Principles and Practices of Process Equipment and Plant Design

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Module - 02
Lecture - 24
Sieve Tray Design (Contd.)

Well, hello to all of you. Today we will be continuing our discussions on the Sieve Tray Design. In the last class, I had given you a basic layout of the sieve tray, and we had also defined the different design parameters associated with a sieve tray.

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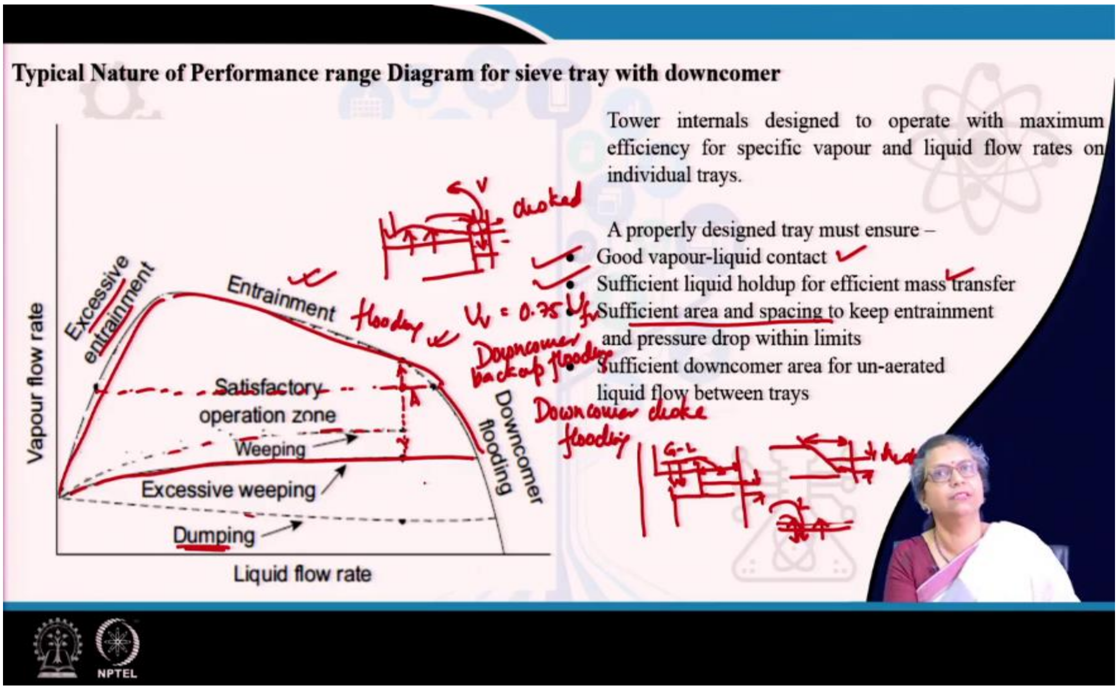

Typical Nature of Performance range Diagram for sieve tray with downcomer

Tower internals designed to operate with maximum efficiency for specific vapour and liquid flow rates on individual trays.

A properly designed tray must ensure –
- Good vapour-liquid contact
- Sufficient liquid holdup for efficient mass transfer
- Sufficient area and spacing to keep entrainment and pressure drop within limits
- Sufficient downcomer area for un-aerated liquid flow between trays

Now, today before I go into an estimation of the different parameters, what I would first like to discuss with you is a typical range of operation rather typical range over which a sieve tray with a downcomer can operate. Now, typically such a diagram will be available for all tray towers be it bubble cap, be it valve tray, be it sieve tray, the limiting operations will be the same just the appearance of the curve might be different or may be the zone of satisfactory operation that may be different for the different cases.

Otherwise, the typical nature which has been shown in this case for a sieve tray with a downcomer is the same. More or less it is the same limiting factors or limiting phenomena will be there for the other cases as well.

Now, this typical nature of the performance diagram, they are usually plotted in terms of the vapour flow rate versus the liquid flow rate. Now, normally we find that when we are plotting it, there is one particular range of operation where the sieve tray can be operating satisfactorily.

Now, this is bounded by this particular curve, the curve which is shown by the solid line (Excessive weeping curve) and this particular zone (Entrainment curve). I am not going to hatch it out just because I need to show different phenomena here. So, this marks the satisfactory zone.

Now, we would like to operate in the satisfactory zone. What do we think that we are going to expect in this satisfactory zone? When we are operating in the satisfactory zone means we are ensuring very good vapour liquid contact. Secondly, we ensure that there is sufficient liquid holdup on each of the trays such that mass transfer takes place or there is efficient mass transfer, and the tray efficiency is high.

The other thing is that there is sufficient area and also sufficient spacing between the trays such that there is not a large amount of liquid that is entering, and therefore, the pressure drop is also kept within limits. So, therefore, this is also the other thing. So, therefore, when we design a proper tray, so what are the things that we are ensuring?

We ensure that over here, there is a good vapour-liquid contacting or gas-liquid contacting. Next, we ensure that there is sufficient liquid holdup on the tray such that mass transfer occurs efficiently. Both vapour liquid contacting as well as efficient mass transfer is essential for proper tray efficiency.

The next thing you need to ensure is that the area is sufficient such that the vapour velocity is not too high. If the vapour velocity is too high, then what happens to the vapour, it tends to take the liquid along with it to the tray above, and therefore, there is this is known as entrainment. When the entrainment is too much, then we call it entrainment flooding.

So, definitely, we will not want that. So, therefore, they should be to ensure that the entrainment is a minimum. We need to have a balance between the tray diameter and the tray spacing because you know that when the tray diameter is very small, then in that case the vapour velocity is high. Therefore, to minimize entrainment, the tray spacing also has to be increased.

So, therefore, there has to be an optimum balance between the tray spacing and the cross-sectional area such that both entrainment and pressure drop is kept within limits.

Now, there is something which I would like to mention in this case please remember that in actual case you do not think that you can fully eliminate entrainment. That means, you cannot fully eradicate some amount of liquid droplets being carried out with the vapour. You cannot fully eliminate some amount of liquid falling through the vapour disperses.

This is known as weeping. Some amount of weeping, some amount of entrainment is permissible. It is always there. We cannot eliminate it, but we have to minimize, in such that tray or rather the column performs within a limit of the efficiency that is desired by it. The next thing is as the liquid is flowing, it is coming in contact with vapour. Therefore, a vapour-liquid mixture drops into the downcomer.

So, therefore, the downcomer, there are two things about the downcomer that you have to remember. Firstly, this particular area should be sufficient because this particular area provides for the disengagement of the vapour from the liquid. The second thing is that there has to be sufficient height of the liquid inside in the downcomer such that vapour does not short circuit through it.

So, there are two things in the downcomer which is important the area of the downcomer here as well as a sufficient amount of liquid backup in the downcomer. So, very frequently as I have been told to you, we can have a tapered downcomer so that the top portion has got sufficient area for vapour-liquid disengagement. At the same time, the bottom portion of the area is less so that we can ensure up a proper liquid holdup in the downcomer. So, we can have a tapered downcomer for this. So, therefore, these are the things that we need to ensure.

Now, remember one thing among all the trays if there is one tray also where there is maldistribution that is the performance is going to affect the adjoining trays as well.

Because it is the combined performance of all the trays which give rise to the column performance. So, for all the trays we need to ensure that more or less the performance lies within permissible limits such that the vapour liquid contacting, the pressure drop, the entrainment, everything is within permissible limits for all the trays that need to be ensured.

You know that this is the zone of satisfactory operation, wherein this particular zone would you like to have your operation. See the thing is if we go for the maximum possible vapour and liquid flow rate which is very close to this particular limiting operation. Quite naturally as we go for higher flow rates. What do we expect there? We expect that for such a condition we will have the smallest tray diameter which is going to bring about the separation that we desire.

So, naturally, we would like to keep our operation as close as possible to the higher limits of the vapour and liquid flow rates. Now, suppose we start from this particular area, this particular point A – this is our operating point. Now, and now from here, suppose I keep a liquid flow rate constant and I start decreasing the vapour flow rate.

What do you expect is going to happen? The vapour flow rate over the on this particular tray, the vapour flow rate it starts decreasing. The moment, the vapour flow rate starts decreasing what is going to happen? The liquid would like to flow through the perforations on the tray.

So, naturally what happens? Some amount of liquid starts flowing through the perforations. Now, again I repeat that a small amount of weeping of the liquid through the perforations provided for vapour flow is unavoidable. Some amount definitely happens. When the tower is closed down for a shutdown, or some maintenance, the liquid is drained from the tower through these particular perforations in the case of a sieve tray.

So, some amount of weeping is always permissible. It will find that the weeping the onset of weeping line that falls within the satisfactory zone, so that much is permissible. But if we keep on decreasing the vapour flow rate what happens at one point of time, we will find that a great amount of liquid start straining through the perforations, such an amount that it influences the liquid level on the tray.

Whenever it influences the liquid level on the tray that the liquid such a case that the vapour liquid contacting becomes unstable that particular region we call it as excessive weeping.

Now, we would allow weeping till a point where the liquid level on the tray is not significantly affected. So that the vapour-liquid contacting goes on and the distillation operation goes on satisfactorily. The moment the liquid draining is such that the liquid level on the tray gets affected, and this the operation becomes unstable that is not a very desirable situation for us. So, therefore, that marks the limit of the satisfactory operation with a decrease in vapour flow rate at a constant liquid flow rate.

Now, if we keep on decreasing the vapour flow rate still further, what happens, more and more liquid starts coming out, till a stage when almost all the entire amount of liquid starts flowing down to the perforations. None of the liquid reaches the downcomer. This particular operation is known as dumping which we will never want.

We would never want to exceed the situation where excessive weeping has happened. So, this is the thing that happens as we decrease the vapour flow rate keeping the liquid flow rate constant. Now, from this particular point where we want to operate, now suppose we start increasing the vapour flow rate keeping the liquid flow rate constant. What do you expect is going to happen?

You know very well that as the vapour flow rate on the tray it increases, we find that it is going to entrain a greater amount of the liquid on which through which it is bubbling. So, as the vapour flow rate increases, it keeps on entraining liquid. Again I will like to repeat or remind you some amount of entrainment is always permissible, we will have some amount of entrainment.

We cannot eliminate entrainment, just like we cannot eliminate weeping completely. But at the time comes when the great amount of liquid gets entrained as droplets and such that again tray efficiency gets influenced to a great extent. When that happens, then under that condition we call it entrainment flooding. This any sort of flooding you remember that for any counter-current operation you must have studied in your mass transfer classes that the limit of any counter-current operation is flooding.

Under flooding what happens, the liquid is carried over by the vapour. One particular way of detecting the flooding point, you must have done it in your experiments in your mass transfer laboratory that the flooding point is detected by a high very large pressure drop. You will find that the pressure drop was fine at the flooding point. It increases to a great extent and a sudden decrease in tray efficiency.

So, definitely, we would like to operate somewhat removed from the flooding point such that the tray operation can go on, and the tray efficiency can be maintained within a particular specific limit. So, if the vapour velocities increased more and more, it carries such a large amount of liquid with it that the entire tray entire column becomes fixed filled up with the liquid.

Under that condition, we call it entrainment flooding which we will not want. Normally, we would like to operate at a vapour velocity which is about 75 % to 80 % of the flooding vapour velocity that we would like to do for normal liquids. If the liquid as having a very high forming tendency, under that condition, we would like to operate at somewhat much lower flooding velocity.

Now, we have discussed what happens with the decrease and increase of the vapour flow rate. Now, from this particular point, if we are keeping the vapour flow rate constant and we start increasing the liquid flow rate. What do you expect is going to happen? The moment we start increasing the liquid flow rate under that condition, what happens? A greater amount of liquid starts falling into. Even with an increase in liquid flow rate, it is quite expected that more and more amounts of liquid will be entrained, and we are going to have an entrainment flooding that is there.

The other thing which happens more and more liquid, it starts falling into the downcomer. As more and more liquid starts falling into the downcomer we have a downcomer backup. Downcomer backup is essential, but as more and more liquid falls this downcomer backup starts increasing. When the downcomers backup starts increasing then in that case naturally when this height increases, we get a lower amount of high for vapour-liquid disengagement.

Now, as the liquid in the downcomer starts increasing, there is time that can come when the entire liquid when the entire downcomer has become filled up with the liquid. Under that particular condition, we come to a condition which is known as downcomer backup flooding when the entire downcomer has become filled up with the liquid.

Now, after this, what will you what do you expect? When the entire downcomer has become filled with the liquid naturally under that condition what happens the liquid from the tray can no longer enter the downcomer. Now, usually at the downcomer, what happens, liquid enters in this direction and it is a vapour liquid mixture, and the vapour it disengages and flows in this particular direction.

When the downcomer becomes filled up, what happens, the vapour going out from the downcomer the liquid entering the downcomer. It can no longer happen, and the opening of the downcomer it becomes choked. Under this particular condition, we have a condition which is known as downcomer choke flooding.

This is the limiting operation. The moment we have downcomer choke flooding, under that condition that the liquid level in the tray starts increasing. When the liquid level in the tray starts increasing, naturally under that condition flooding occurs. So, therefore, what I wanted to emphasize is, you need to remember that for any counter-current operation, you should remember that we always prefer counter-current operation.

But whenever we are going for any counter-current operation we have to keep the limits of the counter-current operation or it is a limit below which the operation has to be performed that limit is always set by flooding. What happens during flooding the vapour or the gas velocity is so high that it carries the liquid with it.

Now, when we are talking about specifically a distillation column, there are two types of flooding. One is the entrainment flooding the common thing. When does it happen? It happens when the vapour velocity is so high that it carries the liquid along with that. Along with that, we have one other type of flooding in the case of distillation columns which is known as the downcomer flooding.

Now, why does it happen? It happens with an increase in liquid velocity. Now, the question which you will be asking me is that whenever you increase the liquid velocity. The liquid level in the tray rises, and the liquid level in the downcomer rises. So, why do I call it or rather why do I term the flooding which occurs under this condition as the downcomer of flooding?

The reason is definitely when the liquid velocities increase, the liquid level in the tray increases. The liquid level in the downcomer increases. Since the downcomer is of a smaller cross-section as compared to the active area of the tray, the increasing level of the liquid inside the downcomer will be much more significant as compared to the increase in the liquid level over the tray.

So, naturally, the level of the liquid in the downcomer increases, and therefore, the downcomer gets flooded. After the downcomer gets flooded, when we attain the choke condition, then the liquid can no longer enter the downcomer. Under that condition, the liquid level in the tray significantly increases, and it results in flooding.

So, therefore, there are two types of flooding with an increase in vapour velocity, normally we get entrainment flooding. With an increase in liquid velocity, we get a downcomer flooding this is typical to distillation columns only.

Now, this particular my favoured operating point that I have selected. Suppose I start decreasing the liquid flow rate keeping the vapour flow rate constant. What happens as the liquid flow rate keeps on decreasing, the vapour flow rate is kept constant, naturally the liquid they start getting entrained.

Again the same problem the liquid starts getting entrained with the vapour because the liquid velocity is much less. So, therefore, instead of flowing crossflow, the vapour forces the liquid along with it. Therefore, we obtain a particular condition which is known as excessive entrainment.

So, therefore, this particular point we find that this point we attain by keeping the vapour flow rate constant at a much lower liquid flow rate. So, under this condition, we get something like excessive entrainment where the velocity or rather the tray operation becomes unstable. We again from this excessive entrainment, reach our condition that all the major portion of the liquid is carried away with the vapour, and naturally vapour liquid contacting becomes insufficient.

So, by now you have understood that we would always like to remain within this particular satisfactory zone. In this satisfactory zone, we would like to operate at the maximum possible liquid and the vapour flow rate, such that we can operate with the smallest tower diameter to effect the separation that we want.

When since we are operating under this condition, much removed from the excessive entrainment conditions. So, therefore, flooding is something that we need to keep in mind when we are designing the column. We need to see that the column does not flood under any condition.

Remember one thing when we are designing sieve trays along with the flooding. It is important to see that the column is also not weeping excessively. So, once the column is designed, the flooding and the weeping conditions have to be checked.

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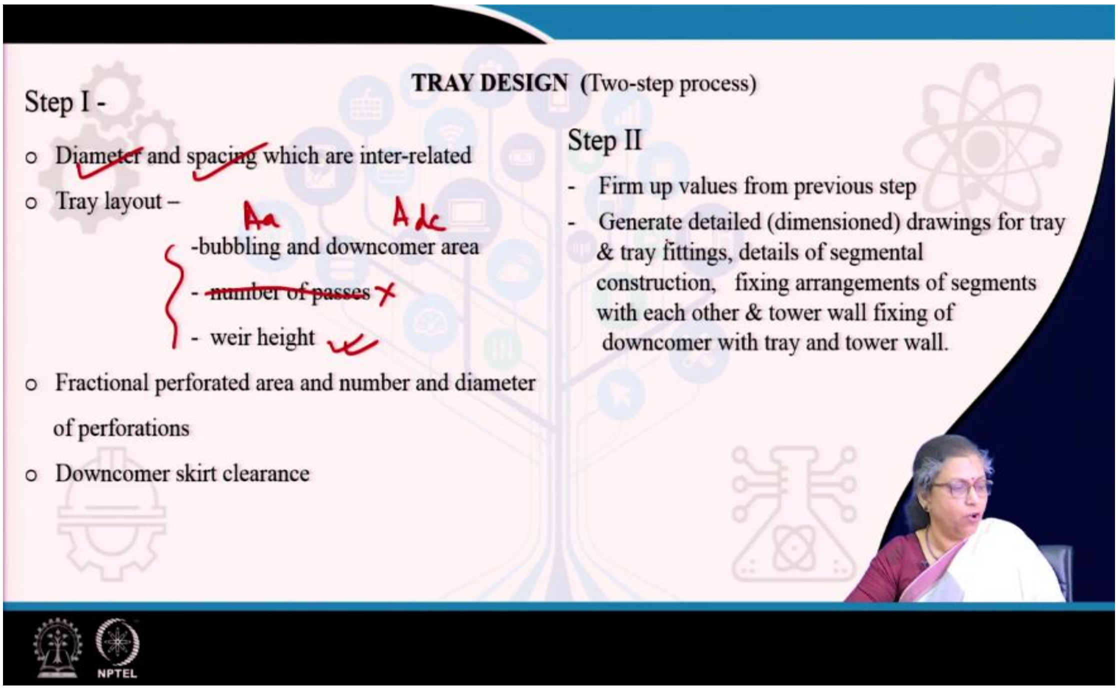

TRAY DESIGN (Two-step process)

Step I -

- Diameter and spacing which are inter-related
- Tray layout –
  - Aa Adc
  - bubbling and downcomer area
  - ~~number of passes~~ ✗
  - weir height ✓
- Fractional perforated area and number and diameter of perforations
- Downcomer skirt clearance

Step II

- Firm up values from previous step
- Generate detailed (dimensioned) drawings for tray & tray fittings, details of segmental construction, fixing arrangements of segments with each other & tower wall fixing of downcomer with tray and tower wall.

So, with this, what are the things that we have done? We have come to know what are the different sections of a sieve tray, we have come to know what the limits of operation of the sieve tray. Now, we go into the actual design. What are the things that we would like to design? Definitely, the first thing that we would have to estimate is the tower diameter and the tray spacing.

Tray spacing has already been discussed with you. So, I will not go into the details. Once the diameter and the spacing are fixed, then we go for the tray layout. What is the tray layout? Naturally, the active tray area has to be estimated, the downcomer area has to be estimated. Generally, when we are dealing with the sieve tray columns, we always have a single pass tray where there is a downcomer at the inlet, the liquid flows downcomer at the outlet.

So, this part will be the number of passes that will be discussed when you go for the bubble cap tray. Apart from the bubbling area, downcomer area, the weir dimensions also have to be decided, particularly the weir height because that decides the outlet liquid height. The perforations etcetera downcomer skirt clearance.

Once these basic steps are done, after that we would like to firm up the values. They generate the detailed drawings which I have also already been discussed in the previous class or rather previous took the introduction portion.

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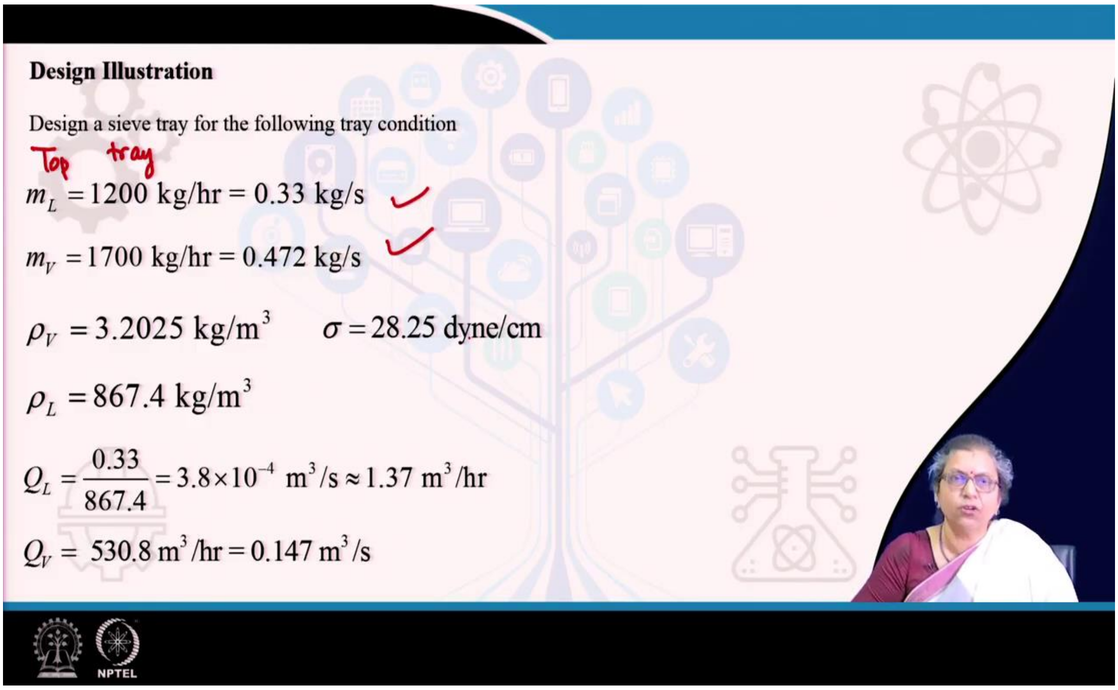

Design Illustration

Design a sieve tray for the following tray condition

Top tray

$m_L = 1200 \text{ kg/hr} = 0.33 \text{ kg/s}$ ✓

$m_V = 1700 \text{ kg/hr} = 0.472 \text{ kg/s}$ ✓

$\rho_V = 3.2025 \text{ kg/m}^3 \qquad \sigma = 28.25 \text{ dyne/cm}$

$\rho_L = 867.4 \text{ kg/m}^3$

$Q_L = \frac{0.33}{867.4} = 3.8\times10^{-4} \text{ m}^3/\text{s} \approx 1.37 \text{ m}^3/\text{hr}$

$Q_V = 530.8 \text{ m}^3/\text{hr} = 0.147 \text{ m}^3/\text{s}$

Now, when we go for a design, I have taken up a problem where liquid and vapour were a mixture of benzene, toluene, and ortho-xylene. We assume that we are going to perform distillation in the sieve tray. So, therefore, the flow rates on the top tray are discussed. It was told to you that generally based on the top tray we decide the diameter etcetera.

Then if a smaller amount of holes are required in the bottom trays, we just compensate it by blanking some of the holes. So, therefore, on the top tray, the liquid flow rate, the vapour flow rate, the liquid-vapour properties everything has been specified. We would like to go for the design of the tray.

Now, I have put up the specific values. So, that when I go and discuss the design, you can along with listening to the lectures, you can do the calculations yourself and see whether you are getting the correct results or not. Then you can compare with the numerical values that I will provide in the next class.

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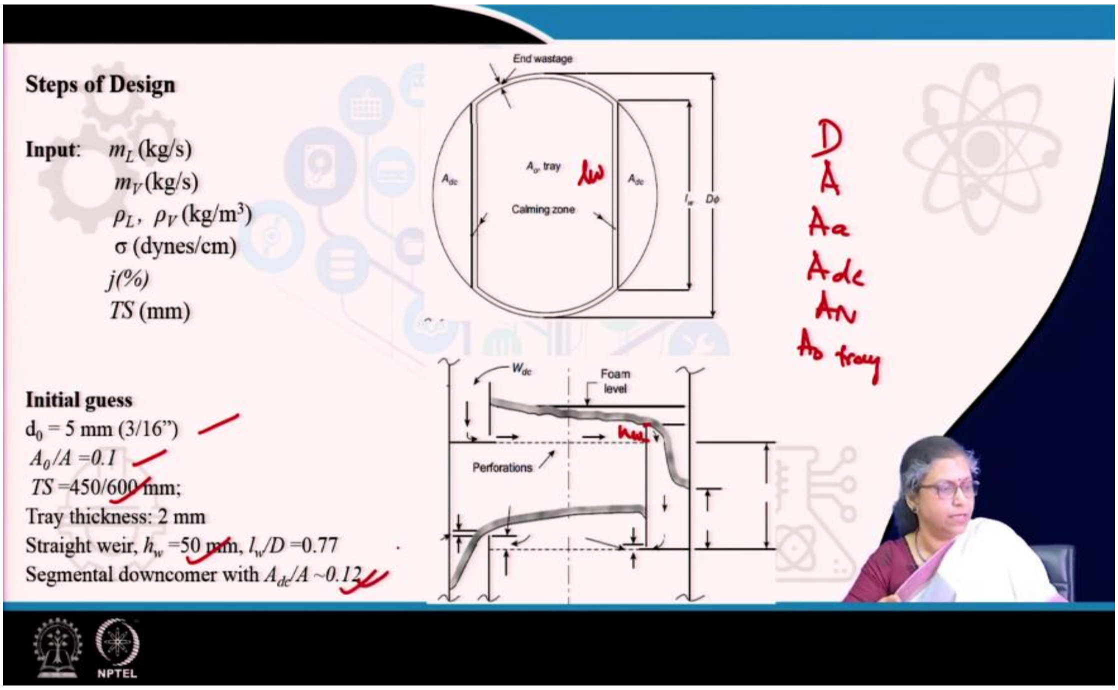

Steps of Design

Input: m_L (kg/s)
m_V (kg/s)
ρ_L, ρ_V (kg/m^3)
σ (dynes/cm)
j(%)
TS (mm)

Initial guess
d_0 = 5 mm (3/16")
A_0/A =0.1
TS =450/600 mm;
Tray thickness: 2 mm
Straight weir, h_w =50 mm, l_w/D =0.77
Segmental downcomer with A_{dc}/A ~0.12

D
A
Aa
Adc
AN
Ao tray

So, for this is a typical problem, and more or less in all the problems, this is the basic data that is provided to you when you go for the design. Now, once it is there, it is you already know what are the different parameters that you have to design. The first thing is definitely D. The other parameters are A, A_a, A_{dc}, A_N, and $A_{o,\ tray}$. Once these are done, then the entire layout etcetera has to be designed. After that, the weir height etcetera I have already told you.

Now, remember one thing, this has also been told to you that generally, any sort of design is an iterative process. We guess some values. We go ahead with the design. That each stage, we come back and check whether our guesses are correct or not. If the guesses are not correct, then we go for a different guess. So, the initial values that we will assume before we start the design. These are the typical initial values to fetch most of the conventional columns in industries.

So, therefore, based on this the hole diameter, the perforated area diameter, the TS are normally 600 mm. The height of the weir, I have told you this particular height, this is h_w. The length of the weir the l_w – this is equal to 0.77. The segmental downcomer with this particular area is 0.12. All those things have been mentioned to you.

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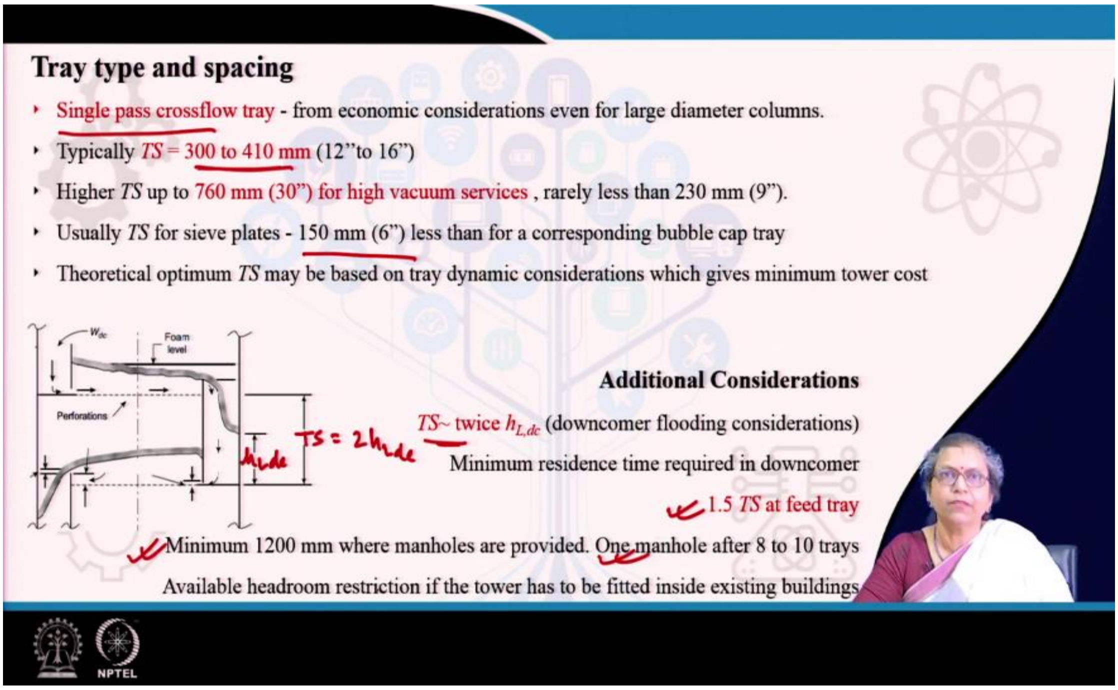

Tray type and spacing

- Single pass crossflow tray - from economic considerations even for large diameter columns.
- Typically *TS* = 300 to 410 mm (12"to 16")
- Higher *TS* up to 760 mm (30") for high vacuum services , rarely less than 230 mm (9").
- Usually *TS* for sieve plates - 150 mm (6") less than for a corresponding bubble cap tray
- Theoretical optimum *TS* may be based on tray dynamic considerations which gives minimum tower cost

Additional Considerations

$TS \sim$ twice $h_{L,dc}$ (downcomer flooding considerations)

Minimum residence time required in downcomer

1.5 *TS* at feed tray

Minimum 1200 mm where manholes are provided. One manhole after 8 to 10 trays

Available headroom restriction if the tower has to be fitted inside existing buildings

So, therefore, now we go for taking up each parameter and starting the design. Regarding the tray type and the tray spacing I have already told to you, generally sieve trays. They are adopted for not a very high liquid and vapour throughput. So, therefore, normally we go for a single pass cross-flow tray which is shown here. I have already told you. Even when we go for a very large diameter also, we prefer a single pass cross-flow tray.

Normally, we have seen that for a sieve tray the tray spacing. It is normally less as compared to a bubble cap tray. So, therefore, typically the spacing is in this particular range. So, you can start with a 600 mm come down or else you can check up that normally the spacing lies here. When we go for a vacuum service etcetera, the TS is much higher.

Now, remember one thing when you are deciding the tray spacing. It is very important that the tray spacing has to be much higher as compared to the height of the liquid in the downcomer or the liquid downcomer backing. Normally, it is taken as TS is taken as twice of $h_{L,dc}$. This is something you have to remember.

The other thing has to be a minimum residence time in the downcomer. So, we are going to talk about it. Regarding the tray spacing, certain things you have to remember. This is common for all types of trays. At the feed tray, the spacing is different. The tray above which the manuals are provided, the spacing is different.

If you are having say within 8 to 10 trays, then maybe one manual is sufficient. Otherwise, after every 8 to 10 trays one manhole is there. The other thing is supposed you have to fit the column within some particular limited space. Then in that case the available headroom can also decide the tray spacing because the height of the headroom again becomes a factor. So, this is about the tray spacing.

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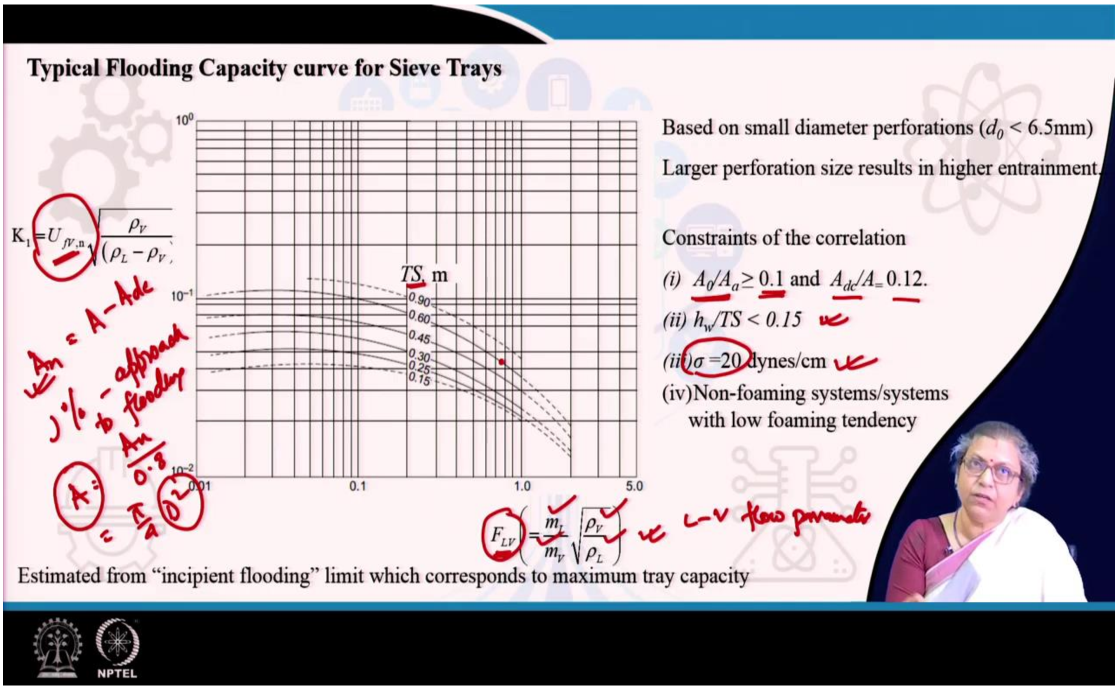

Typical Flooding Capacity curve for Sieve Trays

$K_1 = U_{fV,n}\sqrt{\frac{\rho_V}{(\rho_L - \rho_V)}}$

Based on small diameter perforations ($d_0 < 6.5$mm)

Larger perforation size results in higher entrainment.

Constraints of the correlation

(i) $A_0/A_a \geq 0.1$ and $A_{dc}/A = 0.12$.

(ii) $h_w/TS < 0.15$

(iii) $\sigma = 20$ dynes/cm

(iv) Non-foaming systems/systems with low foaming tendency

$F_{LV} \left(= \frac{m_L}{m_V}\sqrt{\frac{\rho_V}{\rho_L}} \right)$ L-V flow parameter

Estimated from "incipient flooding" limit which corresponds to maximum tray capacity

$A_n = A - A_{dc}$

j% - approach to flooding

$\frac{A_n}{0.8}$

$A = \frac{\pi}{4} D^2$

Now, the next thing is to decide the column diameter. Now, as we have already mentioned that the column diameter will be decided based on your flooding considerations. We will be operating at about 80 to 85 % flooding. Now, you have already realized that the column can flood both by an increase in liquid flow rate as well as by an increase in vapour flow rate.

But the location where we start generally under that particular condition if you remember that the flooding due to vapour flow rate. It is much more important as compared to flooding due to the liquid flow rate. So, therefore, normally when we are designing it, we would like to keep the vapour velocity under flooding conditions. Now, normally what do we do for this particular case?

This is based on some particular graphical determination where the flooding velocity is based on the net perforated area where you will remember A_n= A- A_{dc}. The net area where which is available for vapour liquid disengaging. The flooding velocity is normally determined based on that particular area. We find that this is a function of a liquid vapour flow parameter as this is called which is given by some particular expression of the liquid flow rate to the vapour flow rate. So, this is known as the liquid-vapour parameter.

The m_l and m_v are already given to you. ρ_v, ρ_l are also provided. You can find out F_{LV}. You know what is the tray spacing that you have already decided. So, based on this, you can locate this particular point. Once this point is located, you can find out the K_1 value. Once you know the K_1 value, you can find out the flooding velocity based on the net perforated area.

So, normally we would like to operate at about 75 %, 80, 85 % flooding that we are going to decide. Normally, we say the J % approach to flooding. We denote it as J %. So, therefore, once you know fv, n, you can find out A_n. You know that the A is going to be A_n by whatever it is 0.8 or 0.76 whatever you know. This area (A) is equal to $\frac{\pi}{4}D^2$. So, from there, you can find out the diameter. This is the general procedure that is done.

Now, this particular graph is developed based on certain constraints. What are the constraints which are there? It is assumed that the perforated area is greater than equal to 0.1 times or rather the perforated area comprises greater than 10 % of the active area, and the downcomer area comprises 12 % of the total cross-sectional area.

We also assume that this is generally valid that the weir height is about 15 % less. It is less than 5 % of the tray spacing. Normally, you will find that for all particular correlations to find out diameter for both bubble cap as well as sieve trays. They are based on surface tension of 20 dynes/cm.

We assume non-foaming systems or systems with low foaming tendencies. Usually for our case also we will find sigma is not equal to 20 dynes/cm. So, therefore, some correction is required from the K_1 that you get from here. Some correction is required to account for the fact that your σ is not 20 dynes/cm. But the σ which was here that was developed based on 20 dynes/cm.

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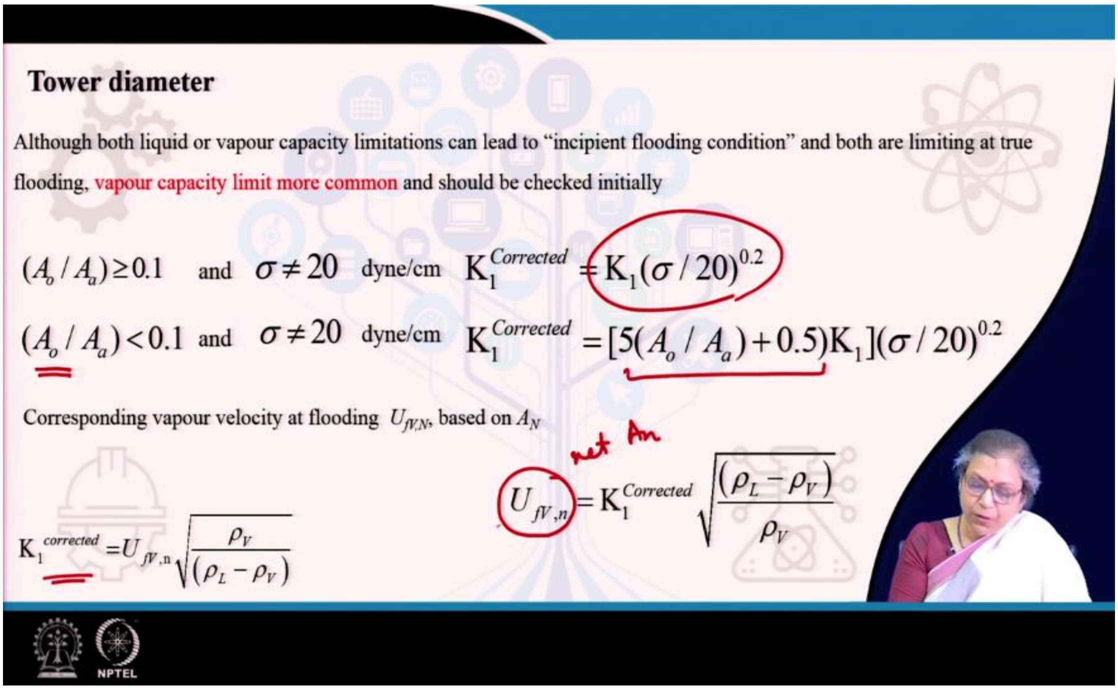

Tower diameter

Although both liquid or vapour capacity limitations can lead to "incipient flooding condition" and both are limiting at true flooding, vapour capacity limit more common and should be checked initially

$(A_o/A_a)\geq 0.1$ and $\sigma \neq 20$ dyne/cm $K_1^{Corrected} = K_1(\sigma/20)^{0.2}$

$(A_o/A_a)<0.1$ and $\sigma \neq 20$ dyne/cm $K_1^{Corrected} = [5(A_o/A_a)+0.5)K_1](\sigma/20)^{0.2}$

Corresponding vapour velocity at flooding $U_{fV,N}$, based on A_N

net An

$$U_{fV,n} = K_1^{Corrected}\sqrt{\frac{(\rho_L-\rho_V)}{\rho_V}}$$

$$K_1^{corrected} = U_{fV,n}\sqrt{\frac{\rho_V}{(\rho_L-\rho_V)}}$$

So, therefore, for that what is the correction? You need to have some particular you need to multiply the K_1 that you have derived from this particular graph with a factor of $(\sigma/20)^{0.2}$. It can also happen that your perforated area is less than 10 % of the active area. So, therefore, when this is there, then an additional correction comes in here. So, therefore, if you have two corrections to the K_1 that you obtained from this particular graph. One is particularly if sigma (σ) is not equal to 20. The other is if the perforated area is greater than 10 % of the active area.

So, depending upon which particular features are applicable, you need to go for certain corrections. Once you get these corrections, naturally under that condition you get a $K_1^{\text{corrected}}$. So, $K_1^{\text{corrected}}$ is after these corrections are incorporated in the K_1 that you have obtained from the graph. Once you have obtained the $K_1^{corrected}$, then from the $K_1^{corrected}$, the flooding velocity based on the net area can be determined.

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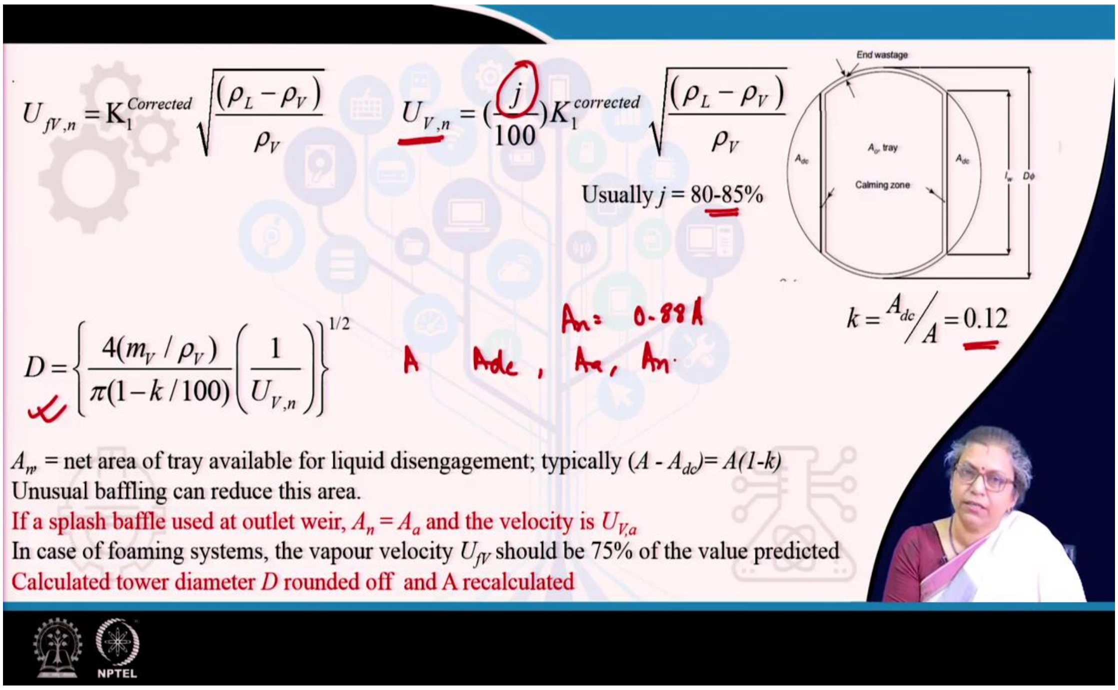

$$U_{fV,n} = K_1^{Corrected}\sqrt{\frac{(\rho_L - \rho_V)}{\rho_V}}$$

$$\underline{U_{V,n}} = (\frac{j}{100})K_1^{corrected}\sqrt{\frac{(\rho_L - \rho_V)}{\rho_V}}$$

Usually $j = \underline{80\text{-}85\%}$

$$k = A_{dc}/A = \underline{0.12}$$

$$D = \left\{\frac{4(m_V/\rho_V)}{\pi(1-k/100)}\left(\frac{1}{U_{V,n}}\right)\right\}^{1/2}$$

$A_n = 0.88 A$

A A_{dc}, A_a, A_n.

A_n = net area of tray available for liquid disengagement; typically $(A - A_{dc}) = A(1-k)$
Unusual baffling can reduce this area.
If a splash baffle used at outlet weir, $A_n = A_a$ and the velocity is $U_{V,a}$
In case of foaming systems, the vapour velocity U_{fV} should be 75% of the value predicted
Calculated tower diameter D rounded off and A recalculated

Once this can be determined, then from there based on the approach to flooding. You can find out the actual vapour velocity through the net perforated area. Normally, we find that the actual velocity is 80 to 85 % of the flooding velocity. So, based on that, you can find out the net perforated area.

Once you can find out the net perforated area, assuming 12 % to be the diameter occupied by the area occupied by the diameter; or in other words, A_n is equal to 0.88 A. You can find out the diameter as I have told you. So, therefore, this is the way diameter is found out.

Now, once the diameter is found out from here, then what we do, we just see that this diameter should conform to the standard codes. So, therefore, we round the diameter to conform to standard codes. Based on the rounded diameter we calculate A. We calculate A_{dc}. We calculate A_a. We calculate recalculate A_n to see that everything is fine for us.

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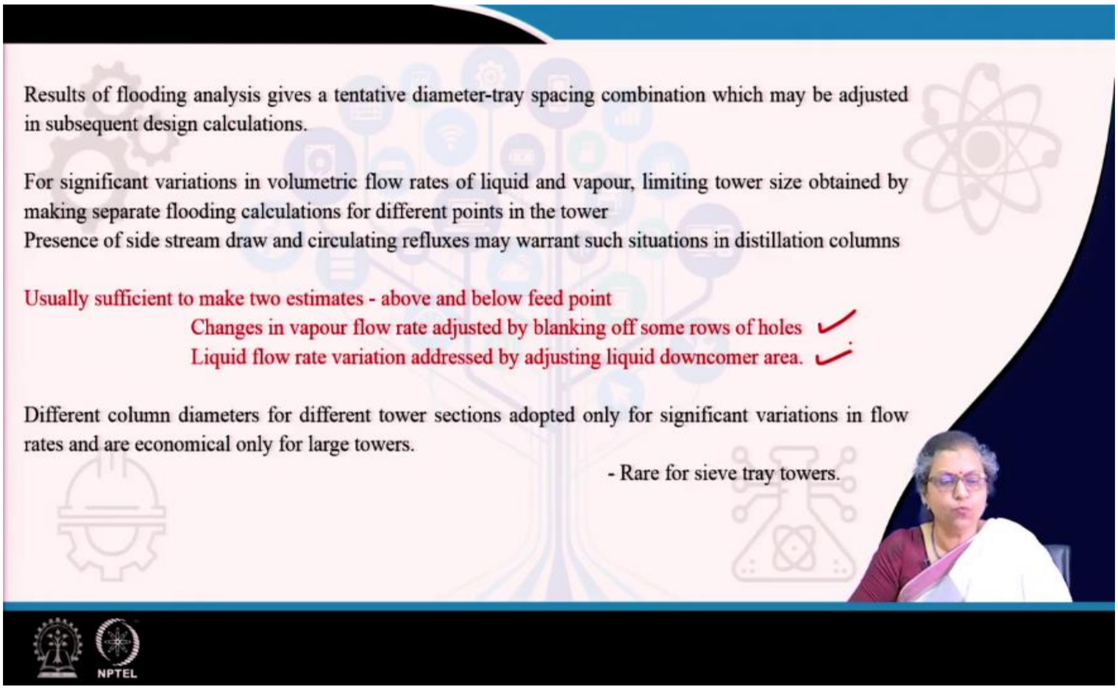

Results of flooding analysis gives a tentative diameter-tray spacing combination which may be adjusted in subsequent design calculations.

For significant variations in volumetric flow rates of liquid and vapour, limiting tower size obtained by making separate flooding calculations for different points in the tower

Presence of side stream draw and circulating refluxes may warrant such situations in distillation columns

Usually sufficient to make two estimates - above and below feed point

Changes in vapour flow rate adjusted by blanking off some rows of holes ✓

Liquid flow rate variation addressed by adjusting liquid downcomer area. ✓

Different column diameters for different tower sections adopted only for significant variations in flow rates and are economical only for large towers.

- Rare for sieve tray towers.

Now, in this case, there is just one thing which I would like to tell you that the liquid and vapour velocities. They are not uniform throughout the tower. So, therefore, to incur normally we do two calculations – one above the feed tray and one below the feed tray. For changes in vapour flow rate, it is adjusted by blanking some rows of the holes.

For changes in liquid flow rate, it is adjusted by adjusting the downcomer area. But generally for sieve trays, we do not have to do any more calculations. One calculation above the feed tray, one calculation below the feed tray is sufficient.

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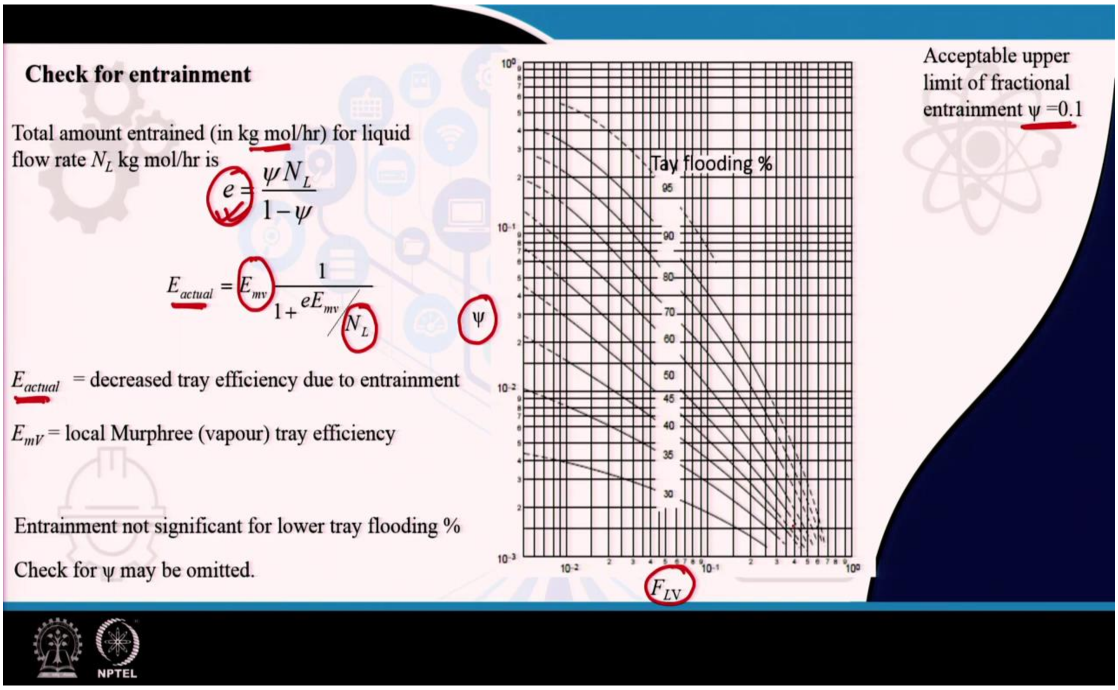

Check for entrainment

Total amount entrained (in kg mol/hr) for liquid flow rate N_L kg mol/hr is

$$e = \frac{\psi N_L}{1-\psi}$$

$$E_{actual} = E_{mv}\frac{1}{1+ eE_{mv}/N_L}$$

E_{actual} = decreased tray efficiency due to entrainment

E_{mV} = local Murphree (vapour) tray efficiency

Entrainment not significant for lower tray flooding %

Check for ψ may be omitted.

Acceptable upper limit of fractional entrainment ψ =0.1

So, once the downcomer rather than once the tower cross-sectional area has been decided. All the areas have been fixed, then we need to see one thing that the entrainment limit that does not exceed a limit, the maximum acceptable limit is 0.1. So, therefore, we need to see that the entrainment that we have is the total amount entrained in kmol/h that does not divide by the total liquid flow rate that does not exceed a particular limit.

For that again in terms of the liquid vapour flow parameter which we know we have already adopted some particular tray flooding say 80 % or something based on F_{LV}. We try to find out ψ. Usually, we find ψ to be less than 10 %. Then we do not have to bother at all.

We would just find out that if ψ is something say 5 % of 10 % something, we find out then under that case what is the total amount that is entrained. When the total amount is entrained based on that naturally, the tray efficiency is going to change. So, therefore, what is the decreased tray efficiency due to entrainment.

We had found out the Murphree tray efficiency. So, therefore, based on the total amount entrained, we can find out what is the actual tray efficiency. Normally, we find that the actual tray efficiency does not deviate much from the tray efficiency that we have assumed. So, therefore, we can go on fine, but it is important to check for the entrainment.

They're just two things which I would like to mention. One thing is when we when you are going for a very low flooding percentage, you find that normally ψ will be very less. So, under that condition, the check for ψ need not be carried out at all. The other thing is when you are working with a very high F_{LV}. You find that you can approach flooding to a much closer extent and you can work with it.

So, with this, I conclude today’s class. We have discussed the estimation of diameter, the check for entrainment. Once the diameter is fixed, we can now fix up the different tray layouts, and we can then start designing the tray. That we will be doing in the next class.

Thank you so much.