**Principles and Practices of Process Equipment and Plant Design**
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**Module - 02**
**Lecture - 20**
**Tower and Tower internals**

So far we have discussed a fair amount of the processes like distillation, stripping, absorption, rectification, and things like that. Most of these have a vapour liquid contacting and an arrangement has to be done. Since we are focusing on the equilibrium based approach, our approach here so far has been to find out how many ideal stages are required for a particular separation.

We are going to discuss today is how to implement these stages in reality. What we are talking about is tower and tower internals. When we are talking about the tower and tower internals, we must define one more thing also that we will be using the term tower and column interchangeably. Both are used and both are equally popular.

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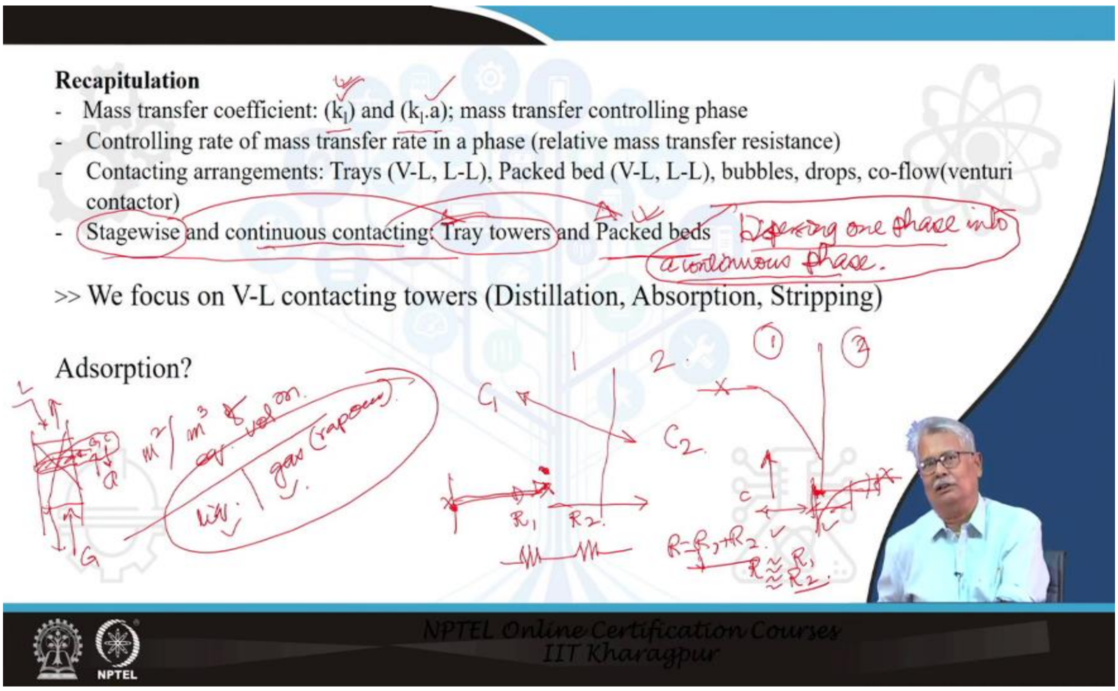

So, we start with a little bit of recapitulation. We talk about the mass transfer coefficient, the mass transfer coefficient denoted by $k_l$. It simply shows that it is based on the liquid phase.

We also have the term $k_l$*a. It is a multiplication of a specific area and “a” is basically is metre square, per metre cube of equipment volume or phase volume, whatever is the total volume of the system. The mass transfer coefficient depends basically on $k_l$ and we can improve by multiplying with “a”. That is what I wanted to emphasize at this particular point.

We also have an idea that controlling mass transfer rate and we are talking about the phase 1 to phase 2 mass transfer. So, the mass transfer takes place from the left to the right. If I have a concentration of a component in $C_1$ and if it is $C_2$ (in phase 2), the driving force is the concentration difference between these two.

That is not exactly the one. What you will find is there will be an interface here, there will be a concentration in the bulk which is fairly constant, then the boundary layer starts and it drips here.

Similarly, for the phase, this is my phase 1, this is my phase 2, you will also have a boundary layer here which is having the bulk concentration here. Phase 1 is having the bulk concentration here. The concentration difference drives the mass transfer.

Now, there is one thing very very clear that resistance to mass transfer lies in this boundary layer. Now, both the resistances may be in fact, here what you find is that both the resistances are in series, if this is R1 and this is R2. The net effect is R1+R2.

It is possible that one particular phase resistance is much smaller as compared to the other one. What will happen? It will be either this one tending to 0 concerning the other, or it is a very small number and we can neglect. So, in that case, R will be nearly equal to either R1 or R2.

So, what is clear to us right now? That, there will be possible in case of interface mass transfer. One of the side resistance which could be the liquid phase side of the gas phase side of the vapour phase side whatever we may call it will be controlling.

Now, we think of mass transfer and implementing the mass transfer is definitely by contacting the liquid and gas phases. Well, if it is a liquid-liquid system it will be liquid-liquid phase contacting also.

But after all the phases across which the mass transfer happens has to be contacted. We know one thing the more intimate contact, lower will be the resistance because with turbulence the boundary layer thins out. So, naturally, it offers less resistance and quite naturally what you have in that case is a better mass transfer which is $k_l$.

There is another thing you have to do even if it diffuses from one phase to the other. In order to go to the bulk, it has to move over a distance. It starts from here and it has to move here. This is a path in which there is resistance. It is not that it just goes and enters the interface and just at the interface of the second phase, but from there it has to diffuse to the bulk.

Suppose we have a length in which across which it has to diffuse and somehow we can reduce this, then we can we are going to help the mass transfer; that means, the mass transfer rate is going to be improving if by this action.

So, what we have here right now is a case in which we think of dispersing. We think of dispersing one phase into a continuous phase. So, any mass transfer equipment that we talk about interface mass transfer equipment will definitely involve a good amount of agitation and it will also try to enhance a mass transfer by dispersing one phase into a continuous phase.

Now, depending on which phase offers the higher resistance, you decide the phase to be dispersed. This is more true in the case of liquid-liquid. It is true in case of a little bit to some extent case of vapour-liquid also. But mainly, the type of contactor that you decide for your mass transfer depends on which phase the controlling resistance to mass transfer resides.

Now, we are talking about towers or columns. We have analyzed continuous systems. In continuous systems like distillation, there are different stages of contact. So, there are different stages of contact. But, you don't have to always have such stages. You can have continuous contact also.

For example, if you have a packed bed which I am showing here through which you have a gas going up and a liquid coming down from the top. There will be any particular section, you will find there is an up-flow of gas and a downflow of liquid here in this particular section.

There is a fair amount of interaction between the two phases. So, what I would like to say is at this particular point your continuous contacting will be offered by packed beds. So, your continuous contacting is going to be packed bed for you.

The tray towers are stage-wise contacting equipment. Well there are different types of contacting equipment and so far you have come across mainly the vapour-liquid contacting requirement of distillation, absorption, stripping. In case of adsorption, you have gas-solid contact.

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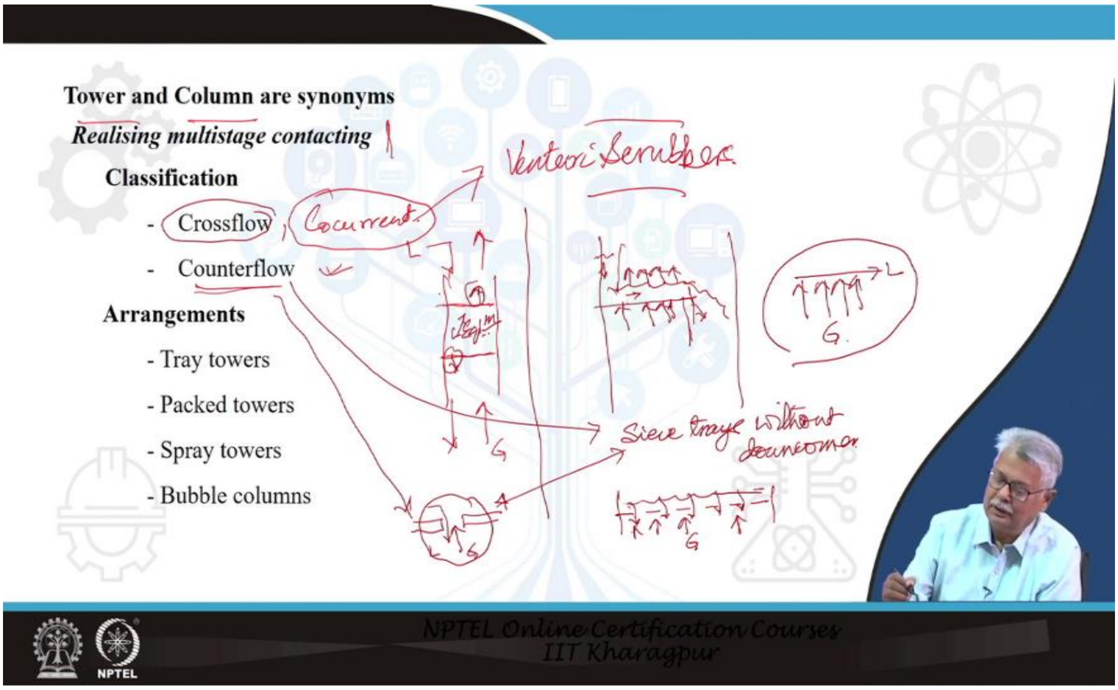


Now, I repeat once more that we are going to use the terms tower and column to be equivalent. What are they used for? They are used for realising multistage contacting. That indicates that in the same piece of equipment, you are expected to provide more than one ideal stage of contacting. Now, so far we already have seen in the case of heat transfer class or mass transfer class that counterflow gives you, in case of contacting of two species, a higher driving force.

Let us see what all arrangements you have. You also have here a co-current flow, but the co-current flow is not normally there in this type of tray contactor. You will find co-current flow in the case of venturi scrubbers only, which is also a vapour-liquid contacting equipment. Now, let us see. Ideally, my equipment should be a counter flow because it is expected to generate a higher concentration gradient. With that, you get a higher mass transfer in the same equipment.

We always have been drawing our contactant like this. You will have a gas flow, the gas goes out. You have a liquid flow and the liquid falls down here. It could be packed, it could be trays. What you have so far drawn are these are distinct trays. So, what I draw is I draw with a different pen perhaps. So, the ideal tray is one in where the gas leaving and the liquid leaving will be in equilibrium. So, we talk about how to implement these in real life.

We are talking about tray towers. If you look at tray towers often, in your mass transfer class you have drawn the tray tower to be like this. You have a tray and over the tray there is a liquid that falls from the upper tray and it moves like this. It moves in this direction, this direction and in this direction.

The vapour from the lower tray penetrates through this liquid column and it goes up. Now, if you look at this particular type of contacting what you find liquid flow (horizontally) and here is your gas flow (vertically). So, what type of contacting it is? It is a cross-flow. So, on a tray, there is a cross flow, except in one type of tray.

Those trays are sieve trays without a down-comer. So, that is the type of counter-flow tray. Now, how it looks? It looks very simple you have a perforated sheet functioning as a contacting device. You have a hole here. You have a small little bit of liquid that showers down through these holes and through the same hole you have a counter flowing gas or vapour liquid.

So, if you have a hole through which you have the gas going up as well as the liquid falling. So, this is a situation in which you have basically counterflow. This is your sieve tray. In such cases, since the liquid falls through the tray itself you do not require a down-comer that is it is too obvious.

Now, the question comes that if this is the case how do we manage in case we have to have a counter-flow arrangement, if we have to have a counter-flow arrangement how do we achieve it in a tray. This is done also in a very nice way.

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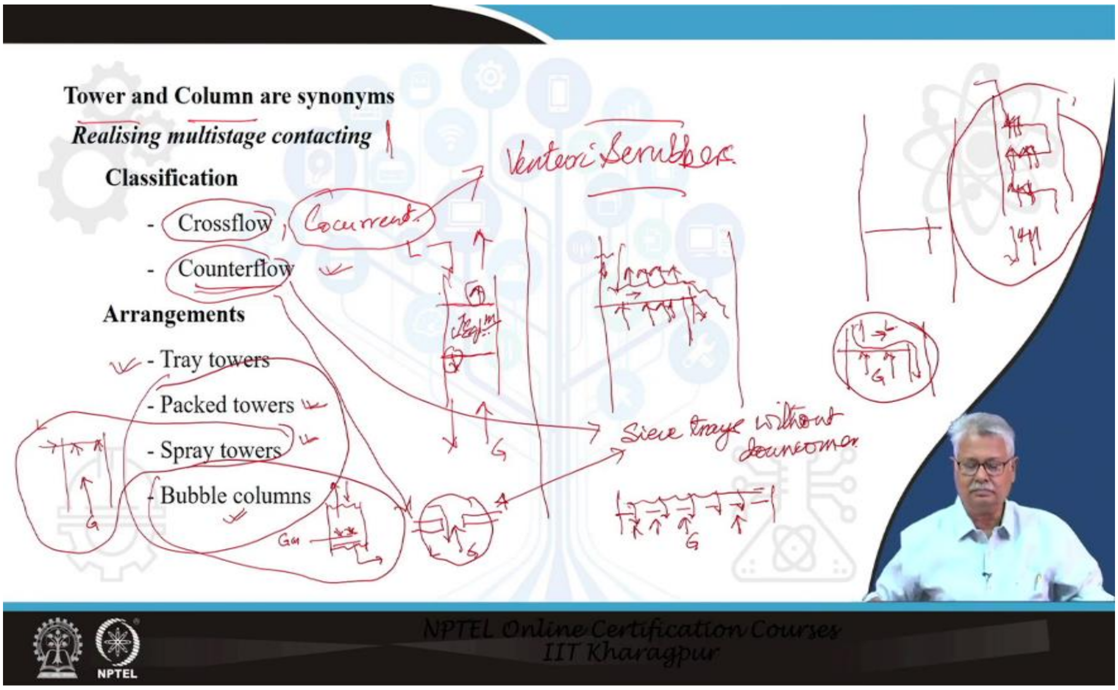


You have one tray here, you have a second tray here, you have a down-comer which comes down. The upper down-comer ends here. The liquid flows across this and falls to the lower tray and this is your gas stream, and this is your liquid stream. Now, you have such trays placed one above the other; that means, in the tray the path of the liquid which comes from the top is something like this and finally, it comes out.

The path of the gas is rather direct. It passes through each of these liquid streams, bubbles through the liquid streams and goes up. So, what you find here in the tray tower even you have, though you have cross-flow in individual trays the overall tray offers a counter-current arrangement.

Now, we look at what are the other tray arrangements possible. So, we have some idea about the tray towers now. We think about the packed tower which we also have said specifically that packed towers will be the typical counter flow arrangement.

If you look at the other ways of contacting, I can also have a spray tower. I could have my liquids being sprayed inside a tower, my liquid comes in it gets sprayed and I have my gas counter currently flowing in that particular tower and it becomes this spray tower.

In exactly, the same way, we could also have a bubble column. That means, I have a tower filled with liquid. I have a distributor for my vapour or gas and the bubbles go up and I bring in liquid and my liquid goes out. So, what you find here, that both packed towers, spray towers, and bubble columns, all are counter-flow towers. Whereas the tray individual trays are cross-flow, the overall tower is a counter flow.

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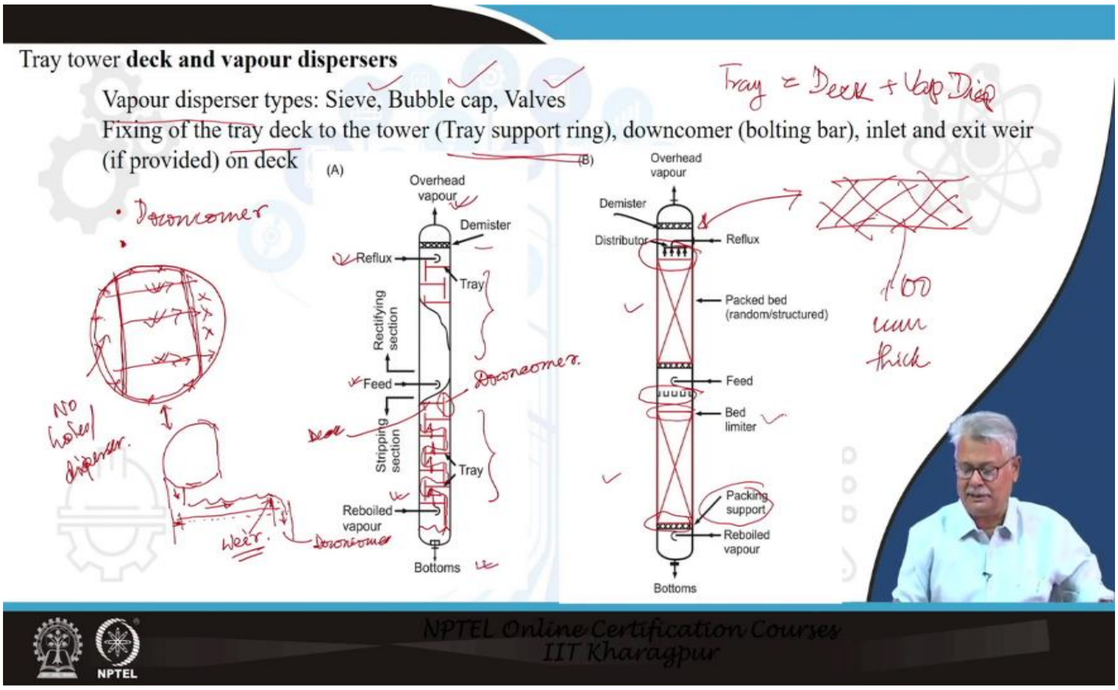


We look at the tray tower and packed tower general arrangement. We talked about dispersing one phase into the other. Conventionally in tray towers, the vapour is dispersed and depending on the type of arrangement we have for the dispersal. It will be a sieve tower which means you just have a hole. It could be a bubble cap where you have an inverted cup-like structure over a nozzle or a riser or it could be valves that have got a movable part also.

Now, each of these types of trays has its advantages and limitations. If you look at all the towers, what are the things common? The first thing is we can have a look at the trays are fixed. We are talking about the tray deck. That means, if you are talking about a tray, the tray is the deck on which the vapour disperser is arranged.

The tray normally will be fixed to the tower. It usually is bolted to a support ring. We will look at the details of each of these with separate drawings later on. But right now what I would like to say is, if I take a section of my tower and look from the top what you will normally have is a tray like this. That means, there will be a segment that will be missing here. You do not have this part, it is a disk. So, on this disk, you have the fitment of your vapour disperser.

There is another section here which is which has got no holes or no dispersers. So, you have disperses only in this particular section. The liquid from the upper tray falls here through the down-comer, and it travels from the left to the right. Since this portion is missing it falls off. So, your tray deck if you are talking about in case of a cross-flow tray like this. This is your tray deck shape.

Now, I would like to fix this onto my tower. If I look at the tower section itself. If I weld a ring here, and on that, I place my tray that, the ring is all through and I bolt it here.

That means, I will have bolting here at this point. I will have bolting here at this point, this point, this point, this point, this point, this point, this point and it does not exist. So, there is no question of any bolting here. So, these are the bolts. This tray ring will be usually welded to the shell, and on the tray support ring which is the tray support ring here, your tray deck will be bolted.

Now, you understand one more thing here also. We look at the other arrangements which are there on tray towers apart from the vapour dispersers. It does have to have a down-comer, it must have a down-comer. You are having expected to have a level of liquid because your liquid flows across this. So, definitely you would like to have a particular level of liquid on your tray.

In order to ensure that you have a level of liquid on your tray, what you provide here is a weir. It is nothing but like a dam. Over the dam the liquid flows down, the liquid flows down this way. To where does it go? It goes to the down-comer, this part is a down-comer of the tray. Where does it come from? It comes from the upper tray. It comes from the down-comer of the upper tray. It cross-flows like this, flows over the weir and comes here.

Now we try to see that whenever we have been drawing in mass transfer class and drawing schematics of vapour liquid contacting or distillation trays, we have very often referred to this arrangement. These are the trays, this is a tray deck, and this portion is the down-comer. It is obvious that in this case also what you find the liquid falling from this tray will be taking a path like this and finally, coming to the bottom.

What will happen to the vapour which goes up? The vapour will flow through this, it will flow through this, it will flow through this, it will flow through this and go up. So, this is what I wanted to show you earlier. You will notice here that your tray will have quite a few connections. One is for your feed definitely, the other is for the reflux which is to be given on the top tray, tray number 1.

There will be a nozzle that will be taking out the overhead vapour. The bottom product has to be taken out, possibly there will be one more outlet that will be taking the bottom liquid to the reboiler and there has to be a nozzle that would be feeding in the reboiled vapour here. Below the feed section, you already know that it is a stripping section, above it, it is a rectification section.

Now we will with this we look at the similarity between the packed tower and the tray tower. The only difference is that you have a packed bed instead of so many trays in the rectification section you have a packed bed. Similarly, the trays in the stripping section instead of having trays here you have another packed bed.

Now, there is a feeding section also. Your feed will in most cases be either liquid or a mixture of vapour and liquid. So, what you expect is after the liquid enters, it has to be distributed, this is something that is very typical. It should be distributed fairly evenly on the bed itself.

So, you have to have a liquid distributor which is important because the quality of distribution will define how much efficiency of contacting you are going to have here. If you have poor distribution, your contacting will be poor and your efficiency will be less.

Exactly, the same problem you will also face in case of reflux, which is introduced. Any liquid which is introduced into a packed tray has to have a distribution arrangement. It could be a pressure distributor as shown here. It could be a gravity distributor which is schematically shown here as well.

On the top, we expect only the vapour to go out. But where does it go out from? It goes out from the top tray. So, what happens is the liquid droplets will also get carried over, and above the top tray, even above the reflux before the vapour goes out what you have is a demister. The demister is nothing, but a weir mesh. It is nothing, but a wire mesh, typically around 100mm thick wire. So, that is your reflection, your demister. Fine liquid droplets hit demister and they get stuck and later on when the layer goes grows it falls off. In the case of a bed, you have to have two more things. You have to support your packing. So, there has to be packing support which is usually a grid. There is a bed limiter also. You have the vapour coming up, under no circumstance you want your top bed packing should be thrown off the bed. So, usually, you will also have a grid here or other than the grid you can often have some bigger size packing here on the top also, so that they do not get lifted and this acts as a bed limiter.

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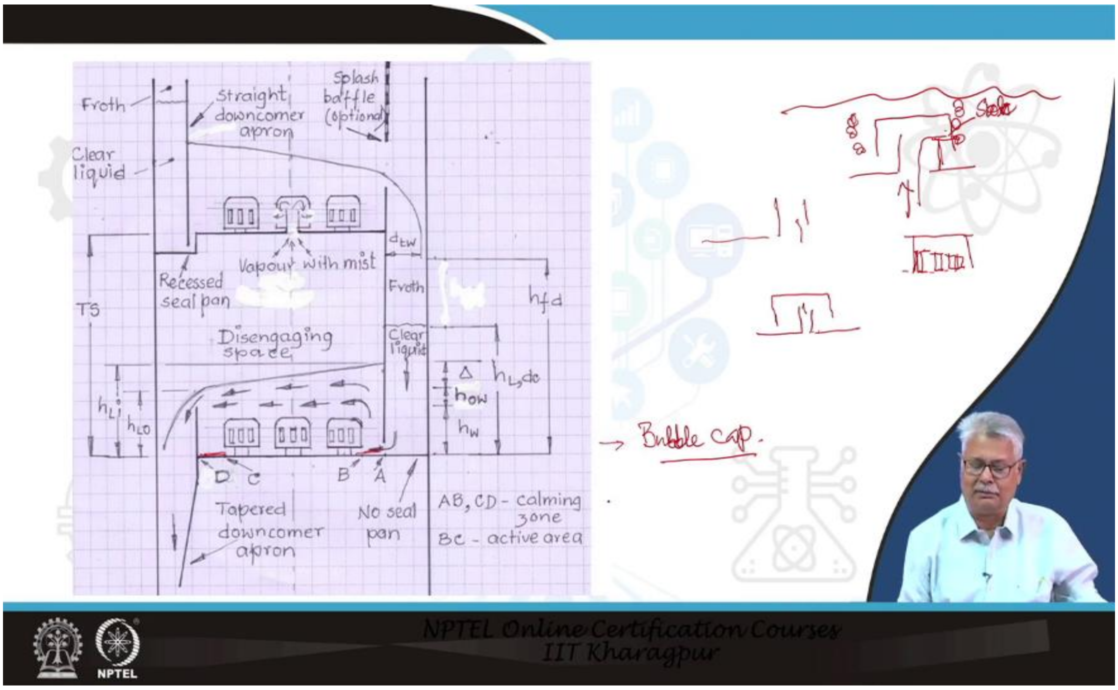

This is again basically the arrangement with a typical type of vapour disperser which we will be contacting and we will be learning the design of this. This disperser is the bubble cap disperser. What it is? It is nothing, but a riser that is fitted to the tray covered with an inverted cup.

So, the vapour coming in here, the cup that you see here looks like this, it will have slots. It will have usually square or trapezoidal slots here through which the vapour bubbles will be coming out. So, the vapour which is or the gas which goes here, it comes out through these slots, you have the slots here. And the entire thing is dipped in liquid. This is dipped in liquid. So, the bubbles form and they go up.

The passage of the liquid has been shown here. The liquid from the upper tray falls to this particular tray. It comes out through this, to the bottom of your down-comer, flows over the bubble caps, the bubble caps remain immersed, goes to the down-comer, and goes to the next tray.

It is obvious that on such a tray, you do not provide the disperser everywhere. When it comes out of the down-comer and when it is going to face the outlet weir. what you do normally is you leave some space here which are known as calming zones. All these will be detailed when you go for the design of the bubble cap trays.

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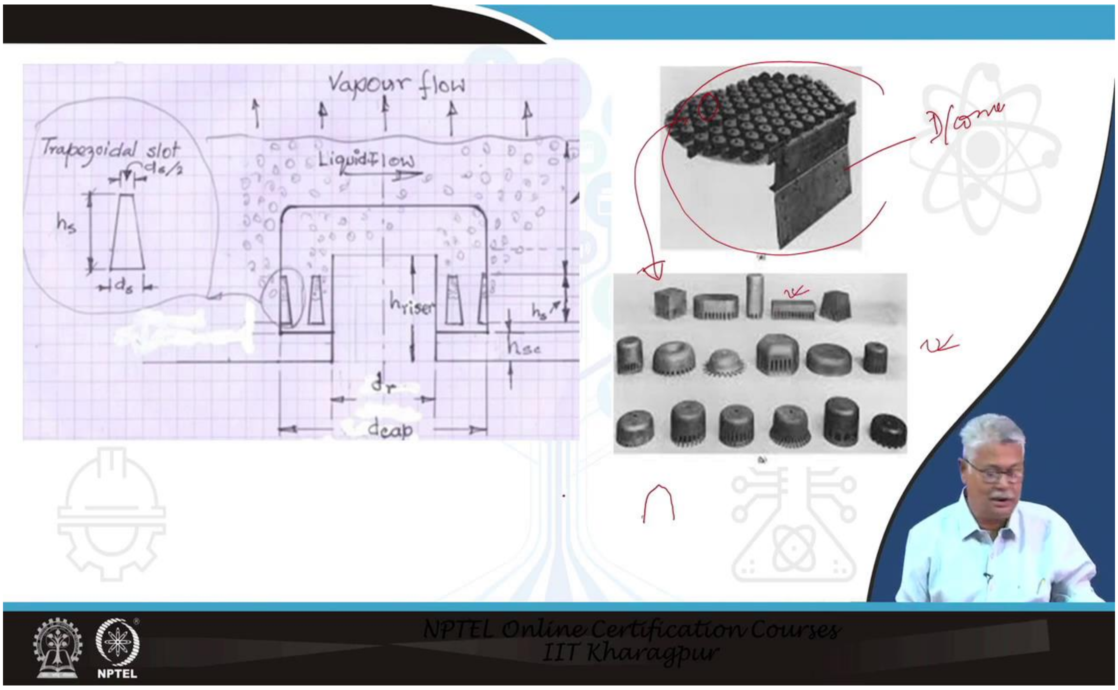

Here what you have is the diagram of a bubble cap tray. The different types of bubble cap trays that are used in industry are given here. You can understand this is the complete tray. This part of it is the down-comer. These are the vapour dispersers in the form of a bubble cap. Though we have said a bubble cap should look like just a cap there are different shapes. It doesn't have to have a circular shape. It could be a rectangular one also or something similar to that.

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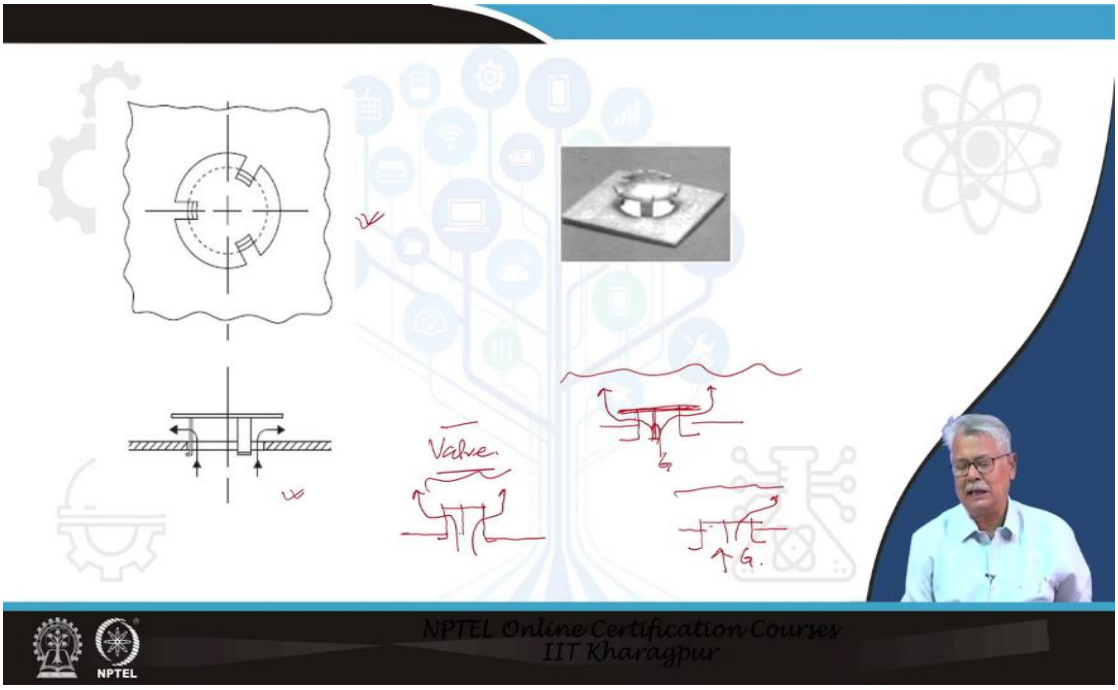


So, beyond this what we see is the other type of disperser. The other type of disperser is the valve type. The valve type means basically what you have in this case is a flat disk. The flat disk if it sits on this hole, it will close the hole. So, and you have the gas which is pushing it up and it emerges in liquid. A gas goes like this, forms bubbles and it comes out.

Now, if I just leave my disk here, this will get shifted at any moment. So, what is done is it is given 3 legs which are bent outside. So, what happens is initially your disk is here, with the legs like this; after, and I have started my gas and when it increases when the flow increases it gets lifted.

So, what happens here in that case? It gets limited by the length of the leg. So, what we have here is just a plan, how it looks like, and here is an elevation or a side view whatever we may call, which shows that the legs are there to hold it inside the hole, so that it does not jump out. This is basically the two type of contactors or disperses that we are going to learn how to design.

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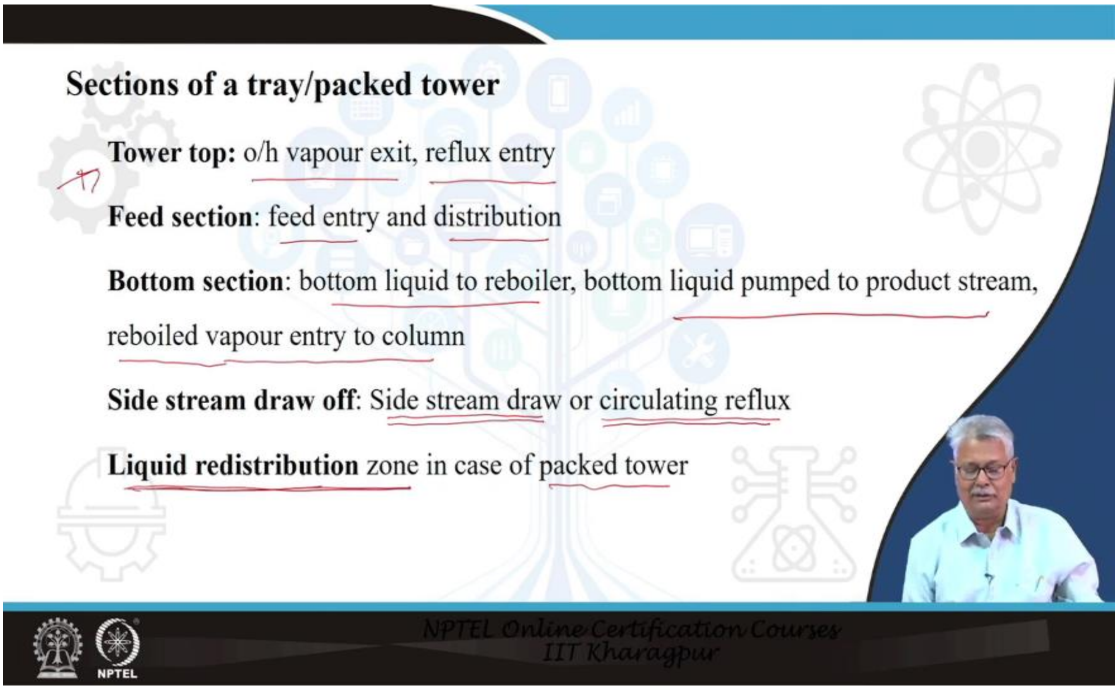


When we talk about the different sections of a tray or packed tower, we have to have the details of different sections. We focus on different sections. We have divided the sections which are common for all types of dispersers and in the case of the packed tower also.

You have to focus on the top tower which will contain the overhead exit and the reflux entry arrangement. You will have the feed section where which will have the feed entry nozzle and the distribution of the liquid.

In the bottom section, the bottom liquid will be sent to the reboiler. It will also go to the pump to be sent out as a product stream. In the bottom section, there has to be a vapour entry to the column which is coming for the reboiler itself. Some columns offer a side stream draw facility also.

So, side stream draws have to be covered and that is a section, and it is a special type of tray, and it is a special type of arrangement which we will learn immediately after this. Such things are required not only, in case of side stream draws in case you have circulating refluxes. Circulating refluxes, no, in most of the common columns you do not require, but circulating refluxes are there in the large columns like in the crude distillation unit.

In the case of packing, we already have said that liquid distribution is absolutely important. So, if you have a packed tower that is fairly tall, to avoid any sort of channelling you have to distribute the liquid. So, wherever you have a liquid distribution zone, how it is done, what exactly is a physical arrangement, we will have a look.

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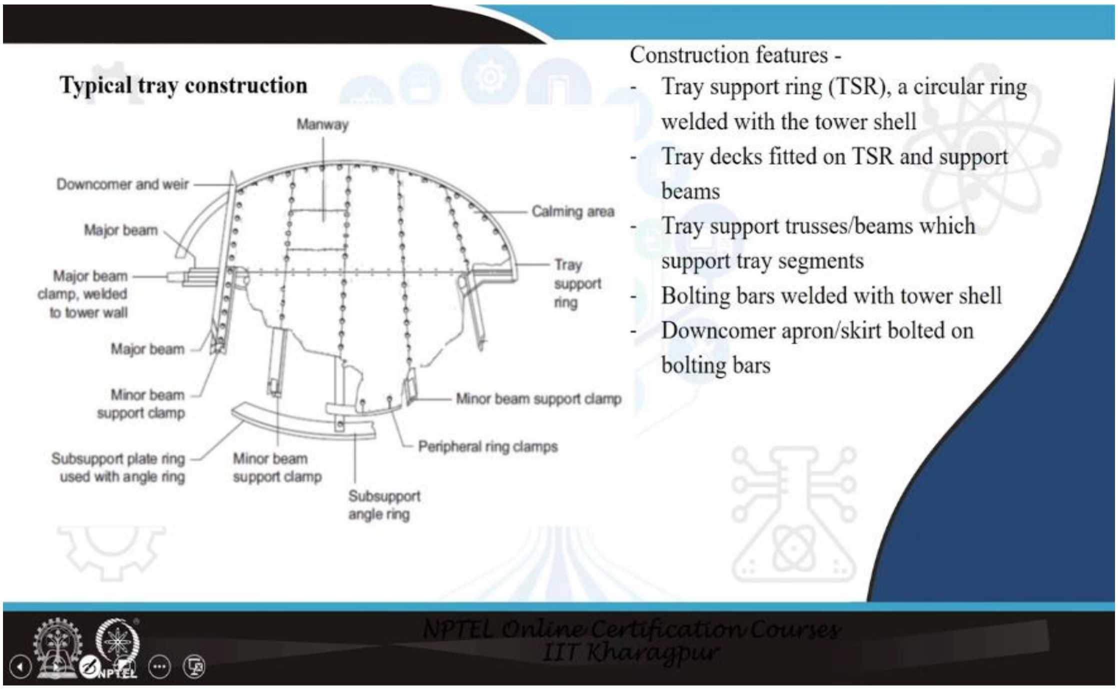


I think with this, I will stop here today. And we will start in the next class, with a typical tray construction.

Thank you.