Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 23
Sieve Tray Design

Well, good day to all of you. So, today after the introduction to columns and column internals have been provided to you and you have been told that what are the different types of columns we have packed columns and we have tray columns and among the tray towers you are also told that the tray towers they are differentiated based on the type of fixtures which are there on the trays.

So, therefore, trays can either be just perforated. They have simply perforations through which the vapour comes out and the liquid is flowing across the tray. Therefore, on each tray, the flow is cross-flow as has been set. So, this is the simplest type of arrangement that you can have. The tray deck consists of a large number of perforations and the vapour rises through the perforations and flows in a cross-flow direction to the liquid which is flowing across the tray.

After that, we can for better vapour-liquid contacting and smaller vapour bubbles just to ensure that the contacting is better and we can go for a higher tray efficiency. We have different fixtures on the perforations. What we have? We can have either risers on the perforations over feet of which are inverted bubble cap can be put and the vapour comes out through the slots in those caps and this arrangement is known as a bubble cap tray.

Otherwise what we can have? On the perforations, we can have a lid sort of a thing where the lid is held in place by means of three legs which are just twisted and they fit on the tray deck. So, that as the vapour comes in the lid can go up. When the vapour flow rate is less the lid can fall on the perforation. This is known as a valve tray arrangement.

So, after the introduction and you were also told what are the different types of arrangements that are common to all trays. The different types of arrangements that are common to a tray tower as well as a packed column even the feed tray section, the column bottom section, the column top sections. They were all discussed. You have also come to know that in a tower. Generally, there is a head and so, the head is welded to the tower.

The place where it is welded that entire circumference this is known as a welding line and, but this is not the same as the tangent line from where the measurements of the different nozzles etcetera are taken.

The welding line refers to that particular portion of the circumference, where the top of the head is welded to the cylindrical portion and the tangent line refers to the tip of the vertical section or the cylindrical portion of the tray over which the dome is there.

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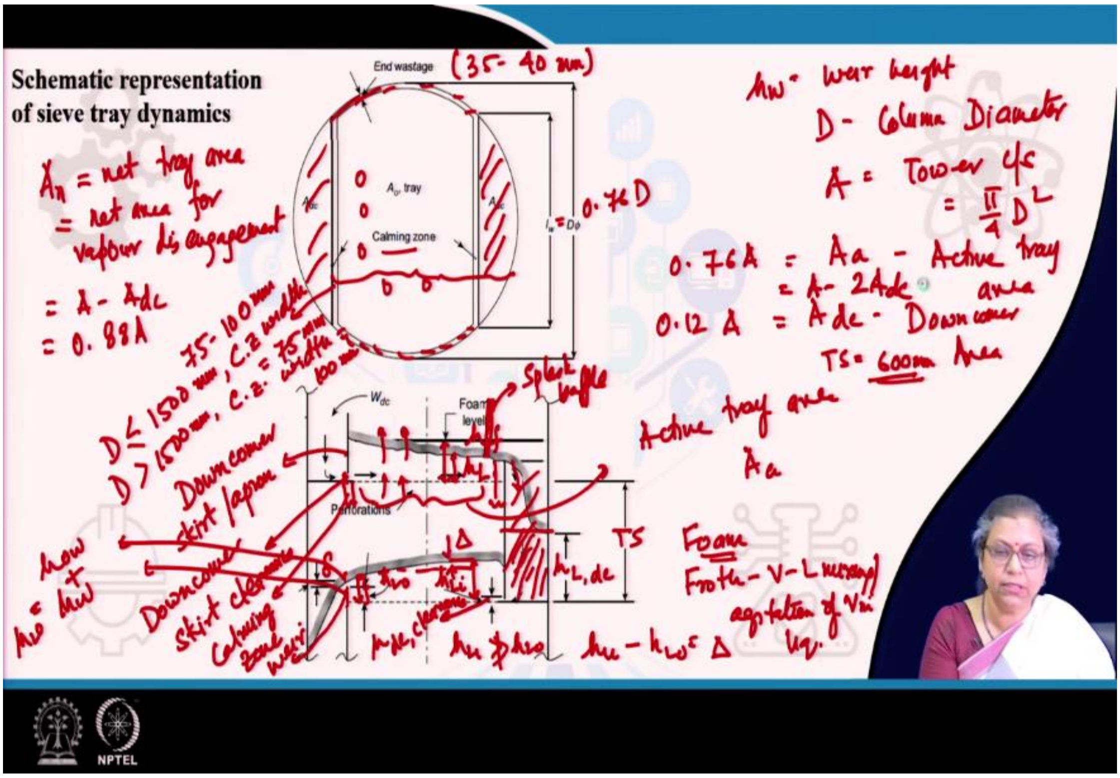

So, with all those things having been discussed today, we go for in detail discussion of the simplest type of tray design. The sieve tray design comprises of perforations on the tray. Now for this simplest tray design if you see what do you have? Certain things have already been told to you.

So, the first thing you know it's you by this time you have already realized that initially there is a large number of trays that are arranged. The liquid falls from the top tray to the tray beneath it and then to the tray beneath it and the liquid path is cross-flow to the tray. After cross flow it enters the downcomer, through the downcomer it comes and then it flows over here the way it has been shown and then it enters the downcomer of the tray. This has already been told to you.

Now, if we look at the at some particular tray section, the top view is shown here and the side view and the front view is here. What do we see? We find that we have a downcomer. This is just you can take it as a recapitulation. This particular vertical wall is known as either a downcomer skirt or a downcomer apron. You will find in textbooks that these are used interchangeably.

It has also been told to you that through this there is a small opening through which the liquid enters the tray. This particular small opening which is which is better shown here also this opening opening. This is known as the downcomer skirt clearance. This is the clearance through which the liquid enters into this particular tray.

Now, on this tray, as I have mentioned that you have got a large number of perforations. Now, these perforations do not start just right after the downcomer. There is a small section here this particular portion of this section is known as the calming zone which is also shown here this is known as the calming zone.

In case if there are some particular froth or something. So, they can get disengaged, but normally pure liquid comes and therefore, we do not require a large calming section in this particular case. In this particular calming section the dimensions if you take this is usually 75 to 100 mm the width of the calming section. Generally, if the diameter of the column which we denote with capital D, we will be using this notation throughout the sieve tray design.

If this is less than equal to 1500 mm, then the calming section the calming zone width is equal to 75 mm and if the diameter is greater than 1500 mm then, in that case, the calming zone width is equal to 100 mm. This is this particular calming zone. It is provided just after the inlet downcomer. It is also provided just after the downcomer of the tray or the outlet downcomer.

So, we have a calming section here, we have a calming section here and we also have a calming section here. After the calming section, they are leaving the calming sections the perforations are provided on the tray. So, in this particular portion where the perforations are provided quite naturally through these perforations the vapour goes out. So, therefore, this particular zone for the perforations are provided is the zone where vapour-liquid contacting takes place or in other words this particular zone. This is known as the active tray area commonly denoted as A_a.

I would like to mention that D is the column diameter. There are certain things which it is important for you to know, capital A is the tower cross-section. The column diameter is the same as the tray diameter. So, therefore, Area, A is equal to $\frac{\pi}{4}D^2$ and the portion of the tray where actually the gas-liquid or the vapour-liquid contacting takes place that particular portion it is known as the A_a. This is known as the active tray area.

The portion of the tray which is under the downcomer. This particular portion of the tray refers to this particular portion as well as this particular portion these two portions this is known as the each of them is known as the downcomer area. So, on one particular tray, the entire on this a there are two downcomers for each downcomer the area is A subscripted d_c which is the downcomer area.

So, therefore, what happens? The liquid enters through one downcomer. After it comes, we give a small calming zone and after the calming zone, it comes in contact over the perforated section. This particular perforated section comprises the active tray area.

Now, on the active tray area what happens? The vapour is rising in this particular way and the liquid is flowing in this particular fashion. So, naturally, with this intense vapour-liquid contact, we have a foamy or a frothy mixture on the tray. That means, it is a well-mixed intense two-phase mixture.

Now, here there is one thing which I would like to bring to your attention. I have used two terms one is foam. The other is a froth. Now, remember one thing that normally even if foam and froth are used interchangeably. There is a small difference between the two.

Usually, we find that froth is that particular two-phase mixture that is formed by the intense mixing of the vapour with the liquid. So, therefore, this froth is related to vapour-liquid mixing or agitation of vapour in liquid. Foam refers to when there are some surface properties or rather there are some other properties rather than agitation and mixing which brings about the dispersion or the intense two-phase dispersion then we call it as a foam.

So, you will find that in several textbooks they are used interchangeably, but you need to remember that while froth refers to them or rather while froth is formed due to the vapour-liquid mixing or it is the intense two-phase mixture that is formed by the agitation of the vapour in the liquid.

Generally, foam refers to that particular two-phase mixture in appearance-wise both may look the same, but when there are some additional parameters say the liquids interfacial tension liquid surface tension etcetera come into the picture. Then the two-phase mixture refers to as the foam.

So, therefore, over the entire tray active area, we find that there is a frothy or a foamy mixture. So, therefore, this particular mixture will have an equivalent height. Say, at any particular location there will be an equivalent height which is referred to as h_f. The equivalent liquid height means after all the vapour bubbles have disengaged. The equivalent liquid height that we get at any particular position in the tray is referred to as the h_L.

Therefore, as we move across the tray from the liquid inlet to the liquid outlet, we find that that the h_L is not constant throughout. The h_L at the entry portion is referred to as h_{Li} (inlet) which is naturally than the h_{Lo} (outlet).

So, therefore, it is quite natural that h_{Li} has to be greater than h_{Lo} for the liquid to flow from the tray inlet to the tray exit. When it flows, it faces resistance across the tray, flows across the tray deck and also due to the rising vapour or the gas bubble.

So, naturally, there is a gradient and this particular gradient is the difference between the two this particular portion. This is denoted by Δ. Where $h_{Li} - h_{Lo}=\Delta$. We have already been discussed with you that during the liquid is flowing, we do not want a very large value of Δ. We do not want that h_{Li} to be much greater than h_{Lo}. The reason has also been said naturally the vapor bubbles will like to rise through that particular portion of the tray where it receives less resistance.

So, therefore, it will naturally receive less resistance in that portion where the liquid depth is less. So, naturally, they will always want to rise towards the exit end and less towards the entry. So, naturally with this insufficient or inadequate vapour-liquid contacting the mass transfer is going to decrease and that is going to affect the tray efficiency. We would always like to operate the tray with maximum efficiency. So, that the separation that we want can be achieved with the minimum number of trays.

Therefore, the tray is comprised of three regions.

1. Downcomer zone,
2. Calming zone: There is a calming zone both at the inlet liquid as well as the liquid exit,
3. Active tray Zone: The main mass transfer occurs in the active tray area.

In this particular portion of the tray, we have a gas-liquid intimate mixture. This extends over some particular portion and then gradually the liquid start disengaging and they fall back and the vapour rises just to engage. To ensure that more or less the minimum amount of liquid is entrained along with the vapour, we need to have a minimum tray spacing.

It has already been told to you that the tray spacing, TS is around 600 mm for normal conditions and it can generally range from 450 mm to 600 mm under some conditions. When the liquid is extremely foamy, we can also go for 900 mm of tray spacing as well. To start with we are going to assume that for normal services it is around 600 mm.

The other thing is quite natural as the liquid is flowing over the tray. More or less the equivalent liquid height is the froth height which is the height of the liquid-vapour mixture. So, as the liquid flows, a frothy mixture of the liquid and vapour enters the downcomer.

So, in the downcomer, you would not like this particular frothy mixture to flow through the downcomer and come to the bottom tray. You would like the vapour to get disengaged from the liquid while the liquid is residing in the downcomer. So that pure liquid can come and it can flow through the tray beneath it.

The reason is again very obvious when the vapour with the greater proportion of the more volatile component, as it is brought down naturally, the tray efficiency is decreased. So, therefore, we need to provide sufficient residence time for the liquid inside the downcomer such that the maximum amount of vapour can be disengaged.

So, this is one particular requirement. We have the other requirement also. We need a minimum downcomer back up here such that the vapour instead of flowing through the perforations they do not enter into the downcomer and they do not short circuit the active area and flow through the downcomer.

So, therefore, this particular downcomer backup is termed as the $h_{L, dc}$. This is the delta here. This particular part is the downcomer skirt clearance which is referred to as the h_{dc} clearance. The other thing also which was mentioned to you that the liquid as it flows we want a definite height of the liquid at the exit end as well.

So, therefore, to ensure that what we have, the downcomer skirt is extended above the tray deck and this particular portion is known as the weir. The height here is known as the weir height. The weir height is defined as h_w. The weir length this is defined as $l_{w.}$ Generally, l_w is equal to 0.76 times of D.

So, therefore, what happens? The liquid as it flows it comes to the weir and then it flows over the weir. So, therefore, the liquid height effective height here is the height of the weir plus the liquid which is flowing above the weir. So, therefore, the liquid height at the exit comprises of this particular height which is h_w and the liquid height over it which is termed as h_{ow}, (liquid height over weir).

So, at the end, we find h_L will be equal to h_{ow} + h_w or rather h_{Lo} equals to h_{ow} + h_w. There is one other thing like the perforations do not start just after the downcomer in the same way we do not have perforations right from the circumference, why? Because the tray has to be fitted.

So, therefore, there will be a tray support ring. Therefore, there will be bolts etcetera. So, therefore, some particular portion towards the circumference, there also we cannot have holes. This particular area is known as the end wastage area. The depth of this end wastage area is normally 35 to 40 mm. So, therefore, the area you can very well calculate this is an annular section with 35 to 40 mm width.

So, therefore, if you know the entire tower diameter then you can calculate the area which is lost as the end wastage areas, again there are two end wastage areas at the two particular ends. Typically we know that the downcomer area A_{dc} = 0.12 A. These are some of the typical values. The active tray area generally equals 0.76 A.

So, therefore, these are the typical values that you can assume when you start. Along with that, there is another very important area parameter which you should know that area parameter is known as the net tray area. This is a net area for vapour disengagement.

What is this area? You can very well guess, the area which is available for disengaging of vapour. Now the liquid falls from here. It flows across the tray. Then, it enters the downcomer. Over this after the first downcomer, this entire area is available for vapour disengagement. Vapour can get disengaged over the active area. It can also disengage over the downcomer area.

So, therefore, this particular area (A_n) is equal to ($A-A_{dc}$) which is generally equal to 0.88 A. There is one thing which you need to remember this was also mentioned in the last class often if the liquid has got a very high it can foam very much under that condition just upstream of this particular weir we can have an arrangement like a splash baffle.

Now when we have this splash baffle, then the liquid comes and strikes here and then there is a good amount of vapour-liquid disengagement. When you have a splash baffle then the net area for vapour disengagement just becomes equal to the active tray area.

Normally, When the splash baffle is not provided under that condition net, tray area is not equal to the active tray area because the net tray area is ($A-A_{dc}$) and the active tray area (A_a) this is equal to ($A-2A_{dc}$).

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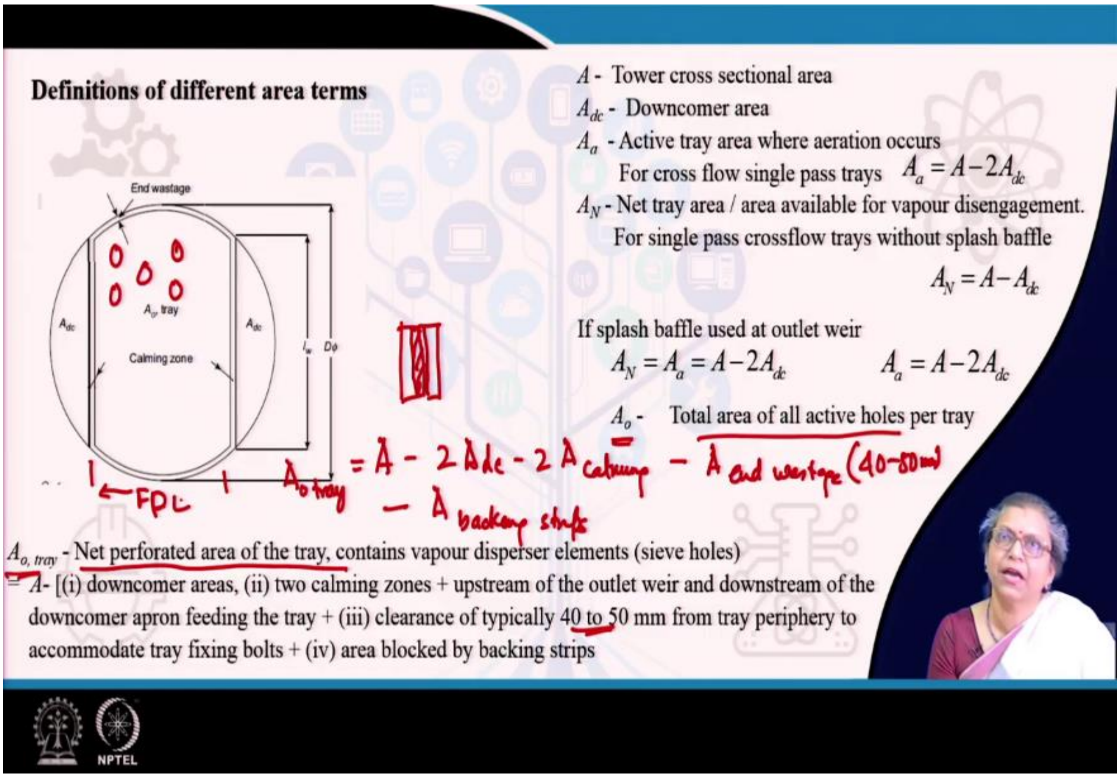

So, therefore, more or less all the terms I believe I have covered. So, now let us go to see the definition of the different terms I have already provided to you. So, therefore, you can just see that if any definition I have left out. One definition, I have left out is that on this particular active area what do you have? You have got holes. These holes can either be punched or they can be drilled here.

Now, the total area of all the holes per tray. Now one thing you have to remember is in this entire active area we can put holes. We can keep on putting holes. The holes are arranged in a particular pitch. Normally, for a sieve tray, the pitch is triangular. So, we can keep on putting the holes here.

Now, there is one thing if you remember that the trays it has already been mentioned to you that the trays are made in sections. These sections are carried inside the tower and then they are fitted. Now when the trays are fitted naturally what happens? We have got one particular tray section, we have got another particular tray section. So, therefore, we have a backing strip where the two sections are bolted.

So, therefore, naturally, on this particular bolt, you cannot have the number of active perforations. So, these particular areas are not available for the holes. So, therefore, leaving this the total area of active holes per tray that refers to A_o.

You have to remember that the vapour and the liquid flow rate are usually not uniform throughout the column. If we have a liquid feed then case the liquid flow rate beneath the column and the liquid flow rate above the column is not the same. Same way, the vapour flow rate beneath the column and the vapour flow rate above the column is also not the same.

Then, in that case normally we do not have a column with different diameters. We design a column with a diameter where the vapour flow rate is maximum. For the other sections often what do we do? We simply blank some of the active holes. So, that the performance is not affected. So, therefore, leaving the holes which are covered by the bolting strips etcetera whatever active holes. We have that is defined as A_o. This is one other term that you need to know.

So, with all this now you tell me what is the net perforated area of the tray? The net perforated area is defined as A_o tray which is shown that contains just the vapour dispersers through which the vapour can disperse.

So, it is natural if you take A the 2 A d cs have to be subtracted from here, the 2 calming zones have to be subtracted from here, the 2 end wastage areas or rather the end wastage area has to be subtracted from here. This is typical as I have told you it is 40 to 50 mm from the tray periphery. This particular proportion is left minus the area which is occupied by the backing strips. So, this gives you the net perforated area of the tray.

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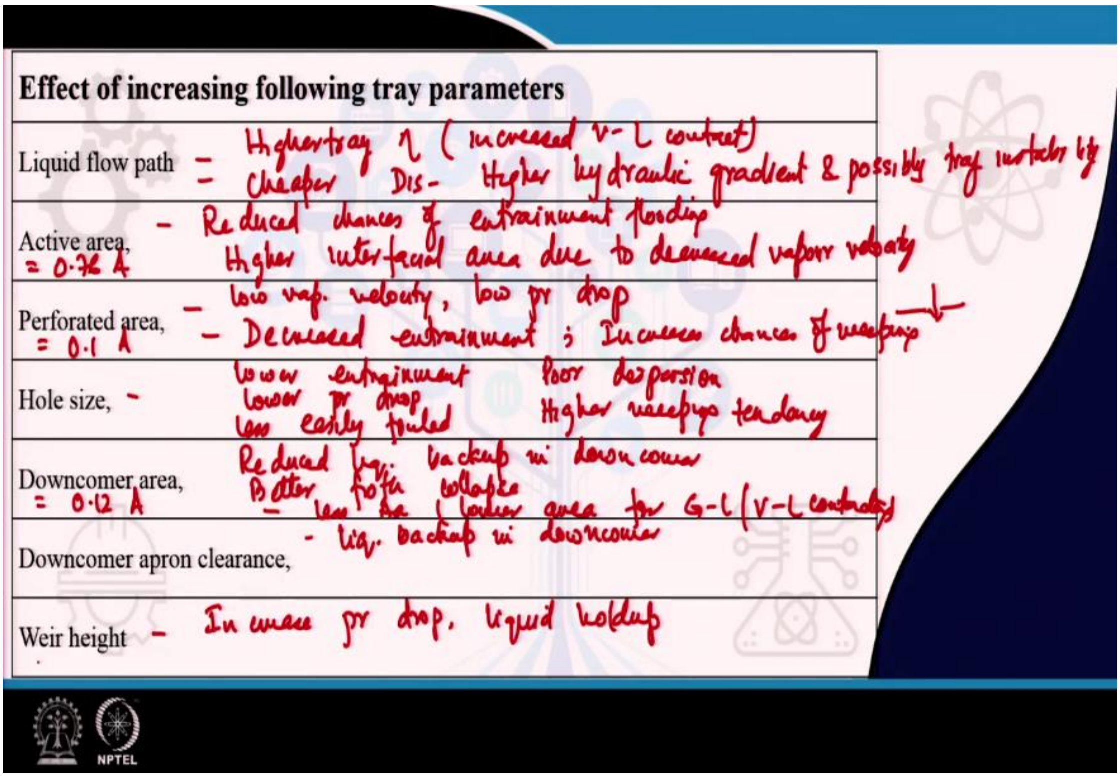

So, therefore, by this time you have come to realize roughly more or less what are the different nomenclatures for the different areas of a sieve tray now before I proceed further just as a revision I would like to discuss that depending upon the different parameters how they influence the tray performance. The liquid flow path for sorry the what is the liquid flow path? The liquid flow path length is the path over which the liquid flows right.

So, therefore, now let us see how the different sections or rather how if we increase or decrease the different sections, how the tray performance is going to get influenced. So, once you know this you know that under what conditions which parameter should be increased and which parameter should be decreased whatever I will be discussing they are primarily just based on logic and nothing else.

Tell me if you increase the liquid flow path what is going to happen? The liquid and the vapour are going to have a greater contact among themselves. So, naturally, what do you expect? You expect a higher tray efficiency when the liquid flow path is increased. Because of increased vapour-liquid contact. Naturally, when the efficiency is higher you will you can make the same particular separation with a smaller number of trays. So, therefore, you can say that for the increase in liquid flow path the arrangement can also become cheaper. One more thing, but there is a disadvantage of increasing the liquid flow path. When the liquid flow path increases naturally the pressure drop also increases.

So, therefore, the disadvantage is that higher hydraulic gradient. So, for every particular parameter, you will find that with increasing there is a plus and there is a minus based on this plus and minus and your requirement you are going to fix the different parameters.

So, therefore, a higher hydraulic gradient can lead to possible tray instability. Definitely, this is when the flow path is very high.

The active tray area is quite evident. If you increase the active tray area what happens? There is a greater cross-sectional area for vapour-liquid contacting and when there is a greater cross-section for vapour liquid contacting under that condition. What you have what happens? A naturally lesser amount of liquid when the contact is more there is also a greater area for vapour-liquid disengagement.

So, therefore, what do we have? Naturally, under this condition, we have reduced chances of. Quite naturally there will be reduced chances of entrainment flooding; what is this exact term we will discuss after a while? But for the time being you remember that the lesser amount of liquid droplets being carried over with the vapour and causing flooding.

Along with this what you will have? You will have also have a higher interfacial area of vapour and liquid. So, therefore, in the higher interfacial area why? Because as the active area is increased the vapour velocity decreases. So, therefore, we have a higher interfacial area.

Next, if we come to the perforated area decreased vapour velocity. They have almost related the perforated area as well as the active area quite naturally this also reduces the vapour velocity. When the vapour velocity is reduced quite naturally the pressure drop also decreases it is quite natural.

But along with that when the perforation size increases that under that particular case at the same time, we also have decreased entrainment here in this particular case we also have decreased entrainment beyond a particular limiting value.

One more thing for a perforated area. I missed out these are the advantages that I have said that when the perforated area increases, the vapour velocity decreases, this results in natural. If the vapour velocity decreases the pressure drop decreases and the entrainment also decreases beyond value. At the same time when more and more vapour is coming when the vapour velocity decreases. There is also a chance that the liquid can fall off through the perforations.

So, therefore, this also increases the chances of weeping. Therefore, there is a higher chance of unstable operation. The same thing applies to holes hole size as well. When the hole size increases quite naturally we will have lower entrainment just similar to the perforated area we are going to have lower pressure drop similarly we are also this one other thing if there is a fouling liquid.

So, therefore, this is less easily fouled, but at the same time when we increase the hole size, the dispersion is naturally the vapour size bubble size increases. So, therefore, poor dispersion and the same thing higher weeping tendency. Tell me about the downcomer area? If you increase the downcomer area what happens?

As the downcomer area increases, the downcomer backup decreases. So, therefore, that might not be reduced liquid backup in the downcomer. Quite naturally this is going to happen in this case and what is the other thing which happens? Naturally when the liquid backup decreases, but when the downcomer area is increased we have a higher area for froth collapse.

So, therefore, we get better froth collapse in this particular case these are the advantages. But again what is the disadvantage? When the downcomer area increases. there is less A_a, the active area naturally down comma area has to increased at the cost of the active area. So, therefore, the active area decreases. So, therefore, we have a lower area for gas-liquid or vapour liquid contacting. Same way down comer apron clearance.

Now, if you increase the apron clearance what is going to happen in this particular case? When you increase the apron clearance then naturally the liquid backup in the downcomer decreases. When the liquid backup in the downcomer decreases. So, naturally the chances of vapour short-circuiting that increase.

Normally, when you increase the liquid apron clearance the under that condition often. We need an inlet weir also to maintain a proper liquid seal in the downcomer and to prevent the vapour short-circuiting.

Weir height what happens if you have a smaller weir height? Then naturally there will be a lower liquid depth in this particular case. So, therefore, when we increase the weir height what do we do? We increase the pressure drop this is a disadvantage and we also increase the liquid hold up in this particular case ok.

So, therefore, these are how the different parameters are in influence the tray performance. Therefore, you have to keep these things in mind and based on these particular the pros and cons of increasing and decreasing. The data or the range of performance, for example, the active area is equal to 0.76 A. Then the perforated area equals 0.1 A. Downcomer area is equal to 0.12 A.

So, these things are have been decided based on the advantages and disadvantages or based on their influence on the tray operating parameters. So, with this, I end today and the next class. What we are going to do is I am we are going to discuss the limits of operation of a sieve tray and after that, we will be discussing the different ways by which we can estimate the different parameters of the tray as well as the downcomer.

Thank you very much.