Principles and Practices of Process Equipment and Plant Design
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Module - 02
Lecture - 26
Bubble Cap Tray Design

Welcome to the class again. You have already been given inputs on how to design sieve trays. Today's session starts on designing Bubble Cap Trays. It is not only the trays, it has to cover the bubble cap tower itself, which is not very different from the others, but let's move on with that.

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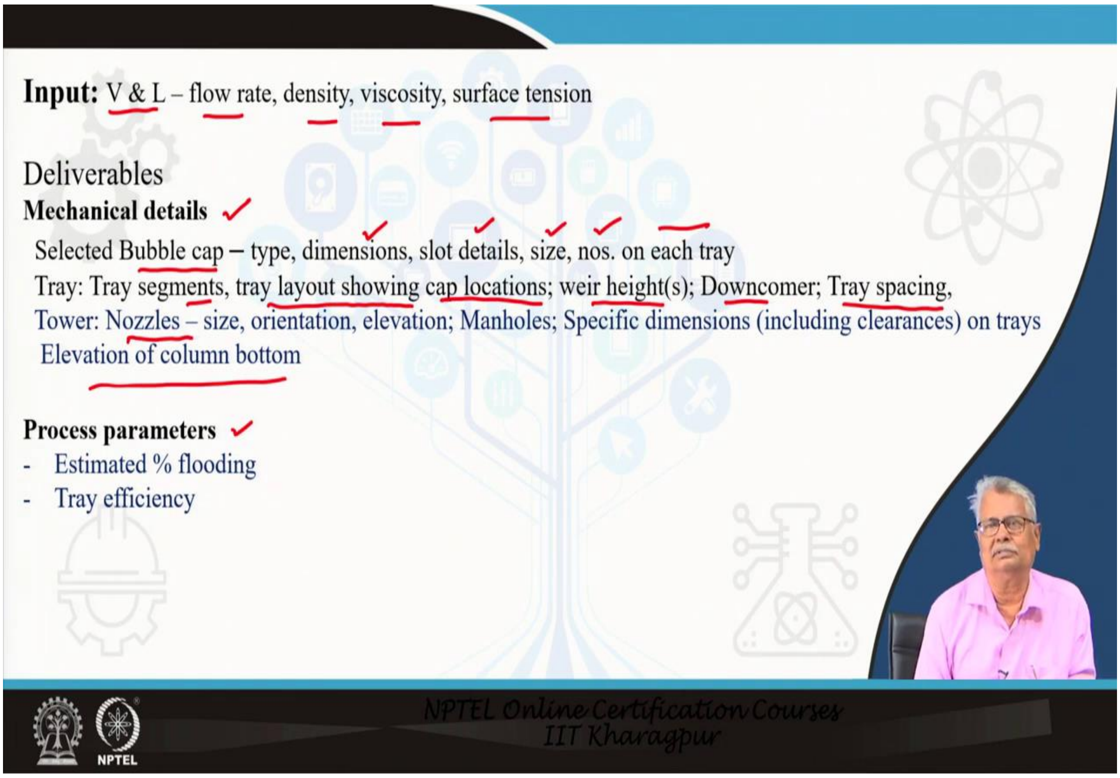

First, we see one thing that in case we have to design a tray, the basic inputs that are required are the vapour and liquid related items like the flow rate, the density, the viscosity and the surface tension. These are the four things that you require. If you are talking about the deliverables, there will be two sets of deliverables, the one set will be the process parameters.

For example, % flooding, % approach to flooding, tray efficiency, entrainment and such things and you will also be delivering quite a good amount of mechanical details which includes the bubble cap type. You do not manufacture normally bubble cap. You specify the type, their dimensions, the slot details, their size, the numbered on each particular tray.

If you are having a sufficiently large tray, it will be built in segments. But naturally, you have to provide the tray layout showing the location of the caps basically. The vapour disperses in this case. You have to provide the weir heights possibly. You will be having a single weir at the outlet. But in some cases, you may require an inlet weir also that also we have discussed earlier.

You have to discuss and give the details of the downcomer. The type and its dimensions. You definitely for the tray has to specify the tray spacings which is expected to be different in the feed tray top section and the bottom section at least. There will be different tray spacing when you have your manhole for man entry as well.

These will belong to the tower. You have to wave out or specify the nozzles, their size, orientation, elevation at which they are to be on the shell. You have to provide the manholes, the same thing about it that means, orientation and elevation and the size. You have to give certain specific dimensions on the trays. For example, the clearance of the downcomer from the tray deck. You have to specify the elevation of the column bottom as well.

The elevation of the column bottom depends on how you are going to take out your material. Basically, it is required to provide the minimum required NPSH for the bottom material to be pumped out. So, these are the list of deliverables in case of any sort of trade hour design.

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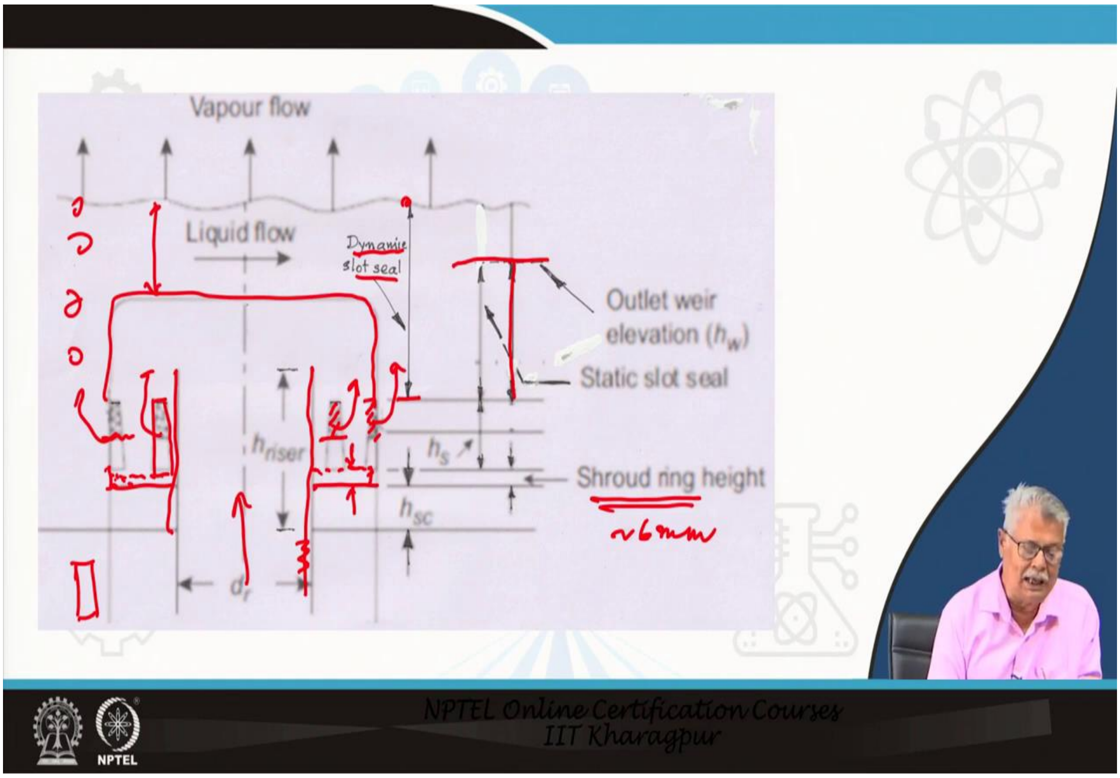

Let us have a look at the bubble cap first. This is the cap. This cap is mounted on a riser. This part you can forget. The vapour goes up this way, comes out through the slots and bubbles up. The mechanism of working we have seen but let us see to function properly. Certain essential things have to be obeyed.

Firstly, there has to be submergence of this which means, your vapour dispersion has to remain submerged. So that only the bubbles come out and the interaction is between the bubble and a pool of the liquid which is surrounding it. The cap has got usually either trapezoidal or rectangular slot.

The vapour comes out through these slots. So, quite naturally, the liquid level in the slot will get depressed to a particular level like this up to this level. So, this part of it is vapour, this part of it is vapour and below that it is liquid. So, there is something called slot submergence.

The top of the slot has to remain under the liquid level all the time and when there is no flow. The minimum level of liquid is the outlet weir elevation. So, quite naturally, this is the static slot seal that means, a minimum level of liquid above the top of your slot. Now, in the case of the flowing liquid, quite naturally there will be a level of liquid over the weir and above the cap. There will be some amount of liquid. From here up to the top of the slot will be your dynamic slot seal.

Similarly, if you look at the bottom of your slot, you will find that there is a rim. There is a solid rim which is called a shroud ring. The shroud ring typical thickness is around 6 mm, a quarter of an inch. You will also note one thing that means, whenever you have this type of slots with which are wider at the bottom and narrower at the top. The top width is roughly half of what you have at the bottom. You can also have triangular slots, but those are not very common.

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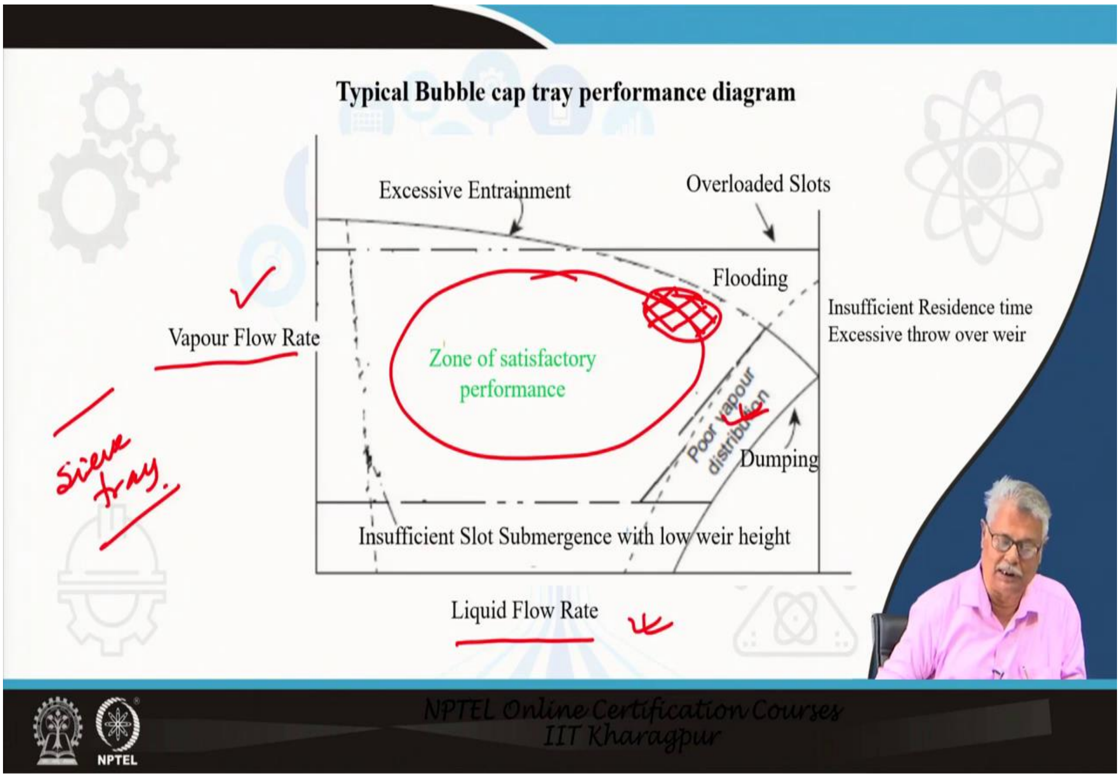

We will go further and have a look at the functioning of the bubble cap over the zone of liquid flow rate and the vapour flow rate. This is very similar to what you have seen in the case of the other disperser which is basically your sieve tray. What you find that in this case also you would like to maxima. You have a zone of satisfactory performance.

Your satisfactory performance is possible in this zone. Quite naturally, if you would like to have the minimum number of caps, you would prefer to have your design operating in this zone with a fairly high amount of vapour flow rate as well as a liquid flow rate. This would make a fewer number of bubble caps necessary for your tray.

I am not going into the details of the malfunctions. These are very obvious. For example, if you have a very high flow rate, your slots will open 100% and if you increase it further, there is no scope of opening further amount of the slot opening. So, what happens is you have almost a jet of vapour that is coming out through your slot which will reduce your contacting quality. So, you do not want to overload your slots and you would like always to operate below your overloaded slot limit.

It will also lead to excessive entrainment particularly if you have a low liquid rate and a high vapour flow rate. You will have insufficient slot submergence with low weir height and if you have a low amount of vapour rate also. So, you have poor vapour distribution in this, and you have dumping as well. So, we know now that our preferred zone of operation is here with a fair amount of flow of vapour and the liquid both tending to be high.

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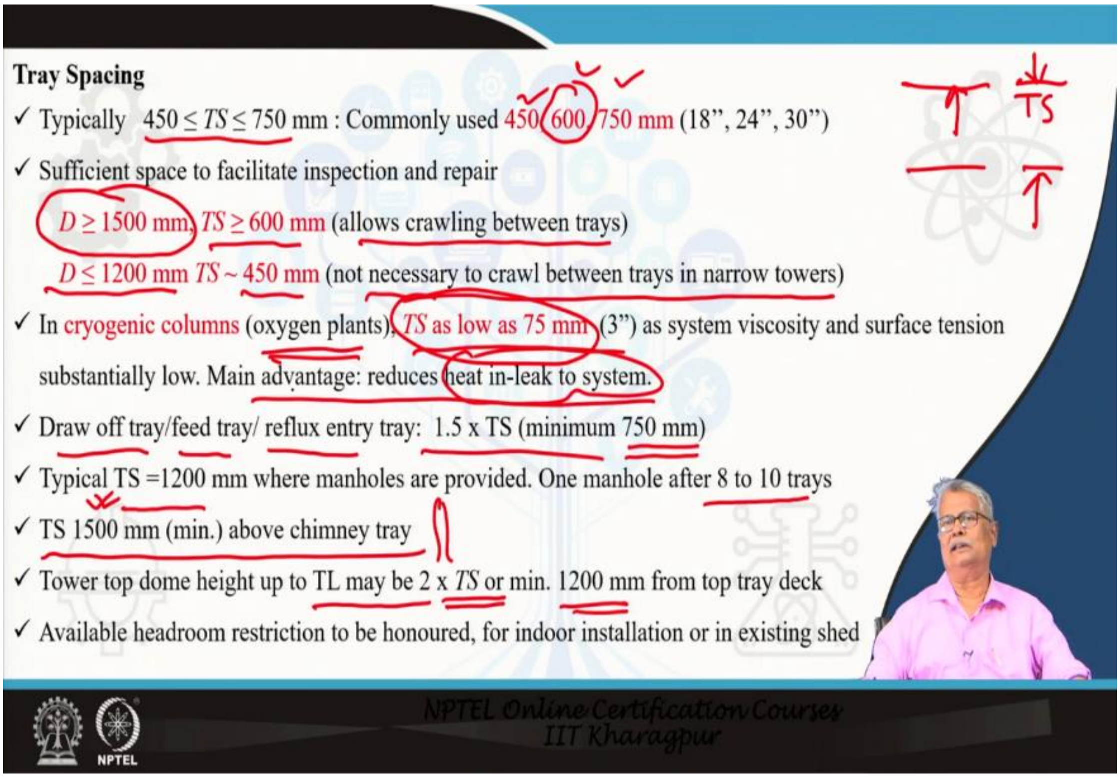

Now, there is something. If you are making a column, tray spacing directly influences the total height of the column that means the column cost. Typical tray spacing lies between 450 and 750 mm. Most common is in fact, 600 mm. Typical standard values are 450, 600, 750 mm. You can have lower tray spacing also particularly in smaller columns.

If you reduce the gap between the trays, the chance of entrainment of liquid along with the vapour would go up. But, there are quite a few other things on which your tray spacing would depend.

In large diameter columns, more than one and one and a half meter diameter column, the tray spacing is normally kept 600 mm onwards. Because to fix the trays, someone has to go in and crawl between the trays. For inspection, he has to go in over there. For smaller diameter columns, below 1.2 mm. Typical tray spacing could be 450 mm. It may not be necessary to crawl between the trays in narrow towers because it is accessible from outside if you have a proper manhole somewhere.

In cryogenic columns, the tray spacing is typically low. I have mentioned that if you have a lower tray spacing, the chance of entrainment is more. In the case of the oxygen plant that means, in the air separation plant, the liquid has got a very low surface tension and naturally, the chance of entrainment is very low and people have gone for very low tray spacing as low as 75 mm. You have a very big advantage over there that means, if you have a low tray spacing, you have a lower height of the column and cryogenic columns have to be very heavily insulated and so, naturally, if you have a lower tray spacing, lower exposed surface and your heat inlet to the system is also low.

Whenever you have a draw off tray which is a chimney tray or a feed tray or a reflux entry, normally you require a minimum of 750 mm of the tray spacing or it will be at least 1.5 times the tray spacing.

Now, if your typical tray spacing is 1200 mm, you usually will be in a position to provide around 20-inch manholes and in tall trays, you require at least a manhole after 8 to 10 trays. The tray spacing above the chimney tray, the standard is to keep one and a half meters of tray spacing. That means, from the chimney tray to the tray upper one, the gap should be about 1500 mm.

The height of the top dome of your column will be up to the tangent line. I had explained what exactly is a tangent line in the last interaction session should be a minimum of double the tray spacing or it should be 1200 mm from the top tray deck minimum. Sometimes the tray constructions and the tray spacing is also limited for indoor installation where there is an existing shed and there is limited headroom.

So, these are the basic considerations for deciding the tray spacing. Overall you will have an idea that tray spacing in industrial columns will be of the order of 600 mm. Higher ones will be required for the draw of feed tray and reflux entry and for providing manholes every 8 to 10 trays.

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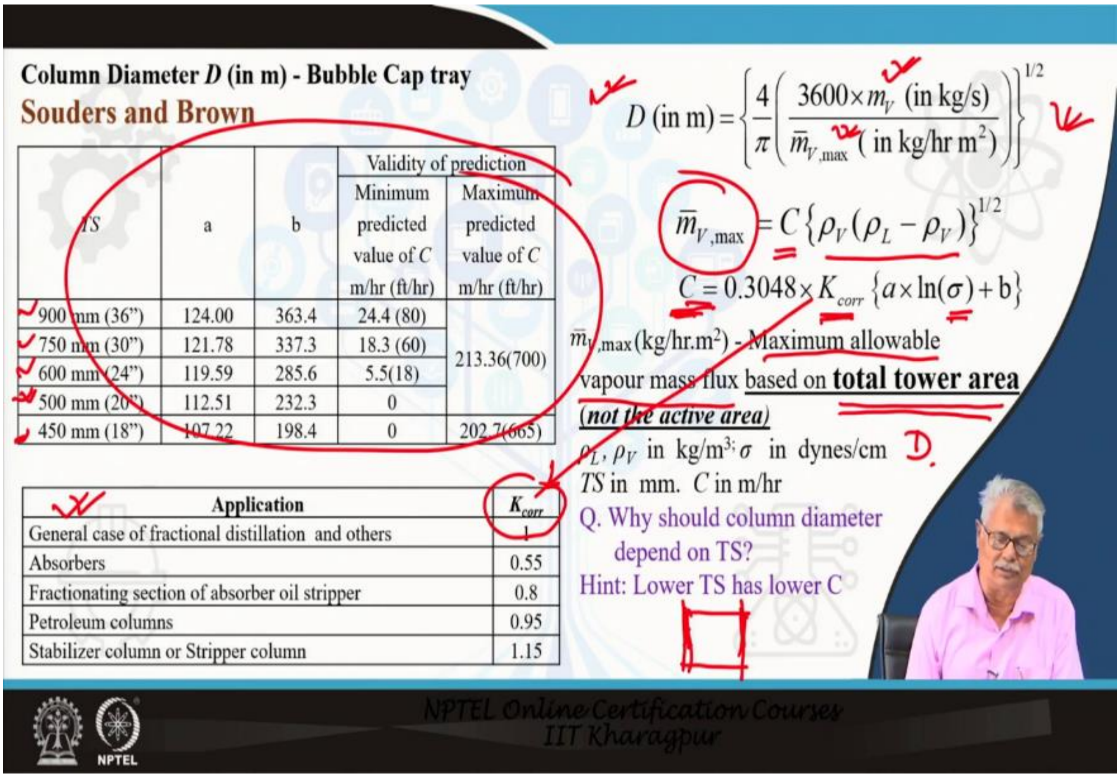

Now, we need to find out the diameter. There are two techniques for finding the diameter of bubble cap trays. The first is proposed by Souders and Brown. This is a very standard and classical procedure. The procedure depends on or rather relies on an empirical relationship of estimating the $\bar{m}_{V,max}$. The $\bar{m}_{V,max}$ is the maximum allowable vapour mass flux. I have put in bold that it is based on the total tower area, it is not the active area.

So, your Souders-Browns equation is based on the total tower area which is a capital D. Quite naturally, if I know my mass flow rate of vapour and if I can estimate my maximum allowable vapour mass velocity. If I divide these two, what I get is a tray area and from there, the expression of D. It is just geometry. The basic thing, the most basic empirical thing which is used here is the C and another constant which is given here.

You will notice one thing, it is ρ_V multiplied by $\rho_L - \rho_V$. It is not ρ_V upon $\rho_L - \rho_V$ and the C is an empirical constant that depends on this K_{corr} factor which is given here depending on the application. It is to be corrected for σ, the surface tension of the liquid. You will notice one thing if surface tension goes up, C goes up, your allowable mass velocity goes up. Your diameter comes down for the same $\overline{m}_{V,max}$.

Now, C is a function of the tray spacing as well. So, what you have here is the different tray spacing that is standard. The expression of C is here, and this is found out from the values which is given here. So, what you have here is the value of C which you find from here, which you ultimately get from your K_{corr}, and sigma. Evaluate the $\overline{m}_{V,max}$ and then, find out the diameter.

I have a question here for you, why should the column diameter depend on TS? We see here the relationship makes it dependent on the TS. Basically, they are related in this way if you see, if I have a very narrow column with a small D, my chance of entrainment is more. But if I have to have a reasonable amount of tray efficiency, I must have a larger TS. That means, if I have for my service a larger diameter tower, I can go for a lower tray spacing and vice versa is also true. So, that is the answer.

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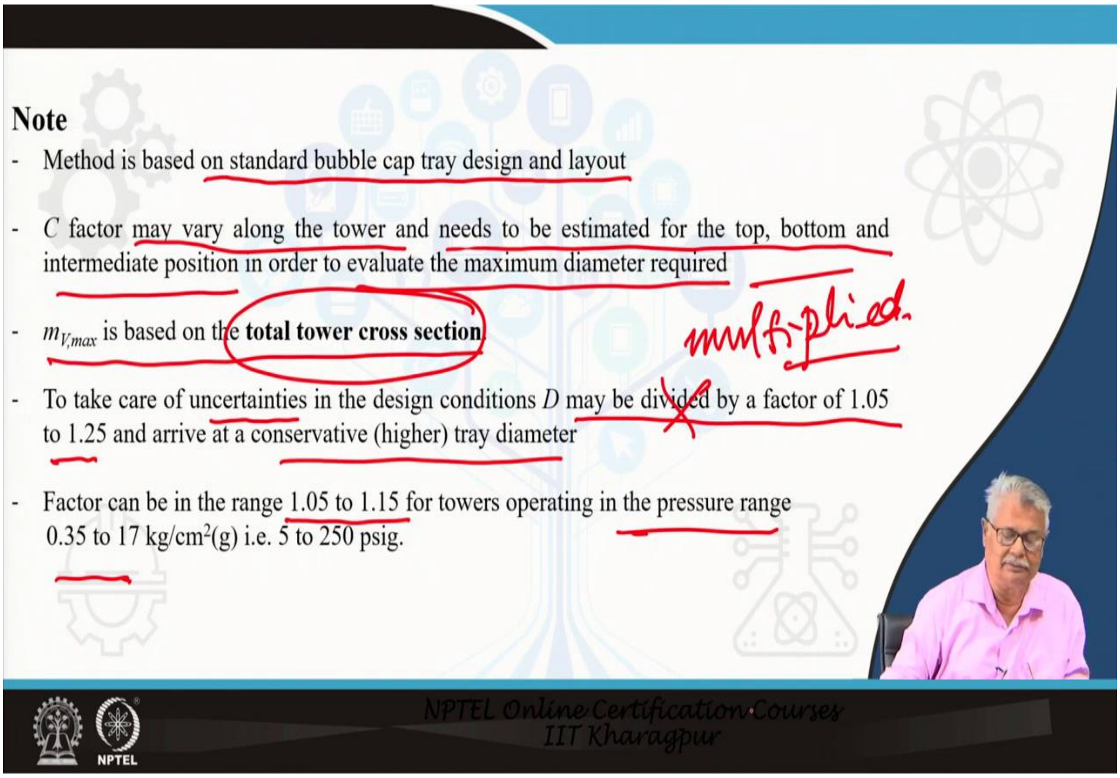

The Souders-Brown method is based on the design of standard bubble cap tray design and layout. The C factor may vary along with the tower and needs to be estimated for the top, bottom and intermediate positions. So that the maximum diameter required in a particular section is determined and normally, that is the tower diameter which is kept for the other trays which may or may not require blanking of certain of the vapour dispersers.

Now, I reiterate that the $\bar{m}_{V,max}$ term is based on the total tower cross-section. It is not the active area or any other net area as in other vapour disperser designs.

Now, to take care of uncertainties in the design conditions. D may be multiplied by a factor of 1.05 to 1.25 and arrive at a conservative (higher) tray diameter.

You generate a higher value of D which will lead to lower entrainment and a better fractionation. The factor that can be reached can be 1.05 to 1.15 for towers operating in the pressure range 0.35 to 17 kg/cm^2 or normally. The value is taken higher for vacuum towers.

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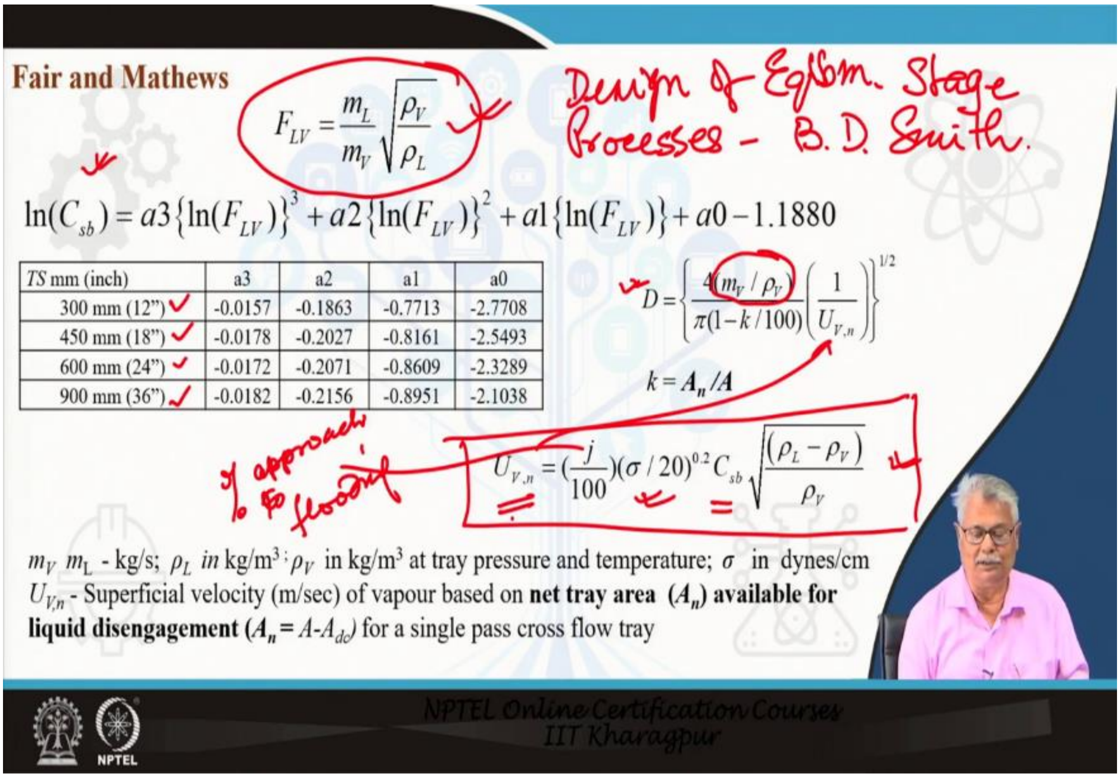

The other method for designing is from Fair and Mathews. You should refer to the book Design of Equilibrium Stage Processes by B. D. Smith, where the procedure is written by Fair himself. Fair defines a factor F_{LV}.

His definition is based on the flow rate, the mass flow rates, and the densities related this way by this expression. Then, what he does? He finds out another constant C_{sb}. sb definitely stands for Souder-Brown. But, he never mentions it anywhere at least in this stage and for different tray spacings. The constants for finding out the C_{sb} are different.

Once the C_{sb} is available, based on the C_{sb} and the value of the densities and the surface tension of the liquid and also another parameter j which is the value of the approach to flooding basically percentage approach to flooding. The conservative value of $U_{v,n}$ is found out which is used in finding out the diameter.

$U_{v,n}$ is used in this expression and this expression gives you the volumetric flow rate of the vapour from where you find out the D. So, this is how you find out the diameter by following the Fair and Mathews procedure.

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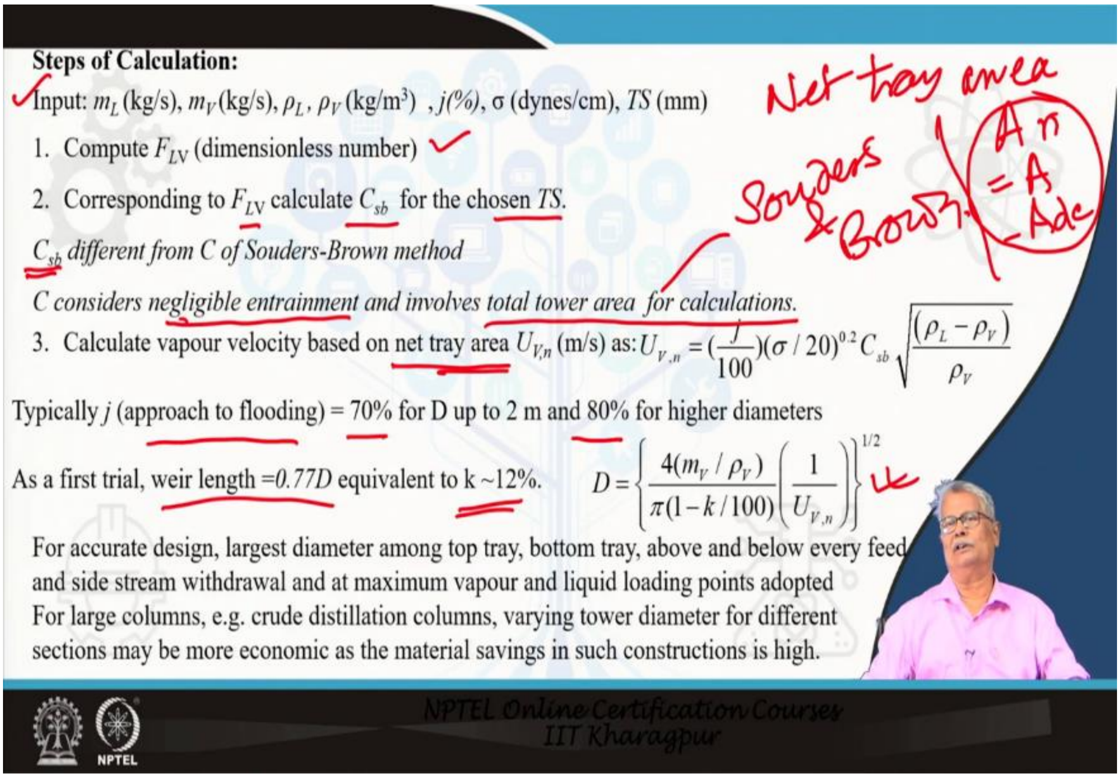

The steps of calculations, in this case, are the compilation of the inputs. Computing the F_{LV} value, corresponding to F_{LV} estimating the C_{sb} for a chosen TS. We will note that here that the C_{sb} values are different from the C of the Souder-Brown equation. C considers negligible entrainment and involves a total tower area for calculation. This is a major difference what you have.

That means C is based on the total area of calculation this is as per Souders and Brown. Whereas, in this case, it is not meant for that. It is based on the net tray area which has already been defined to you as A_n which is for a single pass tray is equal to A of the tray minus A of the downcomer that means. This basically is an area that is available for the vapour to approach the upper tray. So, it is the net tray area that is used. Typically, the approach to flooding is around 70 % or 80 % for higher diameters.

We already know that the weir length typically which is taken is about 76 to 78 % of the diameter which makes k, which is a correction for the downcomer area to be around 0.12 or other 12 %. So, your D is given by this expression which is there in the previous slide as well.

It is customary to check the diameter for the top tray, bottom tray and feed tray and add up the largest of the D as a tower diameter. Normally, varying a tray diameter varying a tower diameter at different elevations is uneconomic because it involves a good amount of increase in the manufacturing cost, but in the case of very large columns like the crude columns, it is done. The crude column typically will have a narrower top and a bottom section and a fatter middle section.

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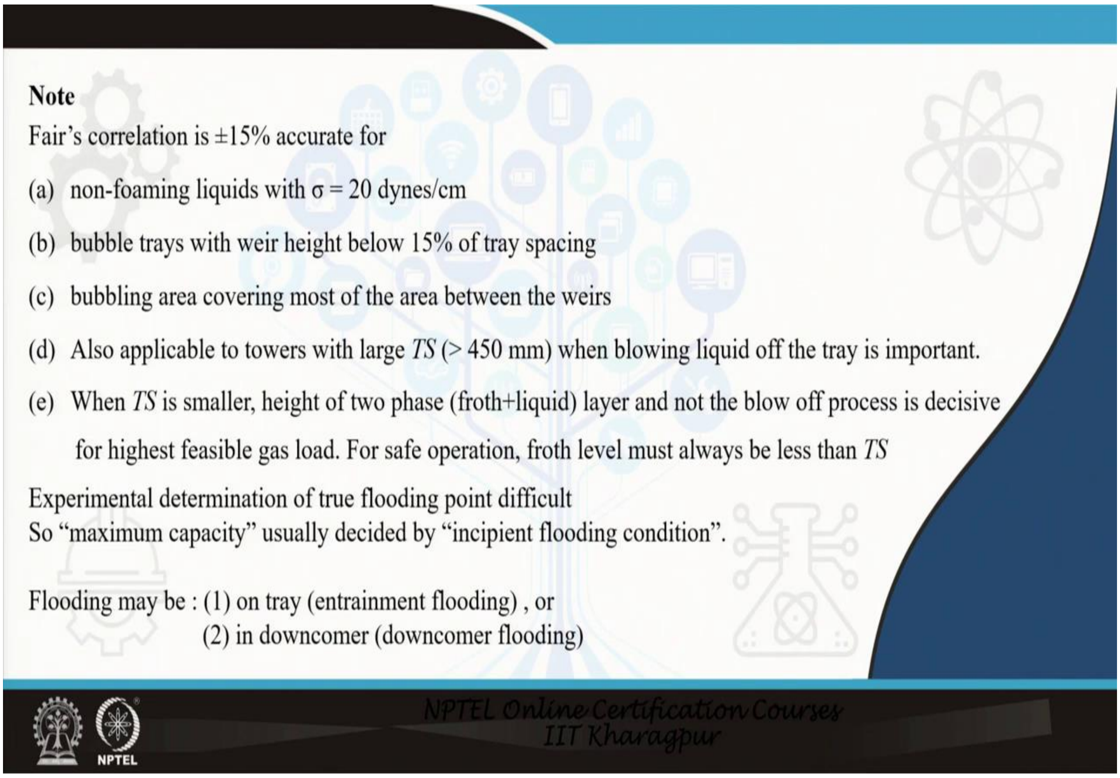

The Fair's correlation is about 15, ±15 % accurate and the basic correlation is for σ is equal to 20 and we already have told you about the correction if the deviation is from σ is equal to 20. The bubble tray where height should be below 15 % of the tray spacing, which is very common. I mean in most of the cases, you will find that the weir height will be something around 50, 60 mm whereas, your tray spacing is much much higher. Bubbling area covering most of the area between the weirs.

When the TS is smaller, the height of the two-phase which is a froth plus liquid layer and not the blow-off process is decisive for the highest feasible gas load. For safe operation, the froth level must always be less than TS. Now, flooding may be on the tray which is by the entrainment flooding or it could be in the downcomer which is called downcomer flooding and it has already been discussed when the other type of vapour disperser has been told to you.

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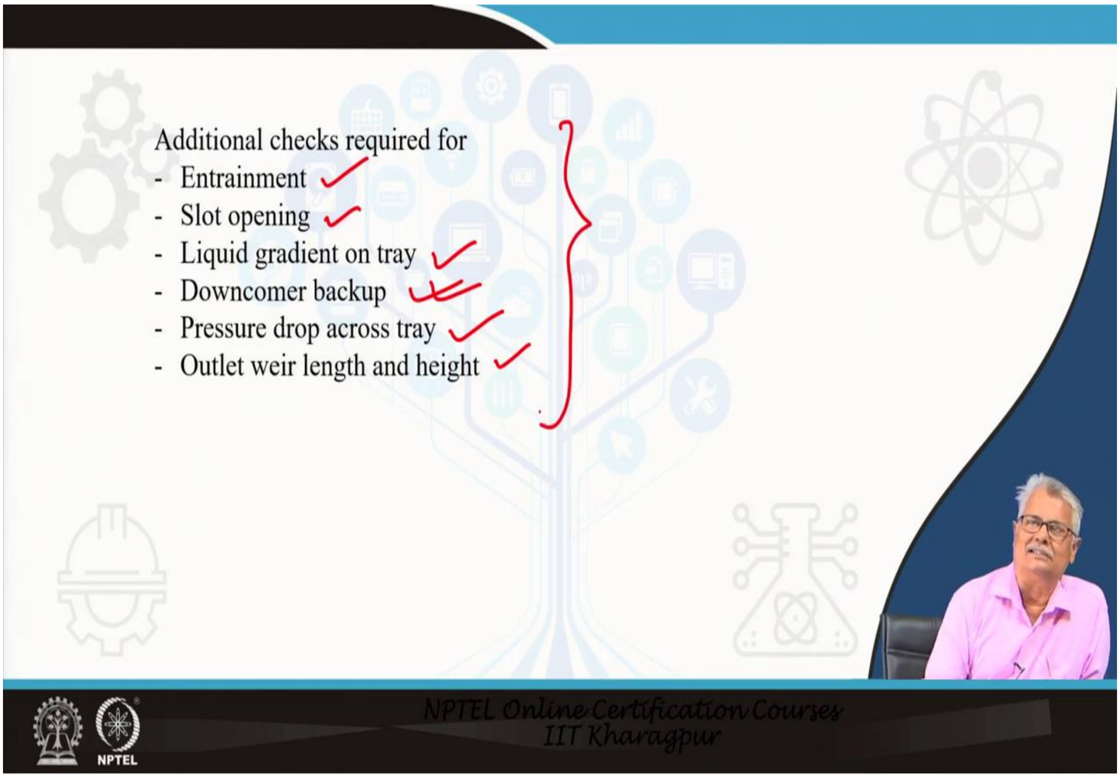

So, to complete this what you further require is to check for the entrainment. That means, you have found out already the diameter, you have decided on the tray spacing now, let us see what all things are still left. We have to find out the percentage entrainment and its effect on the efficiency. You have to find out the slot operating opening under operating conditions.

The liquid gradient on the tray has to be evaluated. The downcomer the procedure to evaluate the downcomer is already told to you in the when the vapour disperser of your sieve tray has been covered. We need to find out how to estimate the pressure drop across the tray and definitely. We have to decide the outlet weir length and height. This will be covering in the next class.

Thank you.