Principles and Practices of Process Equipment and Plant Design
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Module - 02
Lecture - 22
Tower and Tower internals (Contd.)

Wish you all a good day. Today, we are going to have a concluding lecture on the Tower and Tower Internals, the general part of it. This is something which we had continued from the previous one, and we start now.

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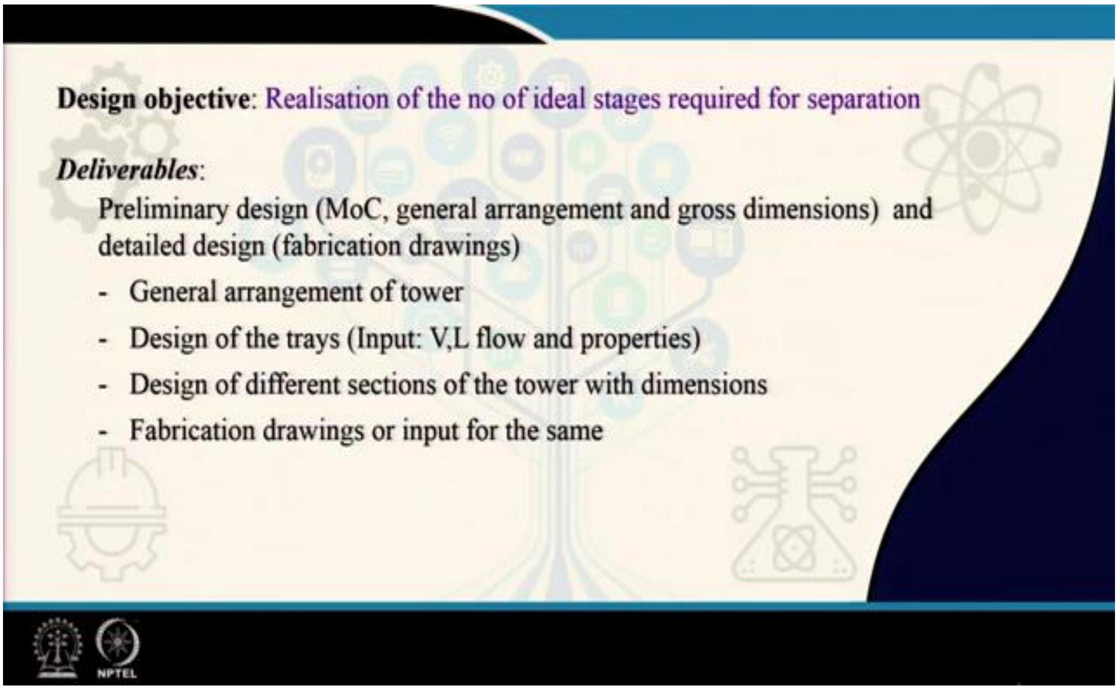

We had a design objective. The design objective was the realisation of the number of ideal stages in the tower which is required for the separation for which the design is being done. If you look at the deliverables, the primary deliverable is the preliminary design which will consist of MoC the material of construction, general arrangement and gross dimensions, and there has to be finally a detailed design which will lead to the fabrication drawings or input for those.

If we talk about the general arrangement of the tower, it will contain quite a few things. For example, the basic dimensions, the diameter, height, location of trays, elevation of different nozzles, and such an orientation of nozzles and things like that. We have to go for the design of the individual trays, all the trays will possibly not have the identical layout or identical design. For the design of any tray, the inputs are going to be the vapour and the liquid traffic approaching the tray, and the flow and the properties.

Quite naturally the tower different sections will have different vapour liquid flow rates, and will also require certain modifications to draw off feed coming in may be the reflux return and things like that. So, those things also have to be discussed and decided independently, that means, the different sections require special focus. A final thing will be the fabrication drawing through which the designer will be communicated his design output for fabrication.

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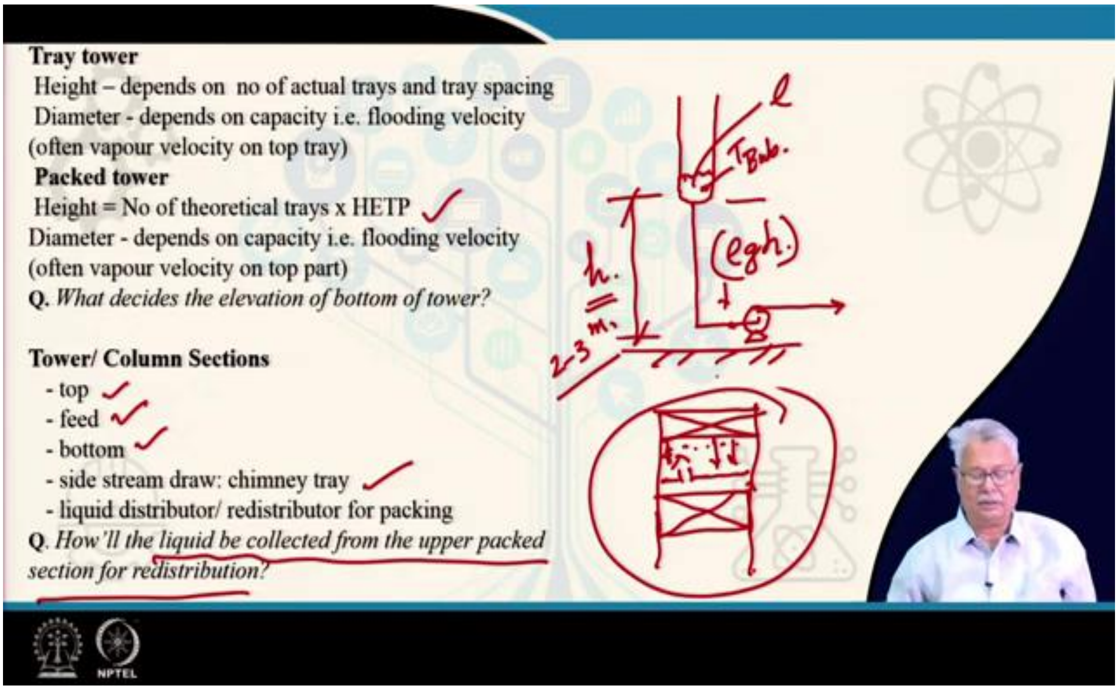

We took a few main features of the tray tower. The height which depends on the number of actual trays that are to be provided and the tray spacing which in most cases will not be uniform all through. There will be two sets at least. Some trays for example like the feed zone and the top one will have different tray spacing.

Similarly, the one major output is a diameter which in most of the cases will be uniform except in the case of very large towers like the crude distillation column where changing the diameter saves on material increases the manufacturing cost, but they even out or gives you an overall advantage.

The diameter depends on the flooding velocity, the capacity of your processing unit may be the distillation column capacity. In many cases, the vapour velocity on the top tray is controlling that is the top tray dimension normally is largest based on the top tray vapour velocity. In most of the designs, the same diameter is maintained particularly when the tower capacity is not too large not like maybe a few million tons per annum.

If you are talking about only the capacity in some meter cube per hour may be 50, 60, 100. It will have a uniform cross-section all through. In the case of a packed tower, the height is given by the number of theoretical trays multiplied by HETP plus some extra in the feed zone, some extra in the bottom, some extra in the top and wherever you have redistributors.

This we have not mentioned in this particular expression, but it is obvious. Here again, the diameter depends on the capacity that is the flooding velocity of the packing. Often in this case also it is the flooding velocity is limiting at the top section.

Now, I have got a question. You have decided on the tower diameter, you have decided on a tower height. What decides the elevation of the bottom of the tower? The towers are cylindrical circular vessels most of the cases they are tall towers. So, what you have here is a tall tower which is like this. This is your ground level where you will be having your pump. The liquid level in the tower the liquid is at the column bottom. What is the condition of the liquid? This is at its bubble point that means this temperature is the bubble temperature of the liquid.

So, naturally, if you send it to any pump, a boiling liquid going to the pump I will immediately vaporize, and vapour locks your pump. So, you cannot do it directly. What you have to do is, you have to either cool it down which is an expensive and a more difficult process that will also encounter pressure drop. The other option is to somehow increase its pressure.

Well, you cannot use a pump because you cannot use a pump right now. The only option that you have is to mount it at an elevation "h". This would add if the density of this material is ρ, it will add a pressure here of "ρgh". So, quite naturally this adds to this increases the pressure at the pump suction. It has to be a sufficient height so that the net positive suction head is maintained, and your liquid does not vaporize inside the pump.

So, you will always find the column bottom pump until and unless it is a very highly pressurized tower. In, almost all cases, you will find the column bottom elevation is at a substantial height typically anything between 6 to 12 feet, which means, 2 to 3 meters is quite common. I am talking of large industries in this case. In small industries, it could be smaller, it could be less.

Now, to design the tower, you have to split it into sections, the top, the feed, the bottom, and the side stream draw which will have a chimney tray. In the case of packed towers, you will require a liquid distribution or a redistribution for the packing. Now, I have got a question for you. How will the liquid be collected from the upper packed section for redistribution?

That means, if you have a tower whose upper section is packed and you have decided to redistribute before it enters a lower packed section, this will be done with a chimney tray. I have shown only one. But, how is this to be collected? Will it be showering directly or will it be collected in some form, and then redistributed here.

We will have a look at this, but that we will do later on. Whenever we are designing a tower, our design aim is to realize the number of stages. These all these we have talked about earlier.

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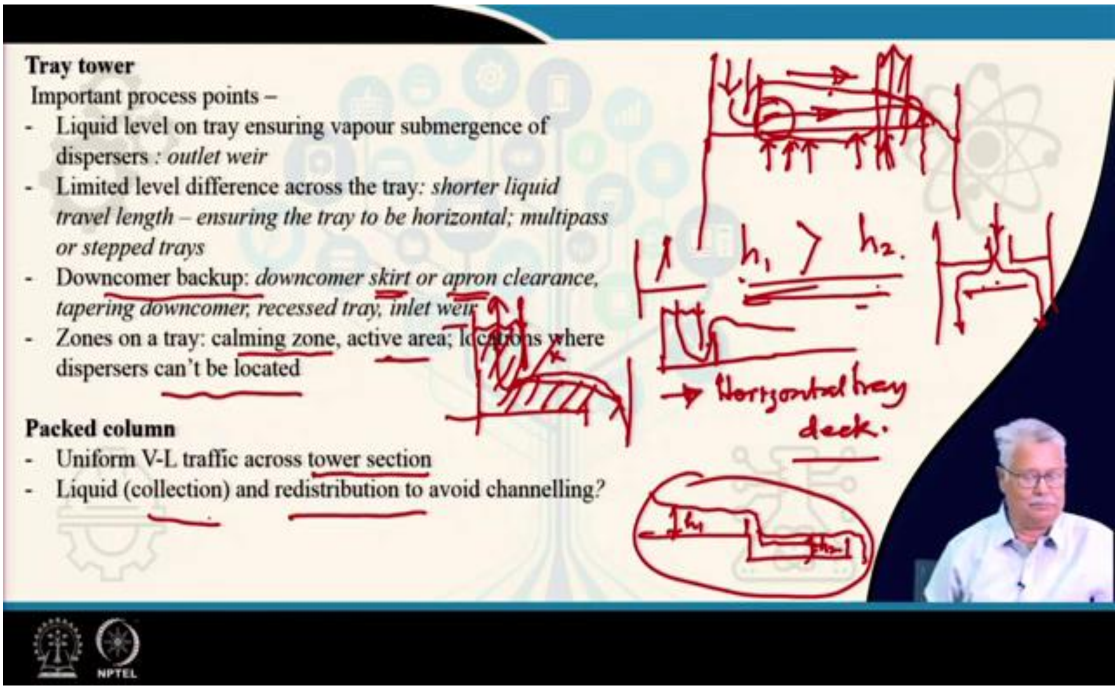

In the case of a tray tower, there are certain important process points. We have distinguished between the cross-flow trays and the only type of counter-flow tray that we have come across is the sieve tray without a downcomer. But, in the case of cross-flow trays, the liquid will be coming from the upper tray will be flowing out like this, flowing over a weir, and going this way, this is the downcomer of the tray.

You will notice one thing that the vapour is approaching the tray from the bottom. Now, if you have uneven depth here and here, see if the liquid has to flow from left to the right the level here has to be higher, and it should be something like this. Suppose, in this zone the if the height is h_1, and just below this just upstream of this the height is h_2, then the liquid flows by gravity h_1 has to be higher than h_2.

Suppose the difference between h_1 and h_2 is too large most of the gas will be passing through this section and hardly anything will go through the upstream. So, you will have an uneven distribution of the gas which is gas or vapour what you may call which is passing through the liquid. Now, in this case, your efficiency of contact will be falling down, and this is something which you cannot alloy allow.

So, one thing is there ideally your liquid should be as close to horizontal as possible. The first requirement for this is your horizontal tray deck. Whenever you construct, immediately after construction that you check is that whether your deck mounting is perfect or near-perfect horizontal or not that is the first thing to ensure that your liquid depth is as minimum as possible. If you have a deck that is sagging at the middle, naturally most of the gas will be trying to escape through the other places and will avoid this particular higher depth of liquid. So, this is one thing.

There is one more thing which is also there that in case we find that the gradient is substantial, in that case perhaps what we will think is like this. We will make a stepped tray. I will have the first weir here, the liquid would come here fall here, go here, fall over a second weir and go.

This depth is h_1 on an average say and this depth is h_2 which means the total gradient available for the travel is $h_1 + h_2$. But you have split it into two and in any case over the tray the depth is not high. So, you can have stepped weir, stepped trays also.

It is also possible to have other configurations of trays which we will not go into right now by splitting the flow. For example, on one particular tray, you have a central downcomer. That means, the liquid follows from falls from the upper one like this. It splits into this, it splits into two streams and goes like this.

In this case, what happens is basically the path that the liquid has to travel gets halved, the quantity also gets halved, quite naturally the difference between h_1 and h_2 would come down in such cases. So, split flow trays and step trays are a solution wherever you have a large difference between the h_1 and h_2.

There is something which is also very important, the liquid which falls from the upper tray has to have the liquid which falls from the upper tray. For example, this downcomer must always run full this downcomer must sorry this downcomer must always run full in the sense there has to be a liquid in this.

If there is no liquid, what would happen is the gas here would simply go up, it will short circuit. It will go above the upper tray without any contacting on this particular upper tray itself. So, you will be losing the number of effective trays in your tower. So, you must have definitely a minimum downcomer backup which I have mentioned here.

By the way this particular plate which is the downcomer plate is also called the downcomer skirt, it is also called the downcomer apron. It is the same term whether skirt or apron it refers to the same vertical or near-vertical plate. Now, to maintain this downcomer backup, you may have some sort of constriction here. For example, instead of a horizontal downcomer, you could have a tapered downcomer also, you can have stepped downcomers also.

The other option is if you have it like this, if you have a downcomer which a very low liquid rate, possibly you could obstruct here with an inlet weir so that the liquid has to flow this. This obstruction increases the downcomer backup. We have talked about tray construction in the last class. There we have mentioned the calming zone, the active area, and the locations where dispersers can be located, we will have a look at that once more.

The parameters in the case and the operating parameter in the case of a packed column is that we would always like to have a vapour liquid uniform traffic across the tower section. We would like to have avoided the channelling for the vapour as well as the liquid stream. To avoid channelling particularly for the liquid, vapour channelling is not very common, but channelling of liquid is. So we definitely have to think about the redistribution and collection of the liquid in the case of the packed column.

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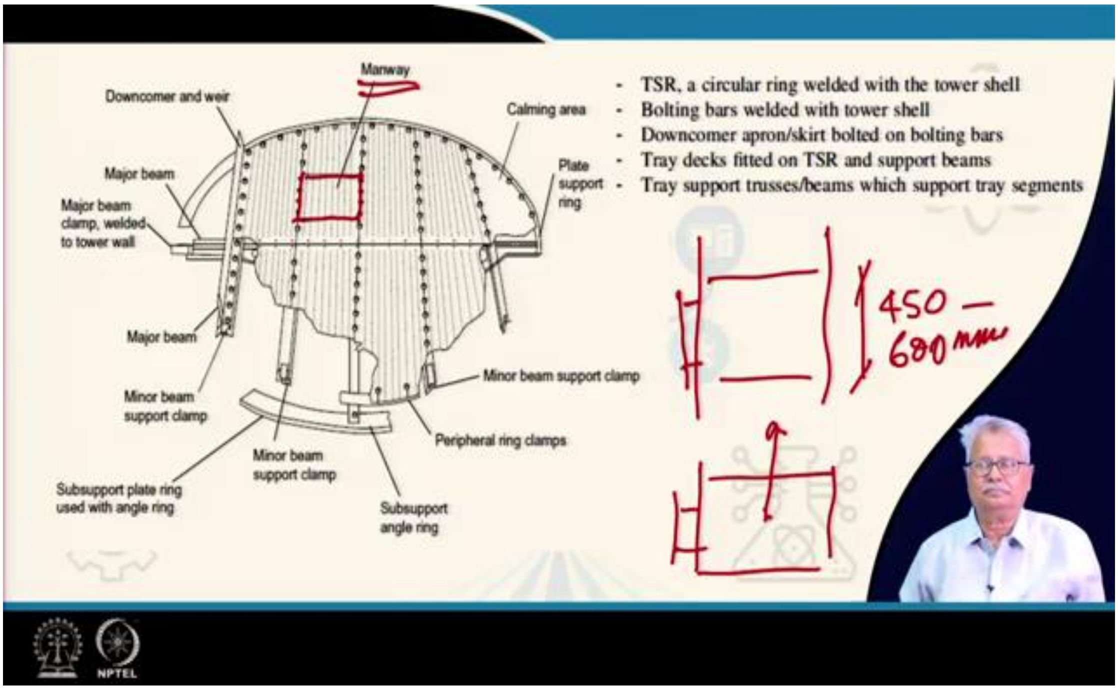

This is again the tray tower. Here, in my last class, I have forgotten to mention about one very important piece. We said that these are segmental decks. The decks are made in the segment, inserted through the manhole and assembled inside. You have typically in towers the tray spacing is anything between 450 to 600 mm. Quite naturally this has to be fixed. If this has to be fixed, then what happens is someone has to go in here.

So, you require a manhole. Naturally, through a manhole, someone goes in and fixes this. Similarly, after about six trays above or below that, you require one more manhole. So, whenever you are assembling your trays you have someone who has to go from one particular tray to above that and bolt that particular tray. For that these square sections are kept.

So, all the rest of the pieces are bolted together, and the person goes to the top, sits over there, and finally, fixes the manway. When he opens this for inspection, the manway is opened first, the person goes down, and then he inspects what is below that particular tray and what exactly is the condition there. So, this I had missed explaining in the last class which I add now.

Manholes are a very essential part, and typically you will understand the manhole size has to be such that it has to be also to pass through the manhole. Why, what I meant basically is a manway which typically is a square. The manhole size could be 20 inches, 24 inches or 22 inches. So, your manway size could be around 20 by 20 inches or something around that.

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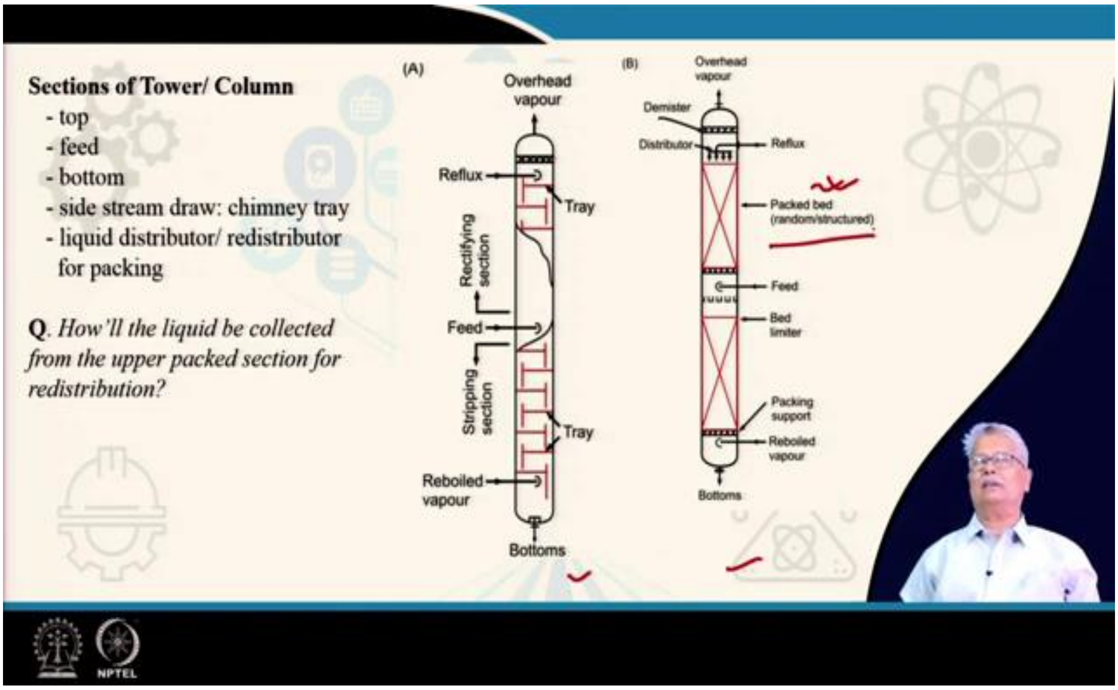

The sections of a tower are the top, feed. We still have the question. We have here the same old diagram which compares the different sections. We also have one additional thing that reminds us that packing for us could be a packed bed which is random or structured. Possibly, we will have structured packing these days because structured packings though more expensive than the random ones, they are they offer lower pressure drop, and higher specific area of contact.

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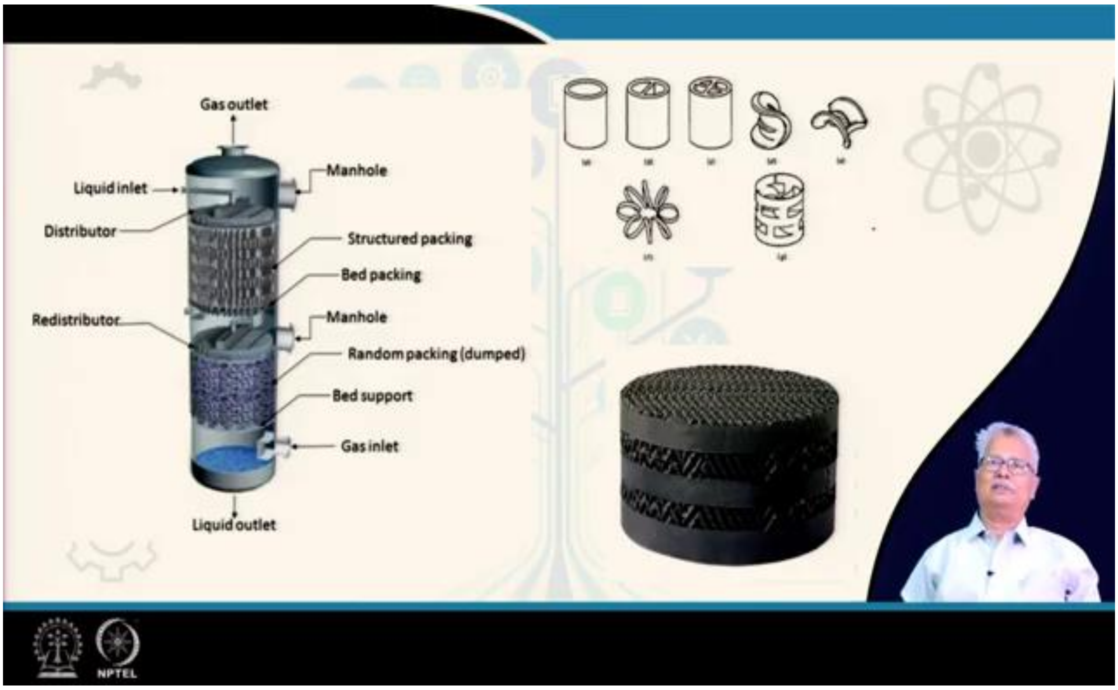

This is also something which we have seen in the last class. This is about structured packing which comes in blocks. These blocks are sewn together and put inside. The random packings are dumped. Various random packing shapes are given here with distinctive names. I am sure that you have come across the individual names while you have started your packed towers in your mass transfer course.

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Now, to deliver a design, we have to talk about the diameter, height, these nozzles, the support, and we have to communicate this first by a general arrangement drawing.

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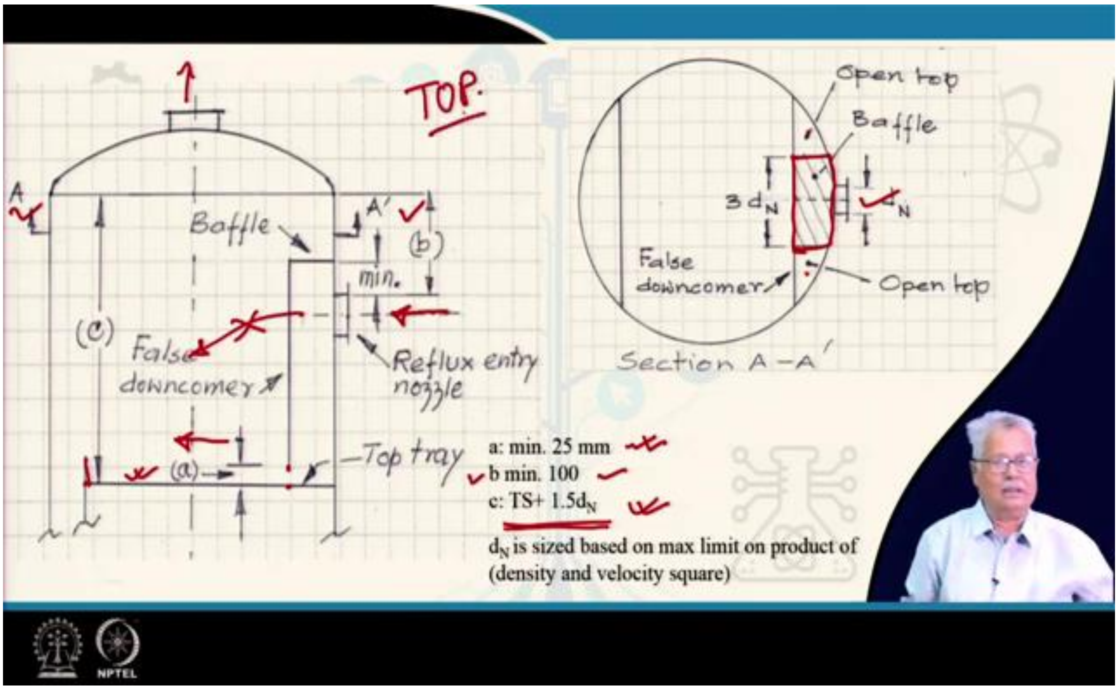

We look at the different sections with dimensions. This is the top section of the tower. This is my top tray. Here in this top section, you will have a vapour outlet. You will have a reflux entry here. The vapour is supposed to be fully vapoured. You may have or you may not have a demister at the top. The reflux entry is supposed to be for a liquid flow rate. So, if I have to provide the dimensions of this, let us understand all are the physical arrangements made here.

The first thing that you have here is a false downcomer, which means, on the entry the liquid will face a vertical plate which is the false downcomer. The dimension is very similar to and the design is very similar to what you have in the other downcomers, but here it is a false downcomer, that means, it basically prevents flashing and going further here. So, that is prevented by the presence of this false downcomer.

Now, there may be some amount of vapour which will be entering for which I have to keep some space. So, the top of this is not fully covered. If you look at the section at the AA' which is drawn here, this is the same nozzle.

The liquid enters only the top section here, only this much has got a roof. This is an open area. So, if you have any vapour coming in along with your liquid in the reflux, that vapour will be coming out and going up this way. The liquid falling here at the bottom on the tray will naturally have a crossed flow. So, you have an outlet weir and the liquid moves in this direction.

Let us look at the dimensions. You have a clearance between the false downcomer and the tray deck. The minimum gap is to be kept is 25 mm. Now, you will also remember the liquid depth on a tray typically will be anything between 50 to 60 mm. This is something that is a thumb rule, but it is true in most of the designs.

Now, you have one more important dimension, which means, how much below the top you are going to inject your reflux that is your dimension b, the minimum is 4 inches that is 100 mm. Next comes the distance c that means how much below the top you are going to place your deck.

If your normal tray spacing is TS mm and your diameter of your reflux entry nozzle is d_N, the practice is to have a slightly higher here higher dimension here and keep it at TS plus 1.5 d_N or more. Now, the question comes how do I know d_N, the nozzle diameter? It is based on the maximum limit on the product of density and velocity square which we will see later when we talk about the vessel sizing and the vessel fittings.

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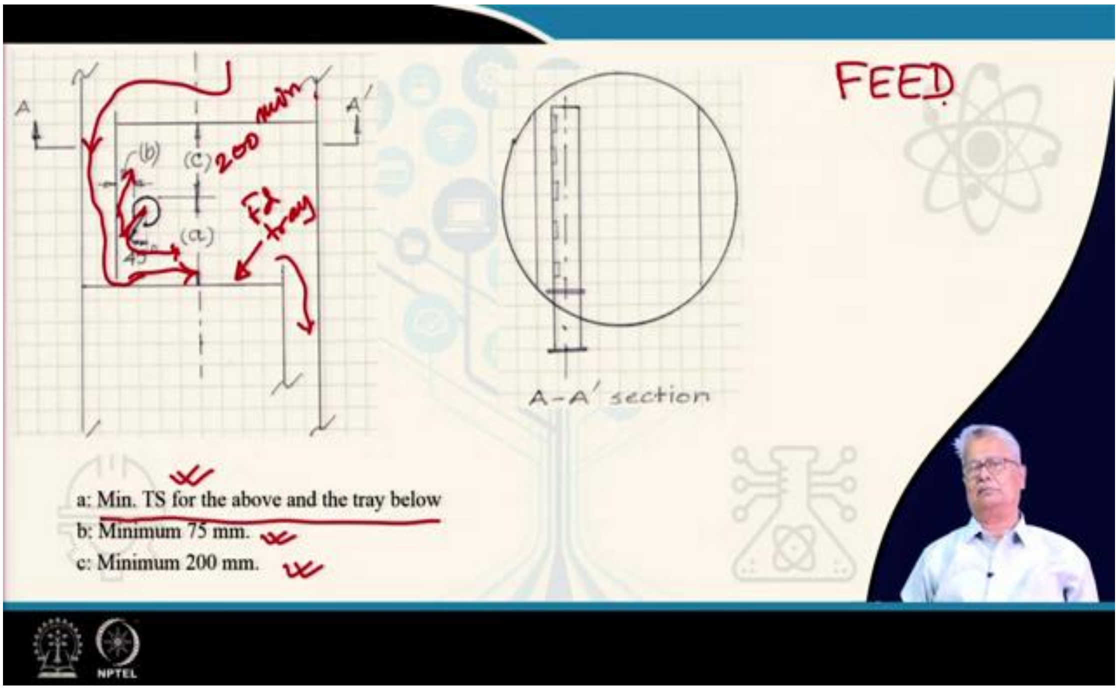

The next I mean the previous case was my top section. The next section that I have is my feed section which I have here. We have here. If I look from the top, this is a very simple arrangement that I have. Possibly what I will have here is a this is my tower, this is my feed zone, and this is my feed plate. I will have the entry through a nozzle that will be going through it, it is a distributor.

You will notice one thing that the liquid from the previous tray from the upper tray moves this way. It comes through the downcomer. Your entry nozzle of the feed will have its holes cut on it. It could be slots or it could be holes which will be at around 45°, and it will be directing the liquid which is coming as a feed from here towards the other side of the downcomer.

Why? It basically would avoid splashing and generation of fine liquid droplets which may get carried over with the gas. So, it the liquid here what it forms will definitely be joining this liquid. And in case there is some gas which is some vapour which is coming in will also be going up. So, this acts as a splash, that means, the other side of your downcomer plate or downcomer skirt or downcomer apron whatever you may call acts as a splash baffle that means it the splash hits it and the vapour and the liquid separate over there.

Well, do not confuse this with the splash baffle term which we are not going to cover here, but if you are interested we can discuss it later on.

Now, we come to the dimensions, how much above the bottom tray or the feed tray deck have we got to mount our feed entry nozzle? It is basically the minimum TS that means if the general tray to tray spacing is TS the spacing will be the minimum of TS it could be even more. Next comes how much away from the apron. It said that you have to keep it about 3 inches away, and it is a good practice to keep it 3 inches away which is about 75 mm. Then comes the upper tray should be how high above your feed nozzle. The good practice is to have a 200 mm gap, that means, this should be 200 minimum.

I believe that you have been given here an idea about the gross dimension that you find in the feed tray section. Well, there are other designs of the feed tray arrangement, but this is very common which you will be coming across in most of your designs.

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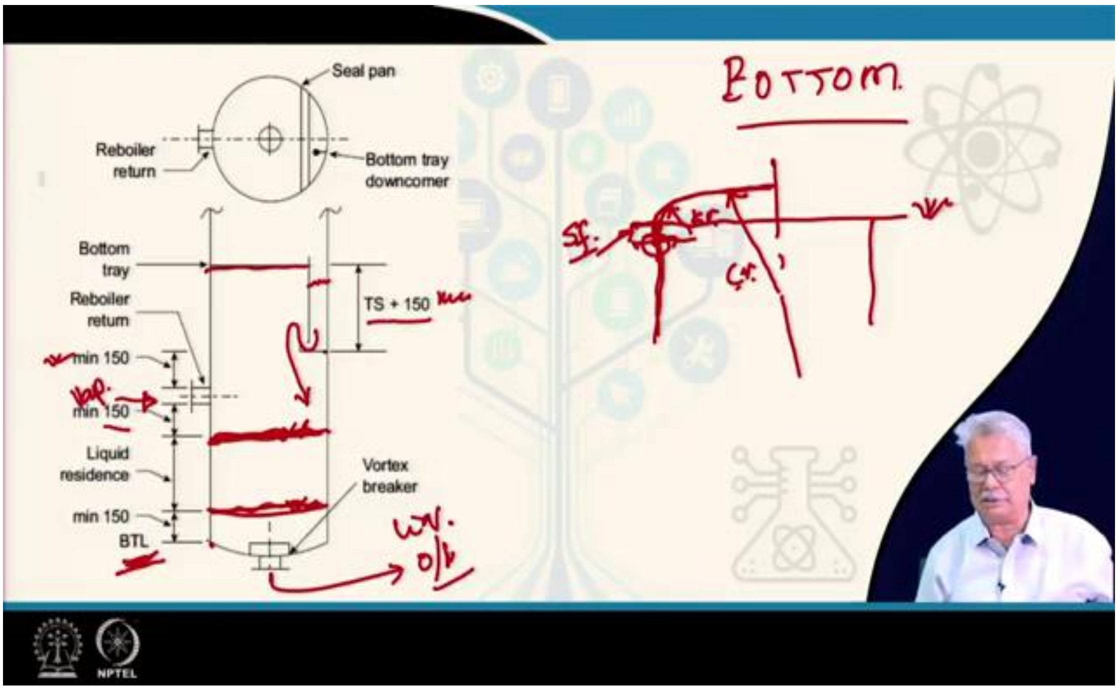

Here what we have is also another absolutely important part. Here is the bottom section of your column. We have been discussing only the vapour liquid column. Typically possibly we will be talking about the distillation column bottom here right now. So, what you find here is a nozzle through which the vapour enters. This is the vapour entry nozzle. You have a bottom outlet. This is not the drain mind it. You have a bottom outlet through which the liquid is taken out.

Now, you have the bottom tray here, you have the bottom tray here. You will also notice one thing, if I do not have any seal here, in that case the vapour would simply go this way. So, you require a seal here as well. So, you have a downcomer apron or downcomer skirt whatever you may see here, and then arrangement well I will just remove this part of using the eraser because it will make it more clear. So, what you have here you got to have a level of liquid, and the liquid has to overflow like this.

Now, the question is where will you keep your liquid? What will be its level? The liquid will there will be minimum and a maximum value of liquid, liquid level. So, your liquid level will be lying between the upper limit and the lower limit. Why do you require a minimum level? The minimum level is required because in most of the cases if you do not if you lose your level, what you will be having is the gas or the vapour inside will be coming out and it will be vapour logging your pump. So, your pump would cavitate.

Now, let us look at the dimensions here. The submargins we ensure for this particular downcomer skirt, this is mounted typically at a distance of tray spacing plus 150 mm below the bottom-most tray. The tray spacing is the common dimension that you have. Basically what we have is from this particular seal, this is basically the bottom seal, there has to be a gap between this and the vapour entry which is 150 mm. You must be noted this.

Below the vapour entry, you require another 6 inches which is 150 mm for the maximum liquid level that you can afford to have, because you do not want your vapour to bubble through the liquid. So, this is a maximum allowable liquid height, and there is a corresponding one. The corresponding one typically is about 150 mm above the bottom tangent line.

Now, I will just add one particular term here which is a tangent line. Whenever you have a head. Whenever you have a head, I am drawing only half of it which is attached to a shell which is attached to a shell, what you will find that there is a horizontal part of your head. Beyond that, you have a knuckle radius. And beyond that, you are going to have a crown radius.

Now, this portion is called the straight flange length and you are joining of the head and the shell is here. So, whenever you are talking about any length, the length reference point is this. It is not this point because this portion is a part of the same cylinder, and your curvature starts from here. So, the term bottom tangent length here refers to the end of the cylinder and it starts of the curvature. This possibly I will be illustrating more when we talk about the process vessels.

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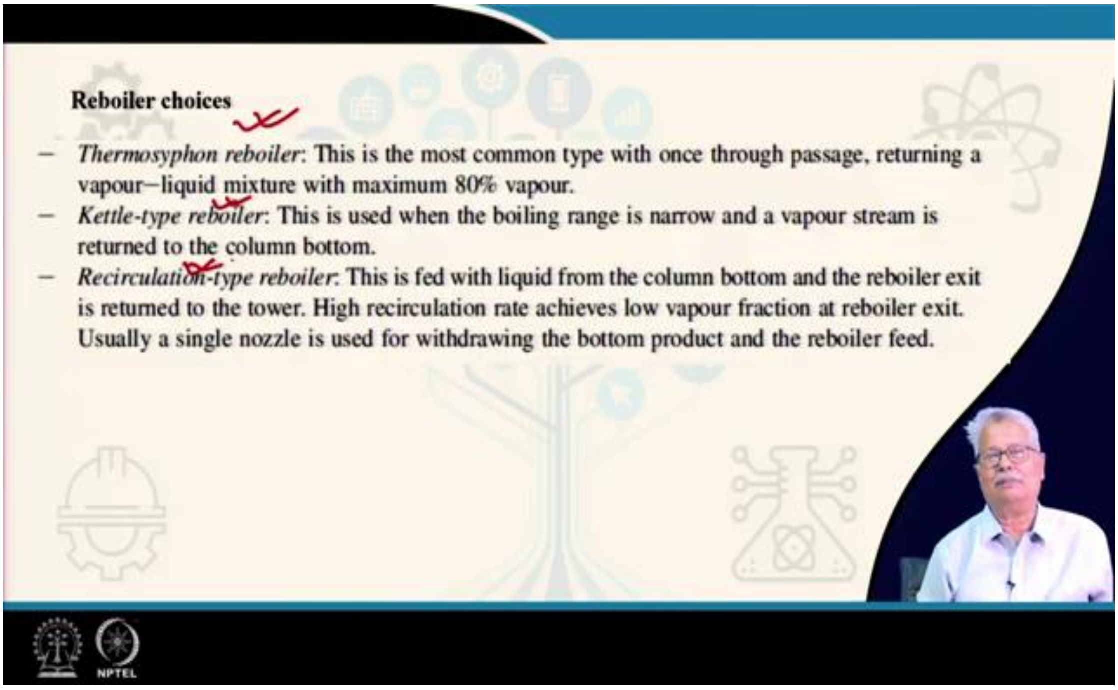

Now, you can have different reboiler choices. You have read about this in your mass transfer. You can have a Thermosyphon reboiler, you have Kettle reboiler, you have recirculation type of reboiler. The basic difference between is their construction. In Thermosyphon what happens, you have a vapour plus liquid recycled, the most of it is vapour.

In kettle type, you have only vapour getting recycled that means, as if we are boiling and generating the vapour in a kettle then feeding it back to the column. In the recirculation column, the recirculation type reboiler what you have is a forced recirculation through a heat exchanger, and the recirculated material comes inside the column and flashes.

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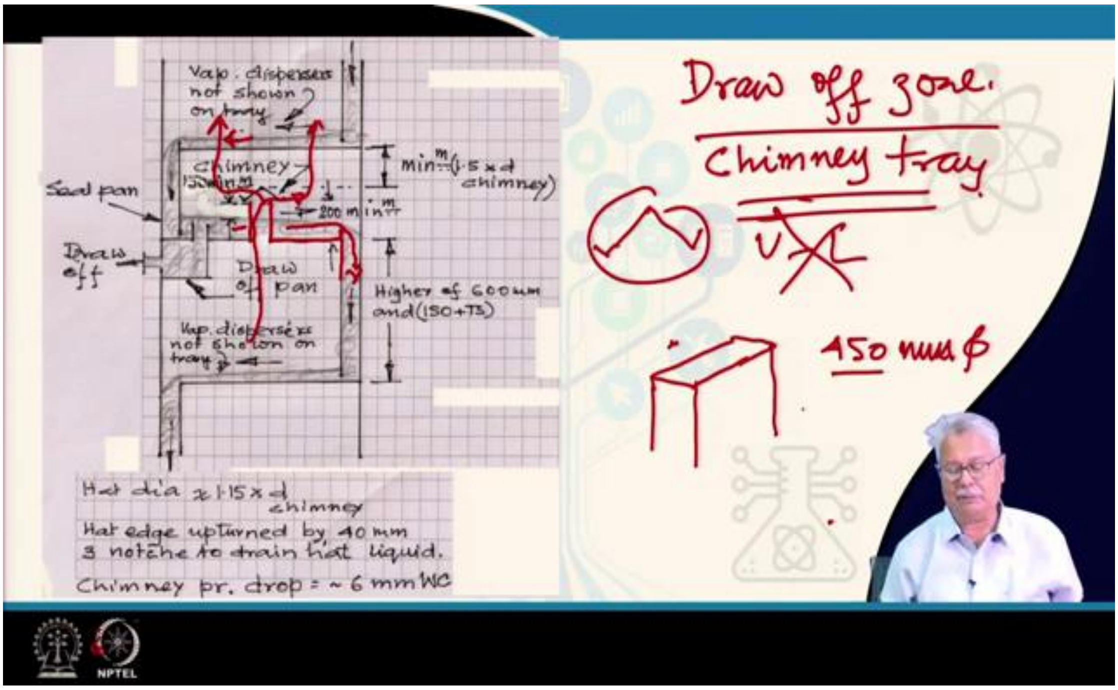

Now, here you have a draw off arrangement. So, I am talking about the draw off zone. This is something which is not very common for you, but it is important at the same time. You will be hearing another term here, very often you have learnt it also that is something which is called a chimney tray. These chimney trays are very different from all the other trays that we have talked about. They are to avoid vapour-liquid contacting.

We have a scheme of arrangement which is there in the case of the draw-off zone. What you have here is a tray the tray goes like this, this is the tray deck. And here is its downcomer. The upper tray fits this particular tray through its own downcomer. So, naturally, this is the direction of the liquid coming in, falling down and going out. Now, it flows across this and comes down. We do not want any vapour and liquid contacting.

So, what we, what is done you have long nozzles going up. Typically the minimum height is 200 mm, it is more than 6 inches. You will notice 6 and a half inches minimum with a hat. This simply the hat is provided with the hat is not a just a hat which goes like this it has got an upturned end also.

It doesn't have to just be a circular chimney. This chimney could also be something like this. It could have a rectangular cross-section also on which you could have a hat which will be possibly either this type or you can have the other type also which is drawn in the next diagram.

What happens in this particular case is, the vapour coming from the bottom goes out and goes up through the upper tray. The liquid here since it does not have any chance of contacting with the vapour. This is not a mass exchange or a heat exchange tray. Now, you have talked about the chimney tray being the draw-off tray.

So, what happens is I have to draw off from a pool. So, how is the pool created? If you look at this particular section, I will remove this particular drawing this part. What you will find here is the liquid falls, the liquid moves like this, and here is a draw off pan to which it falls part of it. Then it goes this way. When it goes, it comes here and goes to this.

So, the draw off is from here itself. That means, you will notice here there are two weirs. The first weir is here to ensure the backup in your downcomer. The next weir is here to ensure that you do not drop everything and you lose your downcomer seal. So, this part of is rather important for you to understand. I believe that you now have an idea that why these two weirs are provided.

Regarding the dimensions, all the dimensions are given in terms of the chimney. The typical chimney diameter could be around 450 mm ϕ. It could be 450 into 450 or 500 mm if it is a rectangular one.

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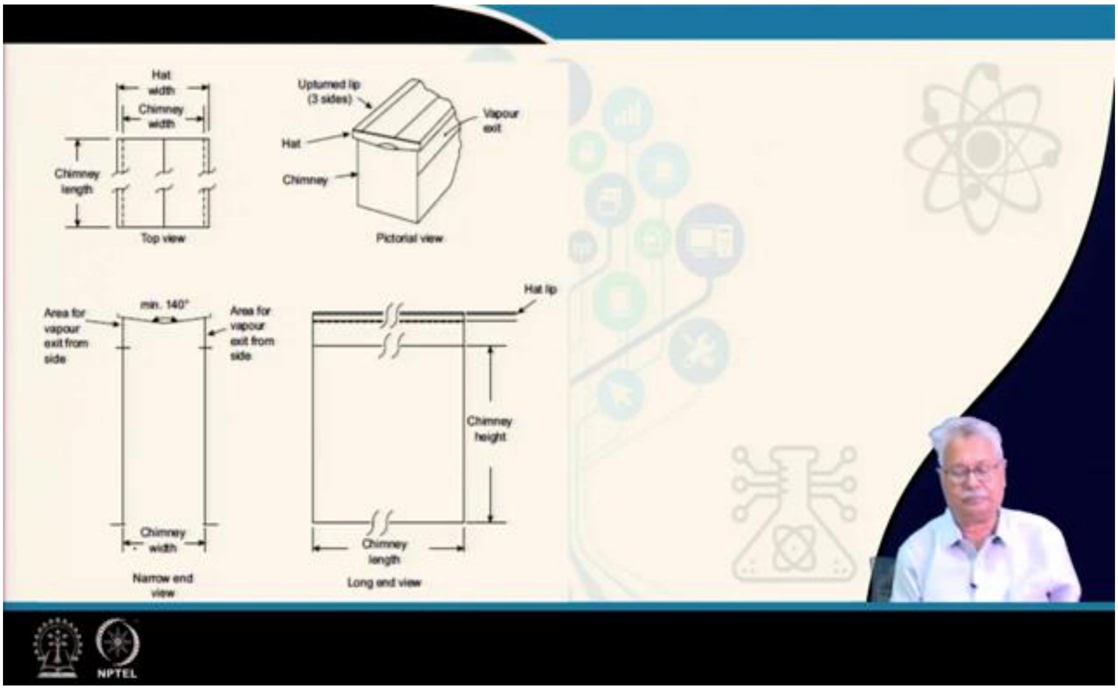

Here are the other designs. Quite naturally if you look at from look from the side what you will find is it is a rectangular chimney, and its detail is given here. The top in this particular case is not convex, it is not just a hat, it is an inverted hat. What happens is I have mentioned the upturned edge of the hat.

The upturned edge does one thing it collects all the liquid on the hat and allows it to drain from one side only. So, quite naturally what you have is it will be collecting all the liquid here, and from the thinner on the from the less weir end, it will be draining off.

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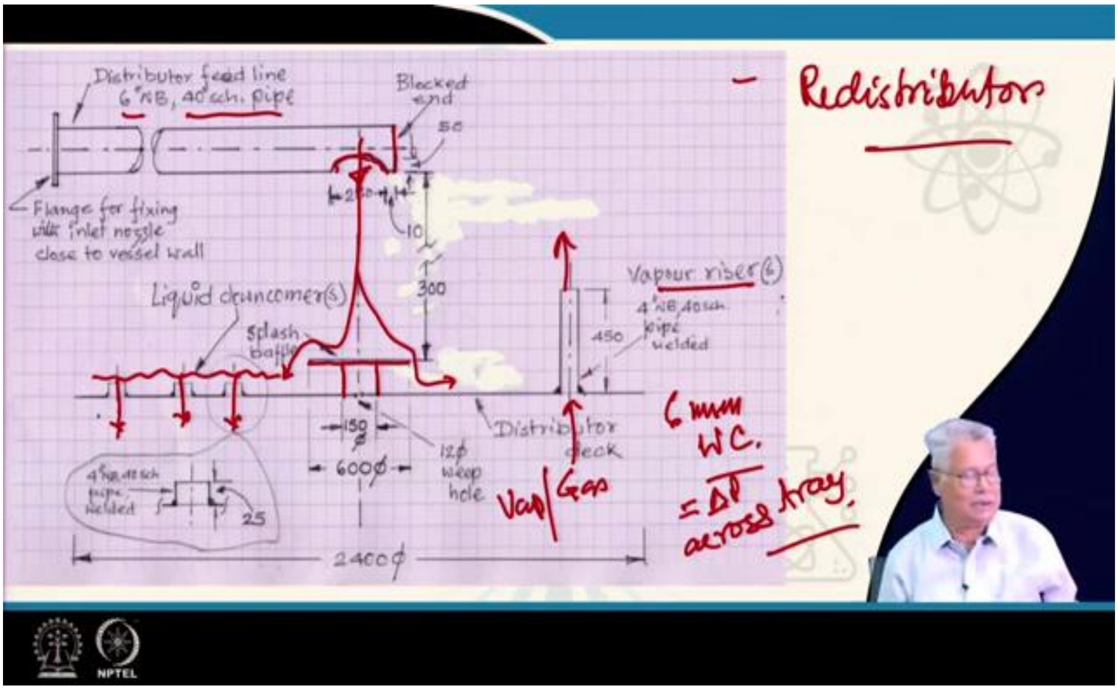

Here is the last part, which means, we are talking about liquid redistribution. Now I have answered one of your old questions that is if I have to redistribute, I have to collect the liquid. The collection of the liquid could be done using a chimney tray. The redistribution is what I am going to talk about right now.

Now, here what we have is a redistributor. So, if I am talking about a redistributor, definitely I am talking about the packed section. The redistributor or the distributor will be above the packed section. You have a feed line which is a typical 6-inch pipe 40 schedule pipe whatever it could be.

It will have a 250 mm cut here. So that the liquid falls through it. It has a blanked end. So, the liquid will be coming out only through this. It falls on the top tray. Suppose, this is the top tray distributor. It will fall on this which is the splash baffle mounted on the tray deck. A liquid would fall this way.

Now, so that the liquid falls, you have liquid downcomers. So, what you have here is a level of liquid. What you have here I have shown only the left side. So, what you will find is the liquid falling this way. The gas has to be given a pass a passage. So, what you have here is the gas or vapour whatever way you call will be coming up. So, this will be the exit or the vapour riser which will allow you to do this.

If you look at the dimensions which are provided on this, these are typically suggested dimension which is used in industry. If you have to design one, you can have your owns number, decisions and things accordingly. I will just add only one thing, the pressure drop in your gas line here is typically taken as 6 mm water column is equal to Δp across such a tray its distributed tray.

So, below this, it has to go. If it has to fall, then it goes falls on the packing definitely it does, and gas gets collected. The number of vapour riser and their dimensions can find it. These distributors are typically made from 4-inch nominal bore, 40 schedule pipes. These are welded to the deck as well. The dimensional values are all given here. If you have to design one, you may refer to those.

I believe with this I come to the end of the Tower Internals chapter. We will start with detailing the different tower configurations with possibly starting with bubble cap or the other tray vapour disperser types or the sieved the first one is going to be your sieve tray.

Thank you.