Process Equipment Design
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Lecture –52
Distillation Column – 5

Hello everyone. This is lecture 52 of the course Process Equipment Design and I welcome you all in this lecture. And as far as this lecture is concerned we are going to discuss the distillation column and for that process design is considered. So, from last week we have started this topic and if you remember the last lecture there we have discussed plate efficiency.

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And as far as this process design is concerned we have already covered number of milestones as distillation and continuous process. Here we have revised the distillation process and discuss the continuous process and then we have designed the distillation column considering binary system. Designing means here we have consider the number of trays calculations and that is done through McCabe Thiele method.

And that is basic method for design of binary system and then we have discussed multi component system where number of trays we can identify based on different methods and after that we have covered the plate efficiency which is basically the last lecture where column efficiency as well as plate efficiency are discussed and there we have discussed detail method of it that is AIChE method.

So, in this way you can consider the plate efficiency considering geometry as well as mass transfer characteristics within the plate. And after that we have the topic plate hydraulic design. So, from now onward we will focus on this topic that is plate hydraulic design it means how to design a plate, what are the parameters and what other factors we should consider while completing design of a particular plate, but before that we will focus on plate contactors.

It means how many types of plates are available and at what condition which plate should be selected. So, let us focus on plate contactors.

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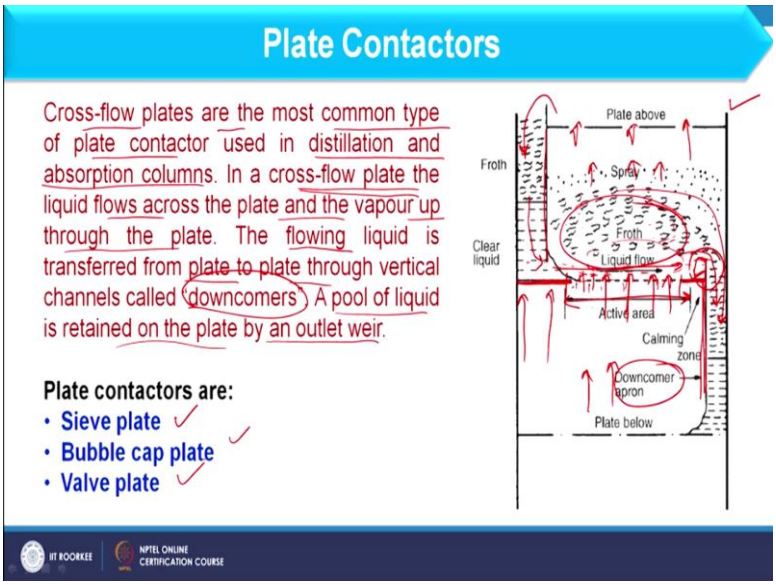

So, as far as plate contactors is concerned we can discus that with the help of this schematic. If you see here I am having the plate and in this plate this section is basically called as weir and this section or we consider this particular section it is called as downcomer. So, liquid is basically coming from upper plate from downcomer to the lower plate. And if you consider this particular section as well as this particular section there sheet is uniform and in between this we can find the holes in the plates.

As far as this plate contactor is concerned we can have only this much area as active area. Active area means where liquid and vapour contacts occur. So, you see when the liquid is coming down it is moving in this direction over the plate and when it will cross this weir it will start falling down. And as far as vapour movement is concerned it is coming from bottom.

And through these holes it comes into contact with the liquid which is available over the plate and when the liquid and vapour contact occurs we have froth formation also. So, some foam or froth will be there over the plate. So, here basically we have the mass transfer activity and after that disengagement of vapour and liquid occurs. Liquid comes down and vapour moves up to plate just above to this.

So, in this way liquid and vapour contact over the plate and if I consider this particular section and this particular section which is basically the part of the plate, but it is not having the hole. So, vapour is not able to move from this section as well as from this section. However, when vapour is coming from the bottom it covers the whole plate, but passage to move upward is available within the active zone only.

So, this zone basically we call as calming zone and this is the downcomer and this section we particularly call as downcomer apron. So, in this way liquid and vapour contact occurs over the plate and so the mass transfer activity. And as far as this flow is concerned over the plate you can consider that liquid is moving in this direction, however, vapour is moving from bottom. So, this is nothing but the cross flow over the plate.

So, as far as cross flow plates are concerned these are most common type of plate contactors used in distillation and absorption columns. In a cross flow plate, the liquid flows across the plate and vapour up through the plate as we have discussed that this type of movement occurs over the plate. The liquid which is available over the plate it flows down and moves from one plate to another plate through a vertical channel and that vertical channel we call as downcomer.

So, a pool of liquid is retained on the plate by an outlet weir. So, this is basically outlet weir. So, how much height of the weir we consider based on that we consider what should be the hold up of the liquid over the plate. So, how much volume of the liquid can be accumulated over the plate that can be decided by the height of weir. So, as far as practical plate contactors occur it means what type of plate contactors are actually used in distillation column and absorption column these are basically of three type.

First is the sieve plate then we have bubble cap plate and then we consider valve plate. So, in this way we can have sieve tray, bubble cap tray and valve tray. Actually we consider this plate as well as tray which are basically synonym to each other. So, any word we can use while discussing. So, as far as these plates are concerned we will consider each type of plate one by one and discuss its merit as well as demerits.

And then we will focus on the selection of proper plate depending upon the process condition.

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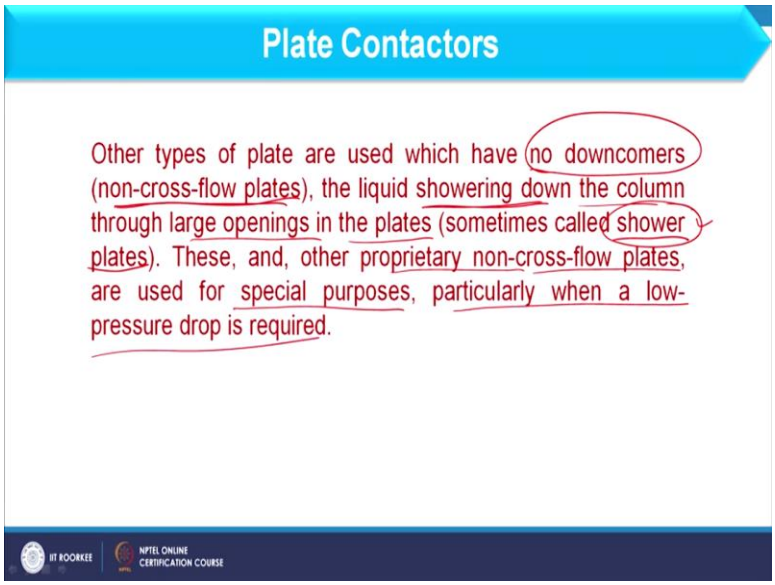

So, let us start with the sieve plate. However, when we focus on the plate apart from sieve plate, bubble cap tray as well as valve tray we have another type of trays also such as showers plates. So, these are basically plates which does not have any downcomer. So, non cross flow occurs over the plates. Liquid is basically showering down the column through large opening in the plate and therefore it is called as shower plates or we consider that as a shower plate also.

These and other proprietary non cross flow plates are used for special purposes particularly when a low pressure drop is required. So, you can consider that pressure drop on the plate is basically occurring when I am having hurdles while passing the fluid. So, when I am not considering downcomer so that section is particularly eliminated. So, we consider that no friction is occurring there. So, pressure drop will be reduced.

So, in that way we consider the showers plate and now onward we will consider the usual plates that is sieve plate, bubble cap plate as well as valve plate and let us have the discussion on sieve plate.

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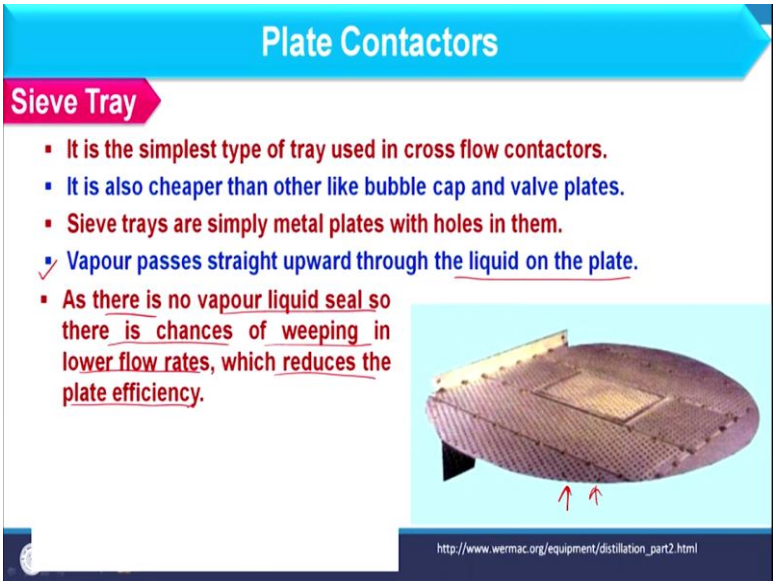

So, as far as sieve plate is concerned this is basically the simplest type of tray which we consider in cross flow contactors. And when you see the image of this it will be like this. So, it is basically the plate where simple holes are there and if you consider this section here solid plate is there no pores are available. So, this is the area where liquid is falling from upper plate and this is below the downcomer section.

So, liquid is basically falling over here it will be stable and then it will start moving in this way. And from bottom we can consider vapour flow. So, cross flow occurs over here and because its geometry is very simple. We have holes over the metal plate and therefore it is called as simplest type of plate and this type of plate we call as sieve plate and now if you consider this section where you are finding some opening and as per the requirement this particular section can be opened.

So, this basically we call as manholes. As far as sieve plate is concerned, it is basically the cheaper type of plate in comparison to bubble cap as well as valve plates. So, as far as design is concerned it is simplest type and cost is concerned it is cheapest among all three. So, sieve plates are simply metal plates with holes in them so as we have already seen in this image. So, if you focus on this is basically weir.

And this we call as the weir height and if you see the bottom section it is nothing, but the downcomer apron. So, in this way we consider the construction of sieve tray so simplest as well as cheapest that you have to keep in mind for sieve plates.

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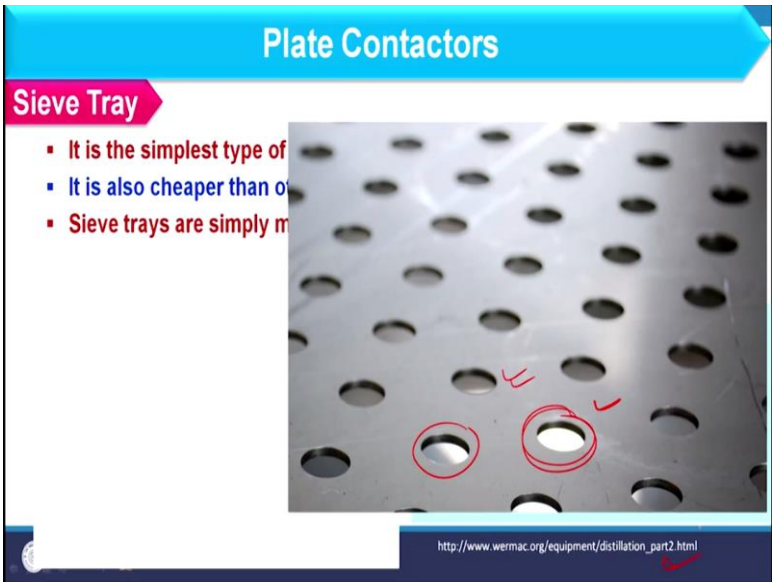

Further, this image you can see where you can find the holes closely. So, this is simple. The metal sheets were close so here we have the metal sheet where holes are available like this you can see and for details you can go through this link about the sieve plate. So, further let us consider few more points about sieve plate and this is basically in the sieve plate vapour passes straight upward through the liquid on the plate as we have discussed previously also.

So, apart from all these advantages we have some disadvantages also for sieve plate and that disadvantage is as there is no vapour liquid seal so there is chances of weeping in lower flow rates which reduces the plate efficiency. What is the meaning of this? When consider the sieve plate you can see that it is only the holes over the plate. So, these holes are not covered. So, whenever I am having lower flow rate of liquid it means liquid will stay for longer time over the plate then liquid will start moving down from the holes.

But you understand that these holes are basically formed for the movement of vapour in upward direction, but not for the liquid, liquid has to move like this. But if we face this condition where liquid start falling from these holes this condition we call as weeping which is not desirable as far as mass transfer process is concerned over the plate. So, that is basically the disadvantage.

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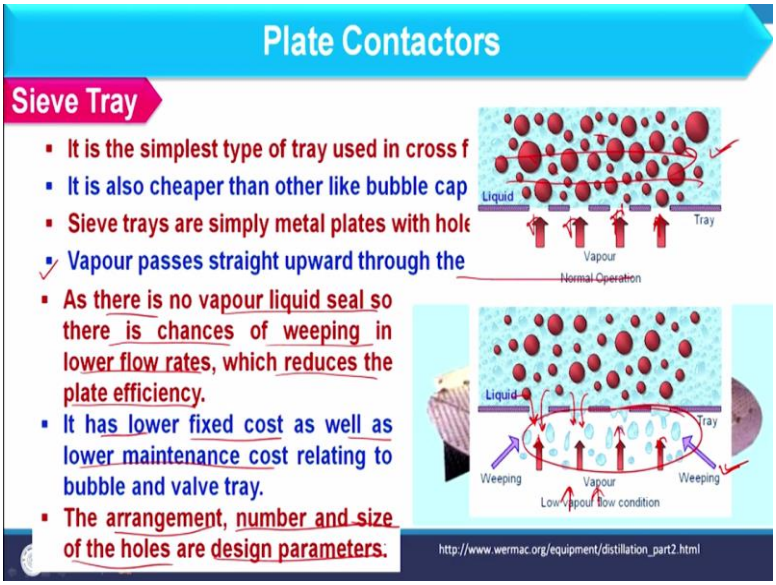

And that you can also imagine from this schematic like here I am having the vapour which is moving from downward and this is basically the normal operation where liquid is available and then whatever vapour is entering from the bottom it will be available in the form of droplets as you can see in this diagram. And further if weeping will occur then what will happen?

We can have vapour from the bottom, but liquid will also start coming from these holes which will hinder the movement of the vapour to upward direction. So, in this way when liquid will start falling down from these hole this condition we call as weeping which is highly undesirable. So, as far as design of plate is concerned this condition must be checked and if it is occurring we have to consider some measures to stop this and what these measures are that we will discuss in due time.

Further, we consider that it has lower fixed cost as well as lower maintenance cost because simple holes are there so fixed cost will not be very large or very high because we consider only the metal plate we do not have any extra assembly to invest the material. So, fixed cost will be less it means fixed cost means the cost of material as well as the cost of manufacturing.

And therefore we consider that it is the cheapest plate in comparison to bubble cap as well as valve tray. So, let us see the design parameters for the sieve plate and these design parameters are the arrangement it means how holes are arranged and number how many holes will be

there and size of holes these will be the design parameters and how we make the holes in the metal plate.

All these points we have to consider while designing sieve tray. So, in this way you can observe the functioning of sieve plate, its advantage as well as disadvantage.

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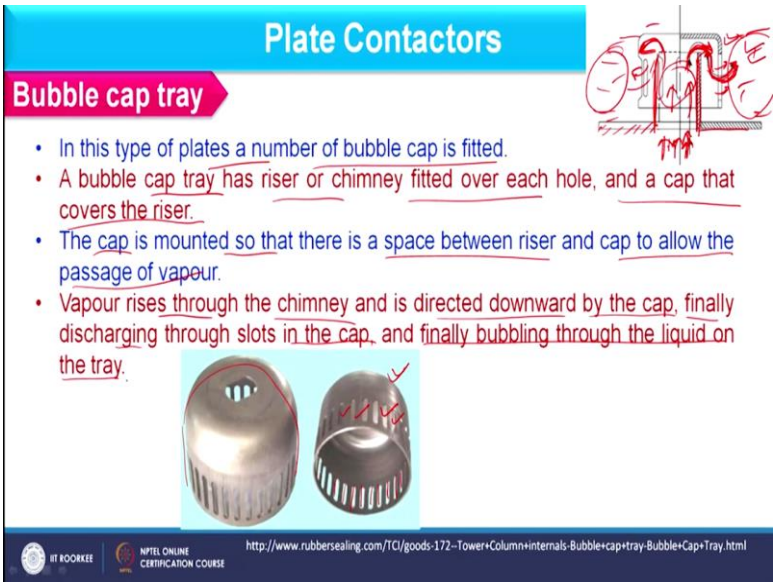

Now, let us focus on another plate and that is basically bubble cap tray. So, as far as bubble cap tray is concerned in this type plates are having number of bubbles cap. So, what is this bubble cap? It is basically the cap which has some sections where we can form the bubble. To give an example here we have the bubble cap. So, this is basically the cap complete cap is there where I am having these type of holes.

And when vapour is coming vapour is entering into these holes and then it will be converted into bubbles and then it will interact with the liquid over the plate. So, in this way it is called bubble cap, cap is there but bubbles are formed when vapour enters from these openings over the cap. So, further if we consider the bubble cap, a bubble cap tray has riser or chimney fitted over each hole and a cap that covers that riser.

That we can understand from this schematic. If you see here we have the hole we consider hole in this way. So, this is basically the hole from where vapour is entering and you consider over this opening we have this type of chimney or we can consider that it is a type of nozzle which is fitted with the hole. So, when we consider this section in this bubble cap it is called as a chimney, but it looks like a nozzle.

So, what will happen over this chimney this type of bubble cap sits. So, this cap is simply available over the chimney. So, if we see this complete plate it is basically like some caps are there how it will look like that we will also discuss. So, what will happen when vapour is entering from this. So, this space is completely open for vapour to move upward. So, when the vapour is moving from this empty space it is coming to this region.

And this region also have some space because height of the cap is higher than the height of the chimney and from this space it does not have any other passage than to move in this direction. So, from this hole vapour coming out and here we have the liquid. So, vapour which is coming out from these hole it is coming into contact with this liquid and when this vapour is exiting these small holes as we can observe over here it is converted into small bubbles.

And that bubbles are basically come in contact with the liquid and mass transfer takes place there over the plate. So, in this way we can understand the complete assembly of the bubble cap as well as its functioning. So, the cap is basically mounted so there is a space between riser and cap to allow the passage of vapour that we have already discussed and vapour which is available it rises through the chimney that we understood through the schematic also.

And it is directed downward by the cap like this section or this section or this section and finally this charging through the slots in the cap and these are basically the slots and finally bubbling through the liquid on the tray. So, all these points we have understood through the schematic.

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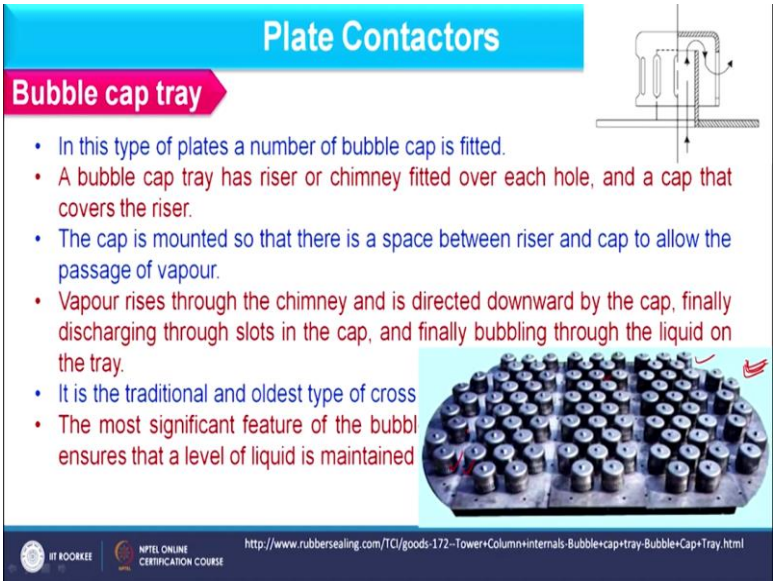

Now, if you see the most significant feature of bubble plate is that it uses the riser and that riser is basically stopping the liquid from coming to the plate through the hole to downward. So, that chimney as well as riser is working as the stopper for liquid to move downward and therefore weeping is not possible in these types of trays and when we consider very low liquid flow rate then also liquid is not able to move from the slots of the cap to the chimney and so through the hole.

So, the basic advantage of this tray is that it can be operated with very flow rate of liquid. If you see the complete bubble cap tray it is looking like this so we have small caps over the plate.

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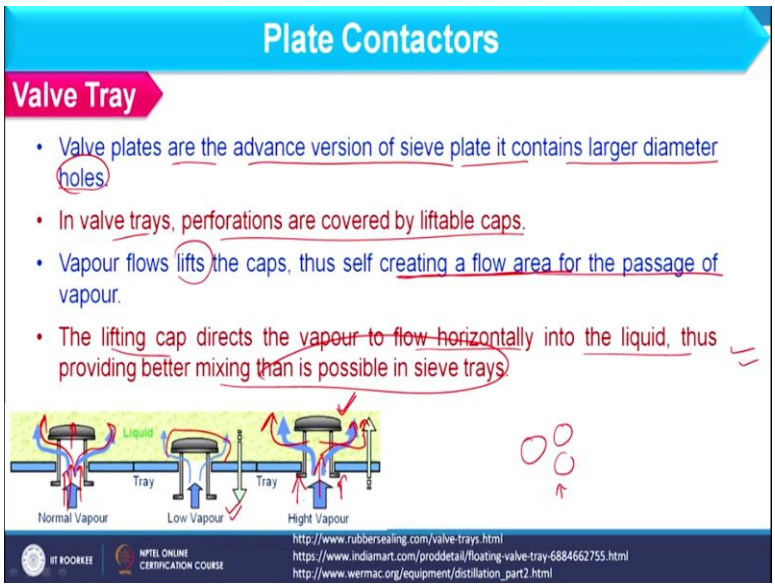

And now let us discuss the valve plate. As far as valve tray is concerned these are basically advanced version of sieve plate and it contains larger diameter holes. So, if I am having larger diameter holes and it is basically like sieve plate so it has more tendency for weeping, but no this is not the case because each hole has some cover. And that is why it is called as advanced sieve plates. So, in valve trays perforations are basically covered by liftable caps.

So, that you can imagine from this image that each hole is basically covered with the cap and these caps are basically liftable caps how it works that we will discuss. So, vapour flows which is coming from the downward it flows and lifts the cap and thus self creating a flow area for the passage of vapour. And that we can understand from this schematic if you see when the vapour is coming from downward it basically pushes this cap upward.

And make its own path from this and for low vapour flow rate we can consider that it will not able to lift the cap properly. So, what is the case that if low flow rate of vapour we are considering and it will not able to lift it properly. So, it will basically stopping liquid from moving through the hole to downward as we had the disadvantage in sieve plate. And as far as high vapour flow rate is concerned it can lift the cap upward.

So as the flow rate of vapour will be there we can get the sufficient space for vapour to move upward otherwise it will not able to lift the cap upward and so weeping can be stopped. So, this point we have already covered that lifting cap directs the vapour to flow horizontally into the liquid like in this way and better mixing is occurring in comparison to sieve plate because it is basically in this way and then in this way. However, in sieve plate only we have the vertical movement of vapour.

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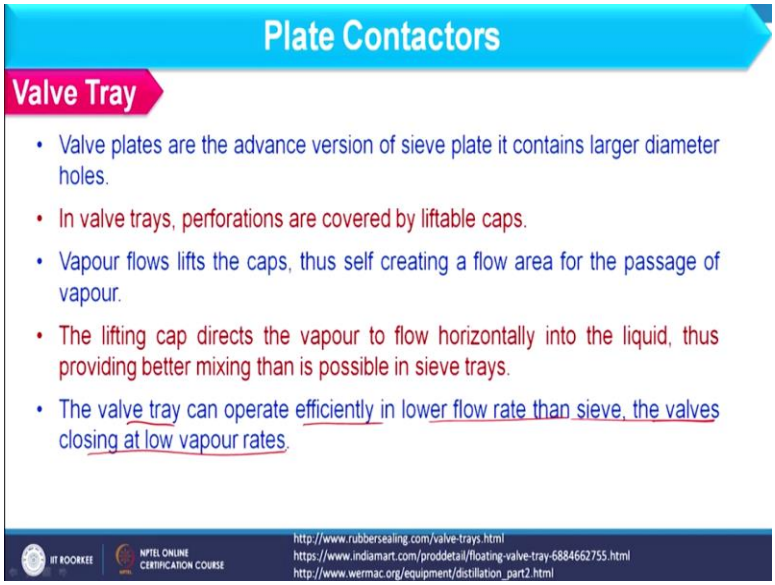

Further, valve tray can operate efficiently at low flow rate than sieve plate and as valves are closed at low vapour rates. So, weeping can be avoided.

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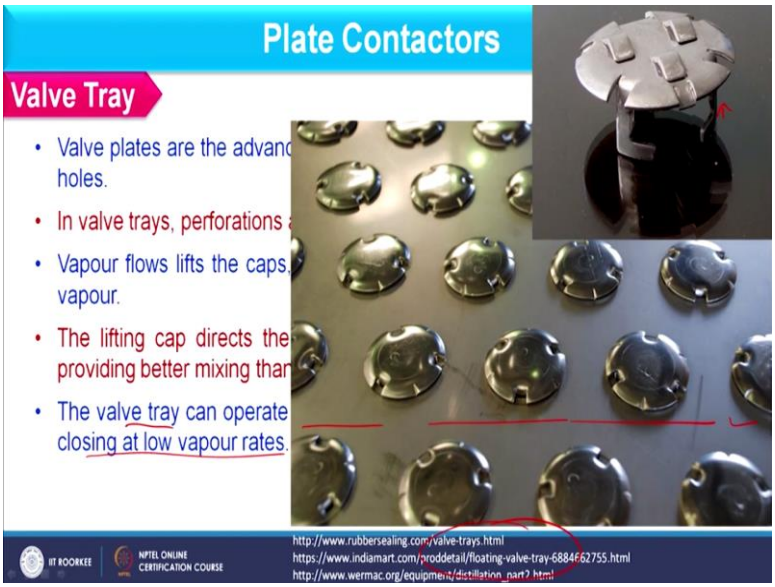

So, you can see the valve plate closely from this image and for details you can go through these links and as far as that cap is concerned it is basically looking like this. So, in this way we can have the valve tray.

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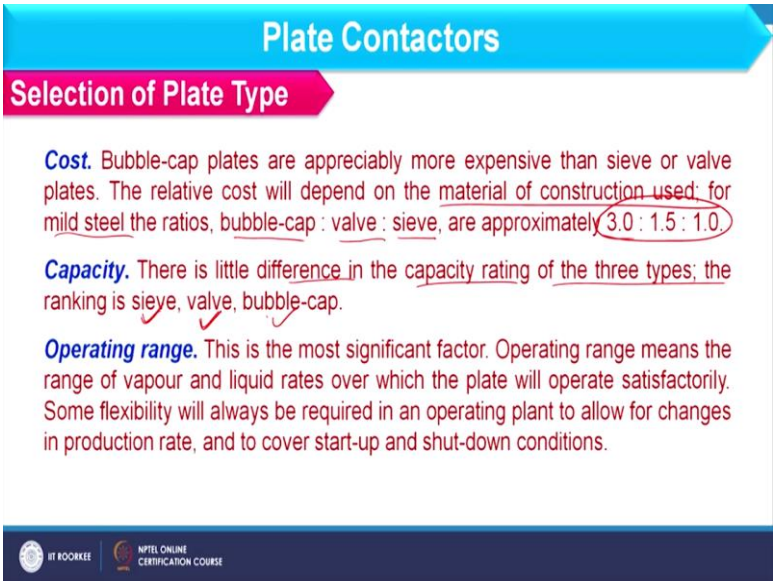

Now, let us see how to select a particular plate depending upon different parameters. So, first of all we have the cost so as far as cost is concerned as you can understand that bubble cap has maximum investment. Valve tray is lesser than this and sieve plate is the simplest and cheapest that we have already discussed. So, as far as material of construction involved in the mild steel when we are making bubble cap valve plate and sieve trays this ratio we basically follow like 3 is to 1.5 is to 1.

So, maximum cost of material can be considered in bubble cap and the reason you can understand. Next, I am having the capacity there is a little difference in capacity rating of the three type and rank varies from sieve plate than valve and then bubble cap and as far as operating range is concerned operating range is basically the meaning of the flow rates. So, as far as bubble cap tray is concerned that can be operated with very low flow rate.

So, that is the advantage of bubble cap. However, if operating condition is mild we should choose sieve plate if we can avoid the weeping through sieve plate and that will be depending upon the vapour flow rate which is occurring in the system.

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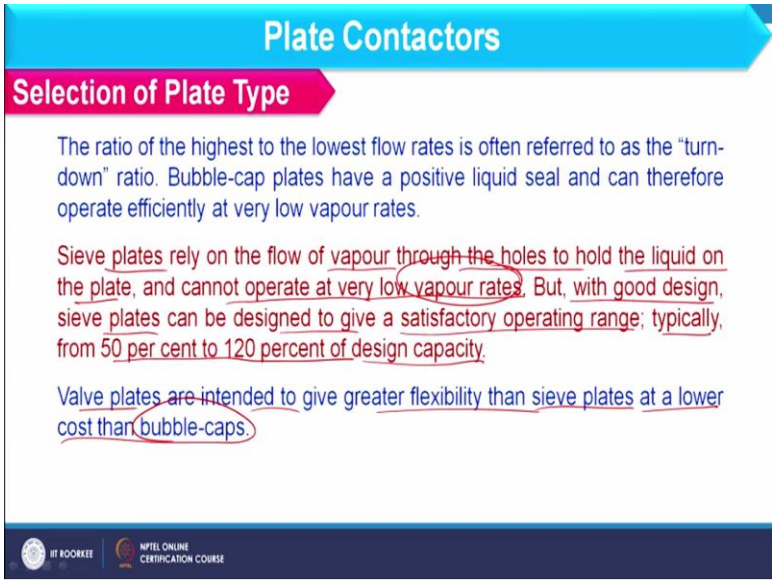

So, basically sieve plates rely on the flow of the vapour through the holes to hold the liquid on the plate and cannot operate at very low vapour rates, but in that condition we can have bubble plate. But with good design sieve plates can be designed to give satisfactory operating range and typically it is 50% to 120% of design capacity. So, there is a flexibility also with the sieve plate, but main disadvantage is it cannot be operated for very low vapour flow rate and in that case we should select bubble cap.

And as far as valve plates are concerned these are intended to give greater flexibility in comparison to sieve plates at lower cost in comparison to bubble cap. So, when we have the choice we can choose the valve tray first in comparison to bubble cap. However, when flow rate is very small we should consider bubble cap we do not have any other choice.

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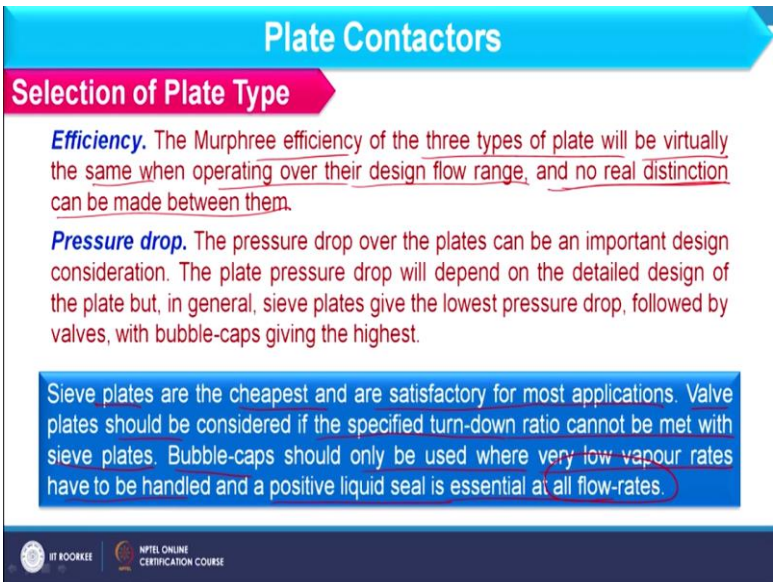

So, next point we have is the efficiency The Murphree efficiency of three types of plate will be virtually the same when operating over their design flow range and no real distinction can be made between them. So, as far as efficiency is concerned it is almost same for all and next we have pressure drop. As we have discuss that pressure drop is basically causing by the friction which is generated when movement of vapour as well as liquid is occurring.

So, when this friction will be maximum where I am having maximum hindrance and where I can consider maximum hindrance obviously in the case of bubble cap. So, bubble cap plate has highest pressure drop. However, as far as lowest pressure drop is concerned it will be obviously for sieve plate. So, conclusion is sieve plates are cheapest and are satisfactory for most application.

Valve plate should be considered if the specified turn down ratio cannot be met with the sieve plate. Turn down ratio is the ratio of maximum flow rate divided by minimum flow rate. And bubble caps should only be used where very low vapour rates have to be handled and a positive liquid seal is essential for all flow rates. So, in this way we should choose different type of plates depending upon the conditions because you know the merits and demerits of all these types of plates.

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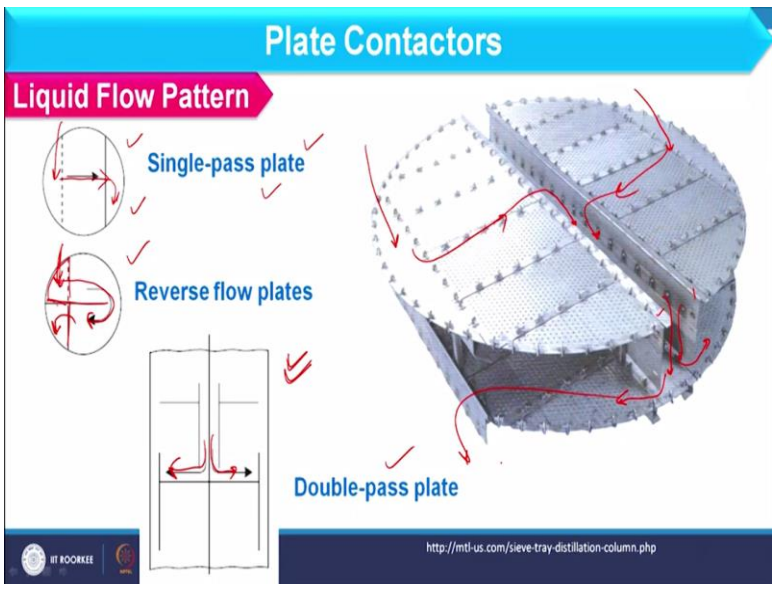

And here we have some flow patterns as well as liquid movement is concerned and here first of all we have single pass it means how the liquid movement occurs over the plate. So, if you consider here liquid is coming from the top moving over the plate only once and then coming

down. So, this is basically single pass plate and in most of the cases such type of flow pattern is considered and second we have the reverse flow.

If you consider here liquid is coming from the top only in this section because at the middle we have the partition. So, some metal strip will be welded over here and here we have the exit weir. So, liquid is coming to this side from upward plate and then it is moving in this way and then from here it moves down. So, this is basically reverse flow plate where entry of the liquid and exit of the liquid is occurring at the same space or at the same side of the plate.

And this is basically used when I am having low flow rate of liquid. So, by partitioning the plate from middle we can basically reducing the flow area and so we can increase the velocity of the liquid over the plate. However, if the liquid flow rate is very high we can consider this double pass plate. It basically divides the liquid into different direction that you can clearly understand from here like liquid is coming from the top in this way it flows in this direction.

And here we have the exit weir and after that it is moving down from this space and then it enters to second plate from the bottom like this and then further coming down like this. So, this is basically double pass plate.

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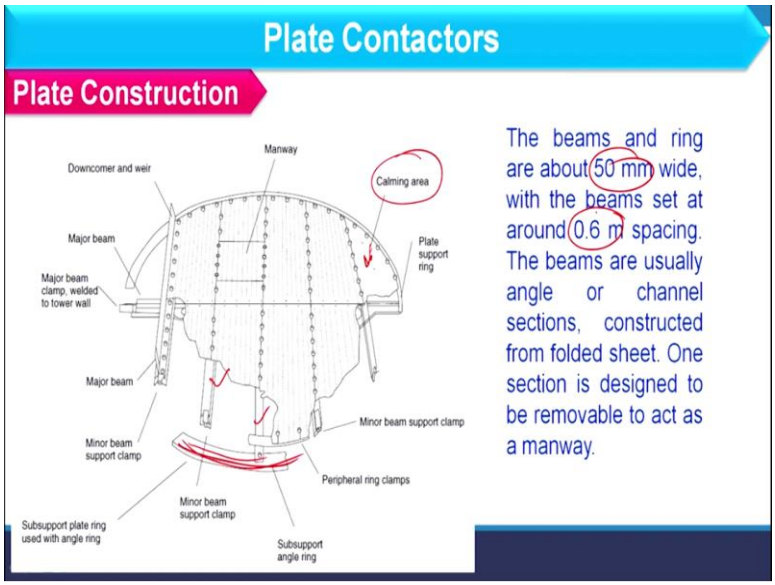

And here we have some plate constructions and we will quickly cover it. Here, you see when the liquid is coming over the plate it is basically the section where holes are not available so it is called as calming area and here we have the metal ring which we call as the support and

over this support tray lies or tray sits. And when the size of the diameter is very large we prepare this plate in different sections.

And these are attached over the beam as you can observe here. And as far as this thickness is concerned beam and rings are usually 50 mm wide and we usually consider spacing between trays as 0.6 meter. So, we have different other spacings also that we will consider in detail design.

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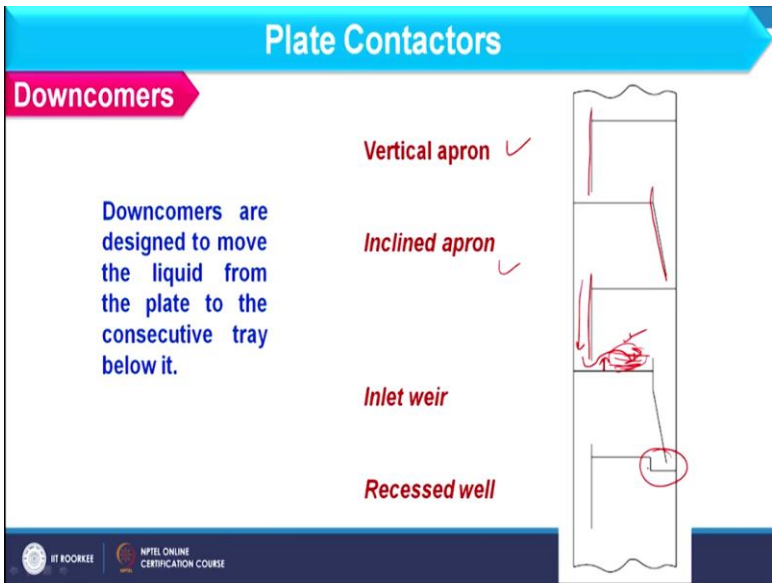

And now we will focus on the downcomer you can see different types of downcomers are there vertical apron, inclined apron like this and here we have inlet weir also like from apron liquid is coming down and then here we have some restrictions and after that the movement of the liquid over the plate has more turbulence. So, we can have better mixing over here and similarly I can have the recessed well as you can observe here.

So, in this way we can have different types of downcomers and as far as plate contactors are concerned we have considered different sections which are available over the plate and we will continue the distillation column design from the next lecture onwards. So, that is all for now. Thank you.