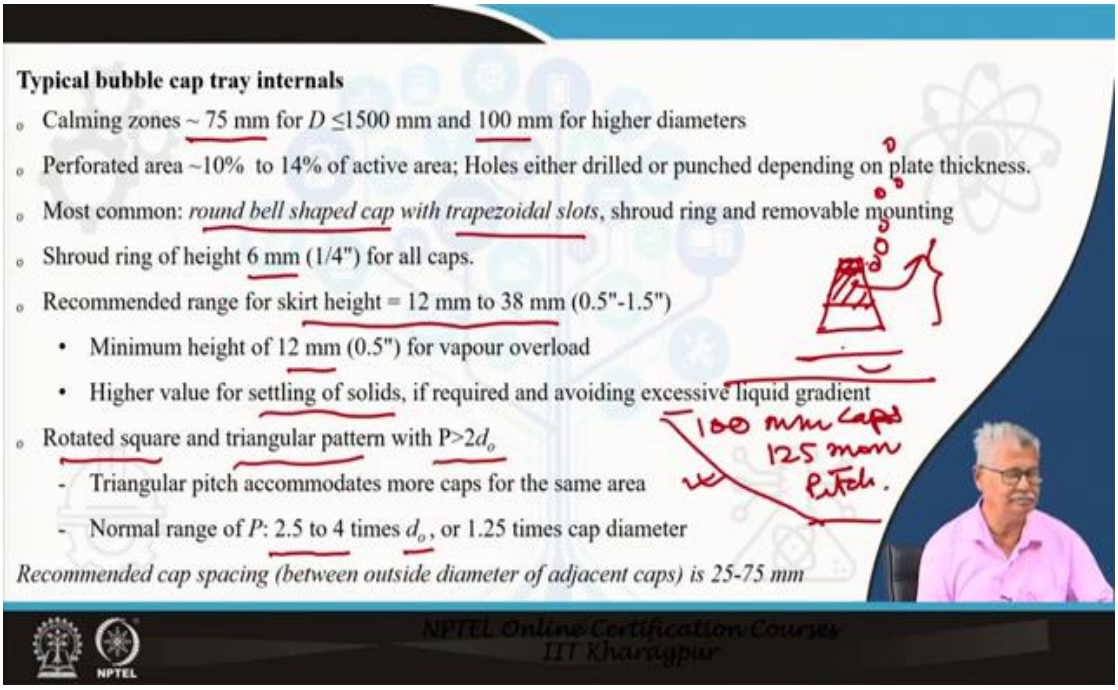

To have the layout, we need to know about the dimensions which are typically used. The first thing is a calming zone. Typically, if the diameter of the tower is below 1.5 m. You have a calming zone of 75 mm which is 3 inches. If it is more, the diameter you go for 4 inches or 100 mm calming zone. The perforated area is about 10 to 14 % of the area. The holes are either drilled or punched, the same thing which you have learnt in the case of the sieve trays.

The most common type of bubble cap is that round bell-shaped caps. They offer lower pressure drop to the flowing liquid with trapezoidal slots. There is one advantage in the trapezoidal slots. If you look at a slot, initially the liquid level will be depressed like this when you have a low flow rate.

As the flow rate increases the area which is available for the bubble to flow out increases. Here what happens is, when you have if you have a low flow rate of the bubble you have, a smaller area and this makes a stream of bubbles more uniform.

So, it is sort of a self-regulating capacity that you have with trapezoidal slots. You will be using rectangular slots when you know that your capacity or the turndown ratio in this case is not going to change much; that means, you are going to operate your tray with a fairly steady and steady capacity or throughput.

The shroud ring we already have said many times that its usually 6 mm, the recommended skirt height is 12 mm to 38 mm. It can be designed it can be set also and a minimum of half-inch skirt height is always kept for vapour overload because what happens is in case there is vapour overload it will be coming out below your skirt.

You require a higher gap if you know that there will be solid settling on your tray deck, and if you have a larger clearance from the deck your pressure drop of the liquid in its path will be less and you will be having a lower delta, the capital delta which is the gradient across your tray.

You can go for a rotated square pitch or a triangular pattern with P greater than 2 times d_o. The d_o is basically your punched area. We already have seen that you can accommodate more number of bubble caps if you are going to use a triangular pitch for the same area and normally the P is 2.5 to 4 times the hole diameter or it is 1.5 times the cap diameter.

Typically, what you find is 100 mm caps and 125 mm pitch. This is the most common deferred style.

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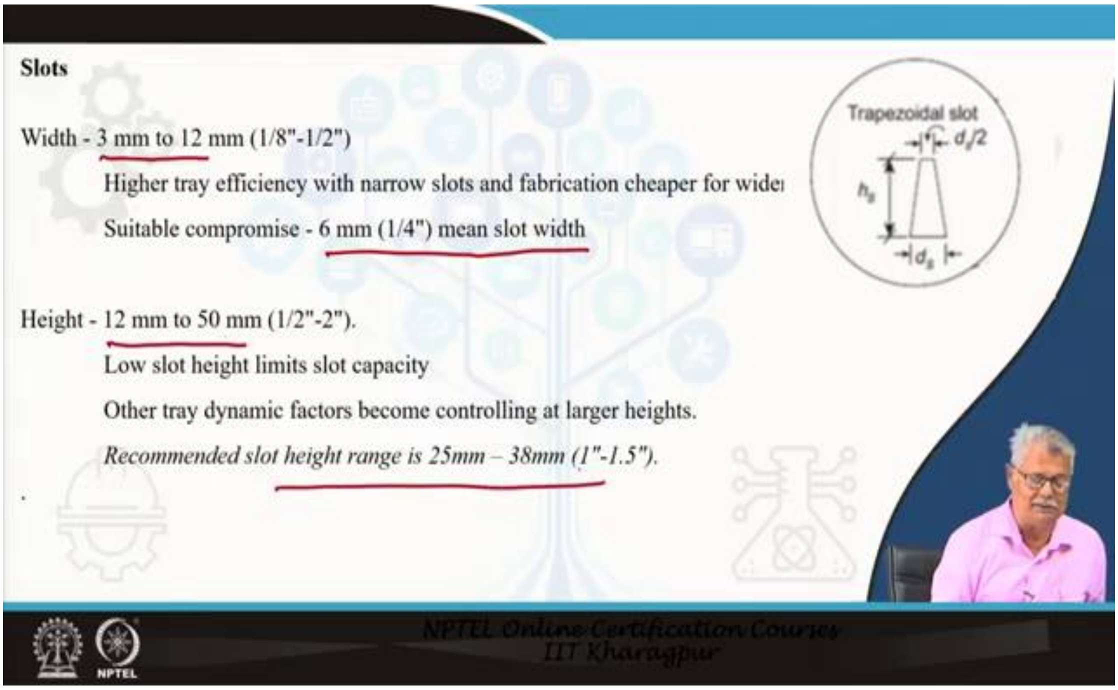

The slots width typically be either I mean will be normally 3 to 12 mm wide. The suitable compromise is a 6 mm mean slot width. The height of the slot can vary depending on the size of the cap from 12 to 50 mm. The recommended slot height ranges 25 to 38 mm. 38 mm mean 1 and a half-inch.

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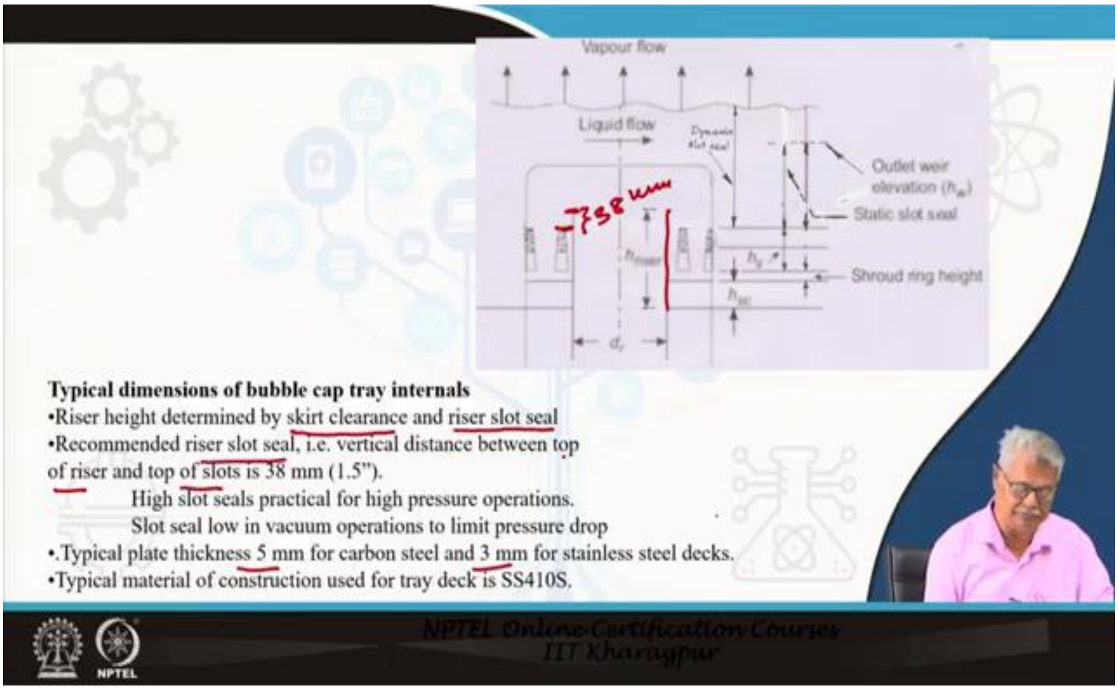

Now, what we have is basically about the typical dimensions of the cap tray internal. We have to specify the riser height. The riser height is determined by the skirt clearance and the riser slot seal. We know what the slot seals are. And the recommended riser slot seal that the vertical distance between the top of the riser and the top of the slots. This is typically 38 mm which is about one and a half inches.

The bubble caps may be made of 5-mm metal sheets. If it is just carbon steel or it will be 3 mm alloy steel caps.

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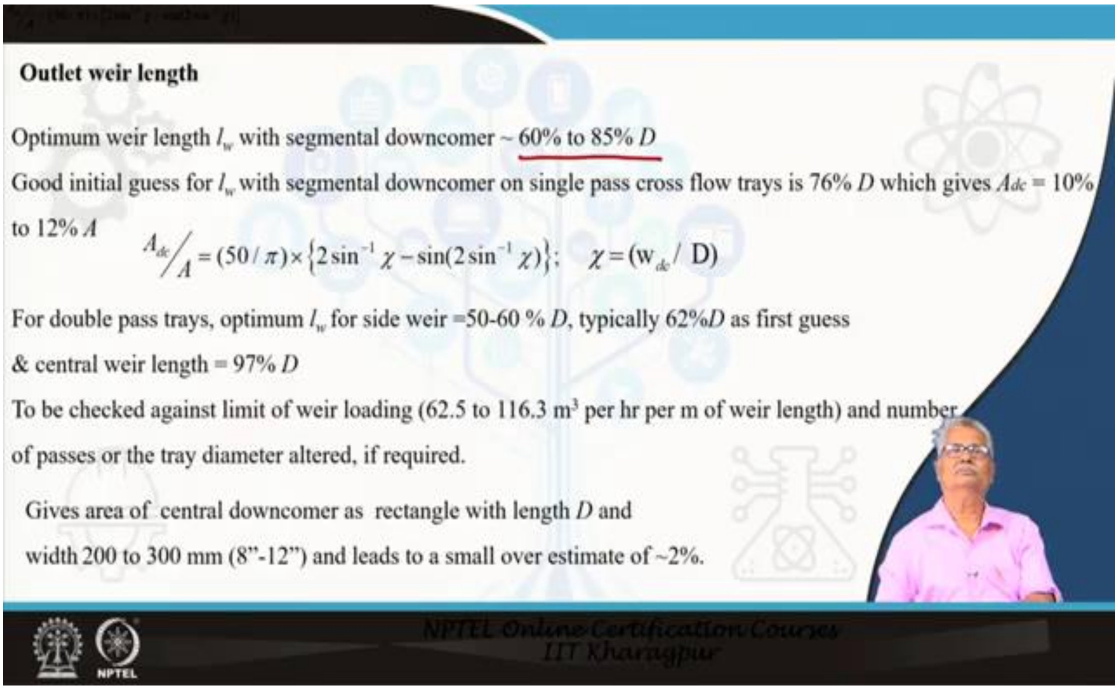

The bubble cap material typically is 410 SS 410. Now we have to have an idea about the optimum weir length with the segmental downcomer. The segmental down comer typically the length is around 60 to 85 D.

You will remember one thing, that in a downcomer if we have a very large downcomer the pressure drop in the downcomer will be less and your backup will be less. We want for a good operation of a particular tray in a column roughly about 50 % depth of liquid in a downcomer.

Now, a good initial guess for l_w is, we already have said many times it is about 76 to 78%. So, 76 % is a suggested value here and the same similar values are suggested for the other parameters like, the double pass tray what it should be and all.

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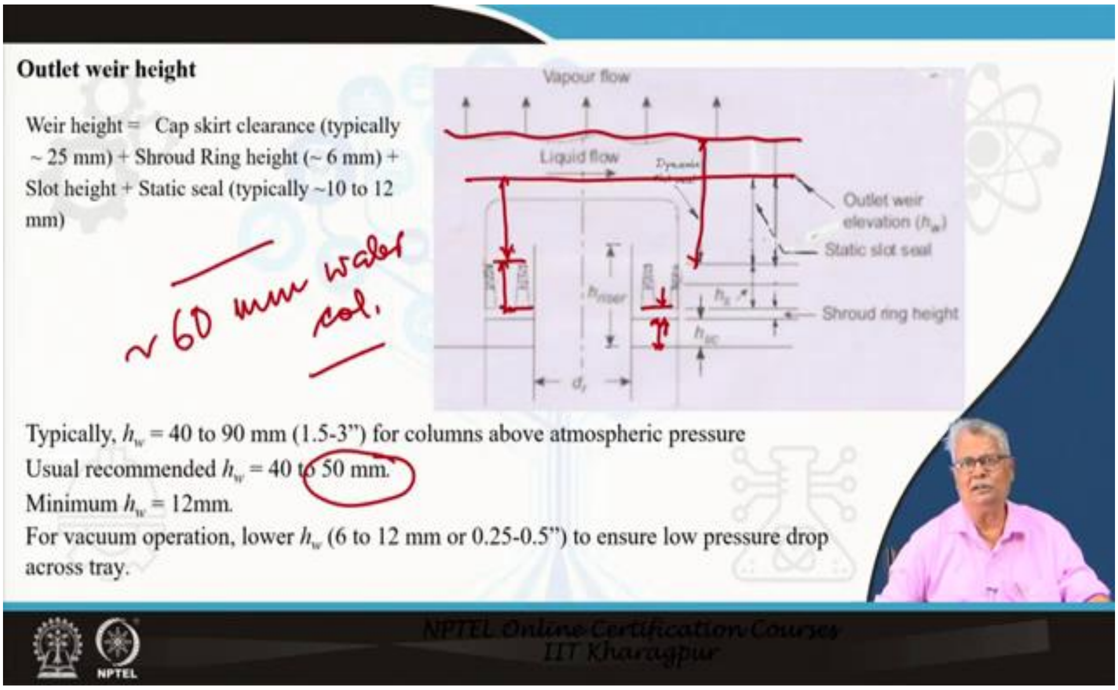

Now, there is a very important point here. I have to have my vapour dispersers submerged in the liquid. So, we provide an outlet weir for this and the weir height is based on, you can see and you can add from here directly. It is a caps skirt clearance; the caps skirt clearance is this distance. The shroud ring height; the shroud ring height is this distance. The slot height; the slot height is from here to here.

Then we required a static seal. We decide on a static seal and we add the static seal height. So, that is the minimum height of the outlet where that we really require. Now, when we operate the level of the liquid will be higher and there will be a dynamic seal here which is this distance. This is the actual level of liquid while it is operating.

Typical h w is 40 to 90 mm for the columns above atmospheric pressure. Typically, around 40 to 50 mm is good enough. The minimum h_w that you should go for is 12 mm.

You will notice one thing, since we often say that it will be around 40 to 50 mm and you will have a minimum of 6 mm of the liquid level above the weir height. So the depth of liquid above the tray deck will be around 56 to 60 mm and through which the vapour has to push through.

So, very often roughly the pressure drop in case of trays, we consider being around 60 mm water column. It is higher than the static head definitely because it has to pass through the vapour dispersers during which it encounters certain pressure losses.

So, your delta p across a tray will be of the order of 60 mm water column. Quite naturally, if you are using a vacuum you cannot afford to have such a large pressure drop and you will be using a lower height of your weir which typically is 6 to 12 mm.

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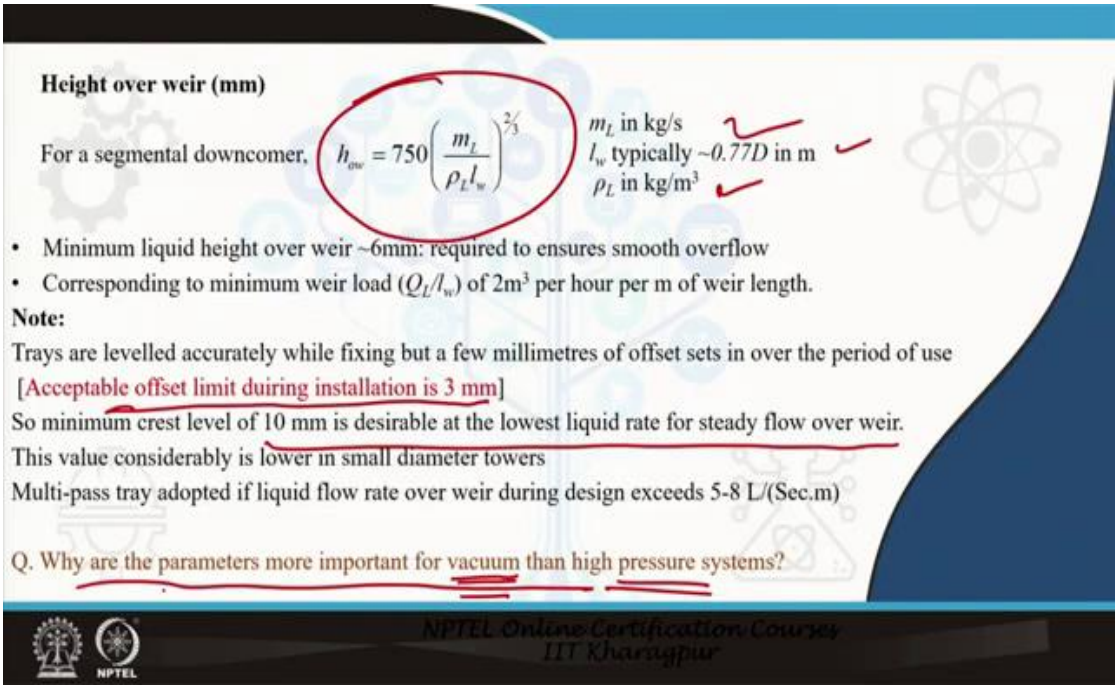

The height over the weir in this case also is given by the Francis formula with proper units that you must note from this. Corresponding to the minimum weir load, we usually try to keep at least 2-meter cube per hour per meter of weir length.

So, this from if I just know what exactly is my Q_L which is my liquid flow rate approximately. I can find out the l_w by considering the weir load to be around 2 m^3/h and we also know that your l_w is roughly around, what percentage of your total tray diameter we can have a cross-check estimate of the diameter as well.

Now, there is one thing which is absolutely important the first thing is the levelling of the trays. This I had specifically said when we were generally discussing all the tray internals. Normally, the acceptable offset limit during installation is 3 mm. That means, the highest point of the deck to the lowest point of the deck cannot be deferred by an elevation difference of 3 mm.

So one thing is true, if I am talking about a crest level of 6 mm it may have an error of about 3 mm. So, what you do is a minimum crest level of 10 mm is desirable at the lowest liquid rate for steady flow over the weir. This is something very important and needs to be checked during the process of design.

Obviously, the value is considerably lower in the case of smaller diameter towers where you can have much better levelling. Multi-pass trays are used if your liquid flow rate over the weir during the design exceeds 5 to 8 litres per second per minute. Now, I have a question for you why these parameters are more important for vacuum; that means, for a tower that is operating under vacuum compared to what you have in a high-pressure system?

The answer is obvious, it is basically the pressure drop which is at a premium in the case of a vacuum tower and a slight difference in level will make a difference in the total pressure drop of your column.

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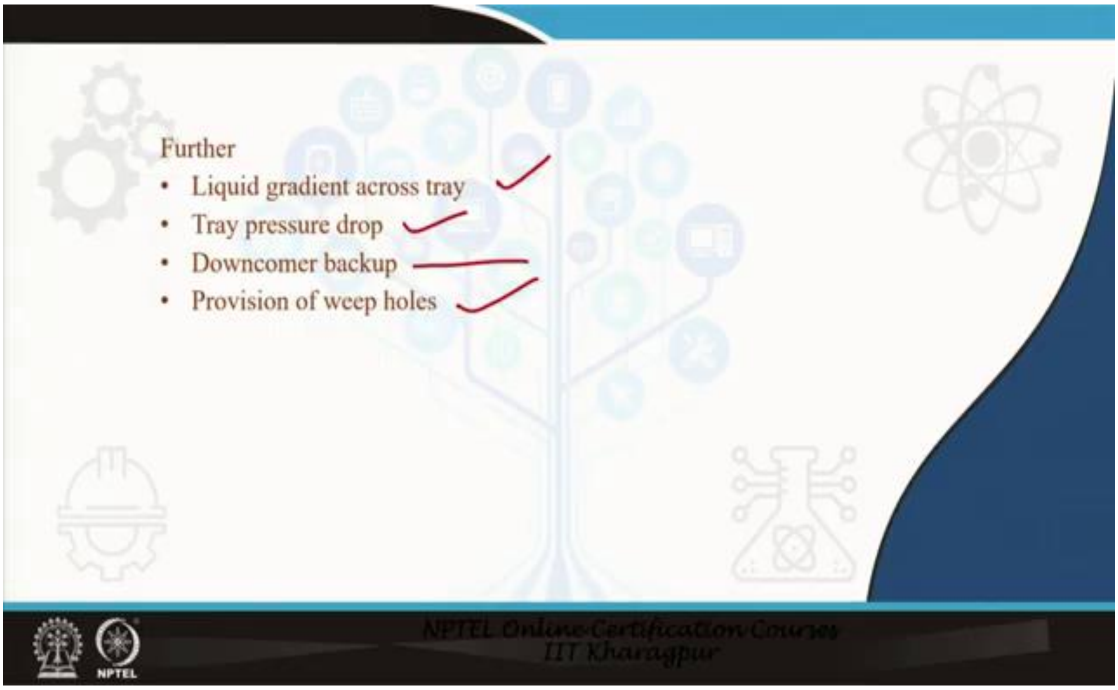

It will affect your design and will be spending more in creating the vacuum and there will be a larger pressure difference between the top and the bottom of your vacuum column.

With this, if we see what is further left for us. These are the items. We need to estimate the liquid gradient across the tray, this has to be done. The pressure drop across the tray has to be estimated. The downcomer backup this we will not repeat, because it has already been covered when the sieve tray design was being considered, it is the same thing here. We will talk about definitely the provision of weep holes. We had introduced you to the weep holes in one of my earlier classes in the introduction to the tower internals.

What we intend to do right now is, we will stop here. We will recapitulate whatever we have covered so far and in the next class, we cover these items which I have just now mentioned.

Thank you