# Mass Transfer Operations-I

Prof. Bishnupada Mandal
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

## Lecture - 18
## Gas dispersed: Tray tower

Welcome to the 2nd lecture of module 2 on Mass Transfer Operations. In this module we are discussing equipment for gas liquid operations. Before going to the next lecture let us have a small recap on our previous lecture.

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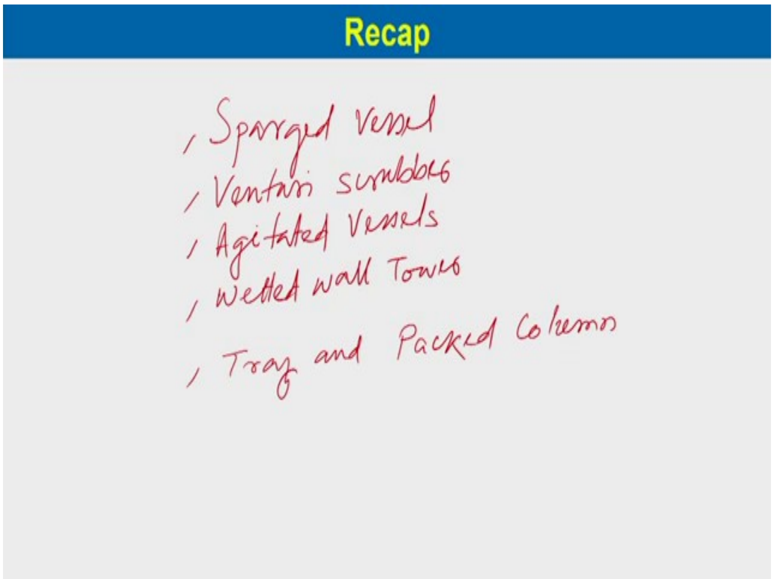


In our previous lecture we have considered different mass transfer equipment both for batch and the continuous mode and those equipments are sparged vessel, then venturi scrubber, agitated vessels, wetted wall column and we have also said the tray and packed column. This tray and packed column are commonly used in industrial application particularly in case of absorption and stripping as well as in distillation. So, we will put more emphasis on the tray and packed column in our next discussion.

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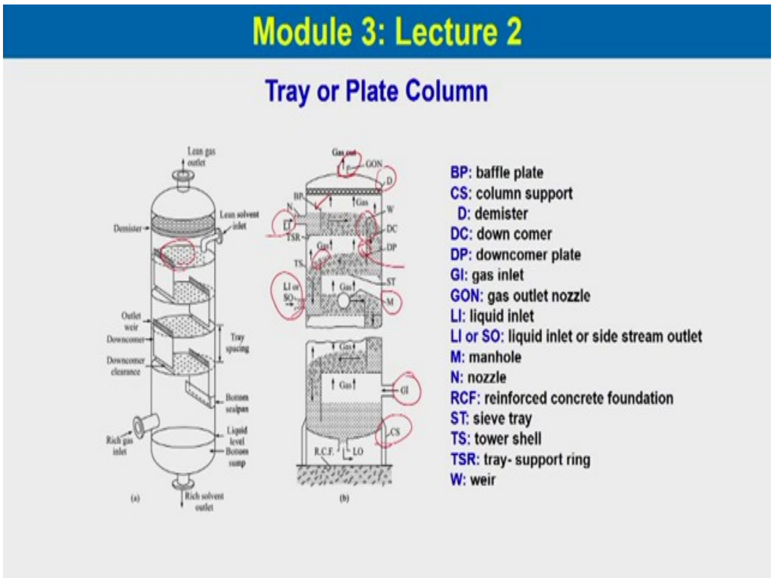


So, let us start with our tray or packed column. You can see the this is a typical look of tray column as you can see in this column you have the different terms used over here already written over here BP represents the baffle, baffle plate over here and we have column support which is over here, then we have demister which is over here and then down comer DC is over here where the liquid comes down. We will discuss more about it down comer, then down comer plate.

So, here this is down comer plate and then gas inlet. We have gas inlet at the bottom and then, we have gas outlet nozzles over here, then liquid inlet which is at the top and the liquid know liquid in inlet or side stream outlet, so which is over here, then we have manholes. You can see over here man holes are written. So, man holes through man holes know when we are the cleaning are required, it is used and then we have nozzles, then we have reinforced concrete foundation, then sieve tray.

So, each tray has a perforation and you can see the tray which is seive like you have learnt in your mechanical operation course, there are different kinds of sieve used. So, it is called sieve tray, then tower shell TS and then TSR tray support ring and then weir. So, weir actually which is maintained is a particular liquid height in a particular tray.

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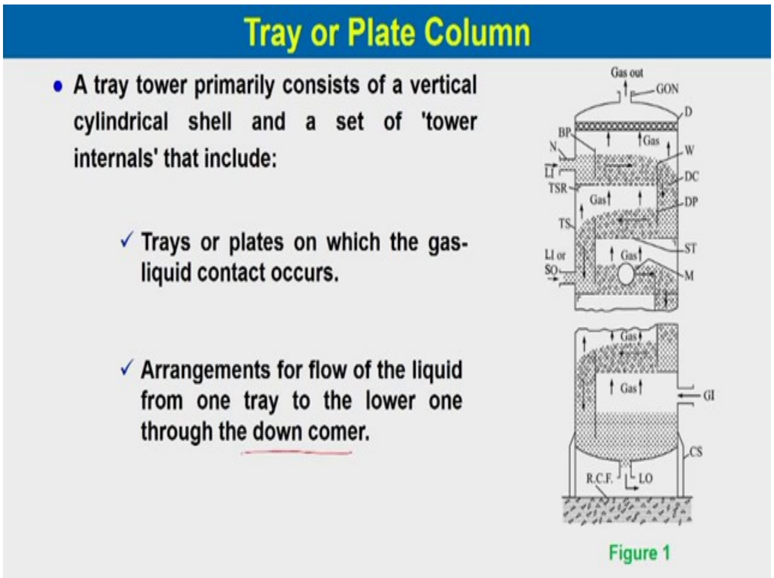


A tray tower primarily consist of a vertical cylindrical shell and a set of tower internals. This tower internal includes tray or plates on which the gas liquid contact occurs. So, for each plate or tray the gas and liquid comes in intimate contact arrangement for flow of liquid from one tray to the lower one through the down comer. So, through down comer the liquid which is know from the inlet, it goes to the down comer and it comes down to the next plate.

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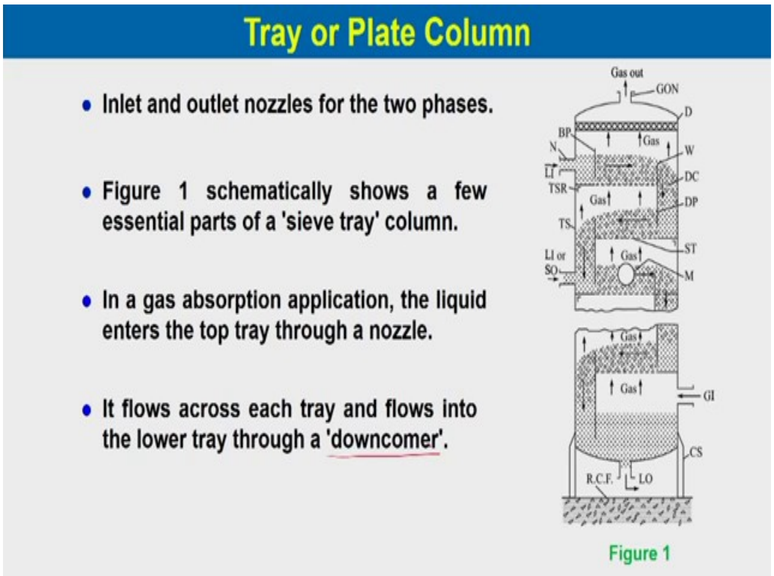

Inlet and outlet nozzles for the two phases nozzles are provided for the two phases. For the two phases the figure 1 which you can see over here schematically such a few essential part of a sieve tray columns in gas absorption application, the liquid enters at the top tray through a nozzle. Here it flows across each tray and flows into the lower tray through a down comer as we have discussed before.

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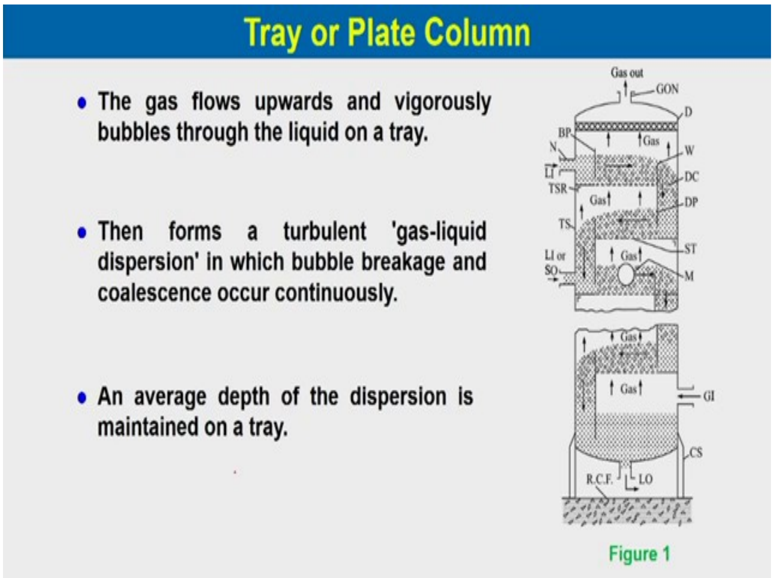


The gas flows upward and vigorously bubbles through the liquid on a tray. So, through the perforation the gas goes up and then, there is intimate contact in each tray between the gas and liquid, then forms a turbulent gas liquid dispersion in which bubble brakes and coalescence occurs continuously.

So, once there is a liquid pool on a particular tray and gas bubble through there is a know gas liquid dispersion occurs, bubble breaks and coalescence and then, it forms continuously that this is a continuous process. An average depth of the dispersion is maintained on a tray, so, for each tray we need to maintain a particular depth of the liquid.

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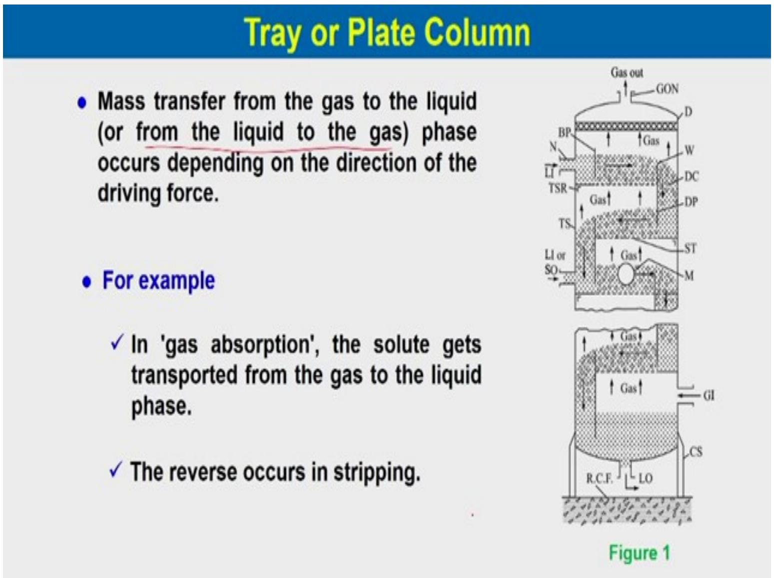


Mass transfer from the gas to the liquid phase or from the liquid to the gas phase occurs depending on the direction of the driving force. So, both the way it is possible for absorption; the solute from the gas mixtures transfer from the gas phase to the liquid phase whereas, for striping or desorption solute from the liquid phase transferred to the gas phase.

For example, gas absorption the solute get transported from the gas to the liquid phase and the reverse occurs in case of stripping.

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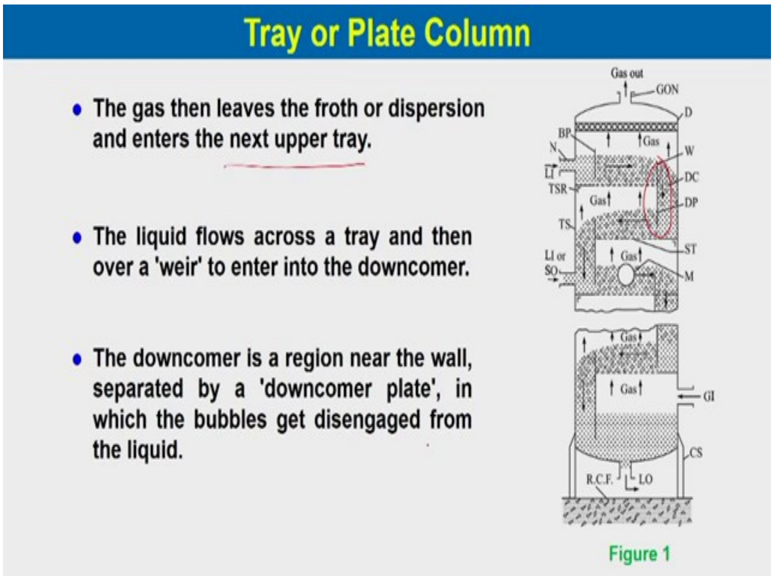

The gas then leaves the froth or the dispersion and enters the next upper tray. The liquid flows across a tray and then, over a weir to enter into the down comer. The down comer is a region near the wall separated by a down comer plate. You can see over here down comer plate in which the bubble get disengaged from the liquid.

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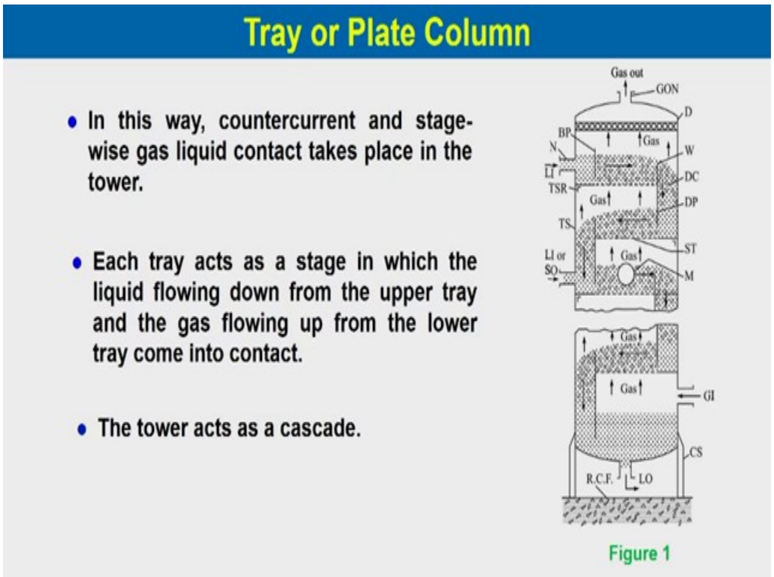


In this way counter current and stagewise gas liquid contact takes place in the tower. Each tray acts as a stage in which the liquid flowing down from the upper tray and the gas flowing up from the lower tray come in contact ok. The tower acts as a cascade because you have multiple tray and the vapour and liquid flows from tray to tray.

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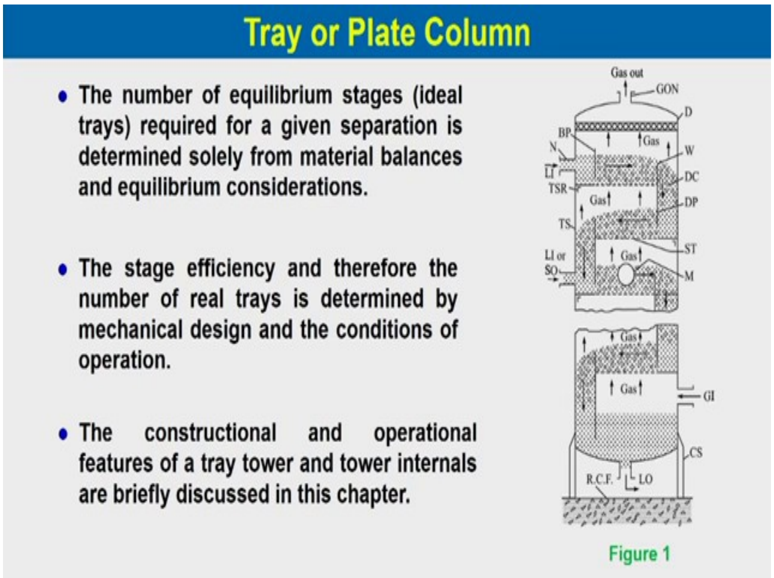


So, it acts as a cascade. The number of equilibrium stages or we call it ideal stages or trays required for a given separation is determined solely from the material balance and equilibrium consideration, the stage efficiency and therefore, the number of real trays is determined by mechanical design and the conditions of operation. The construction and the operational feature of a tray tower and the tower internals are briefly discussed in this on lecture.

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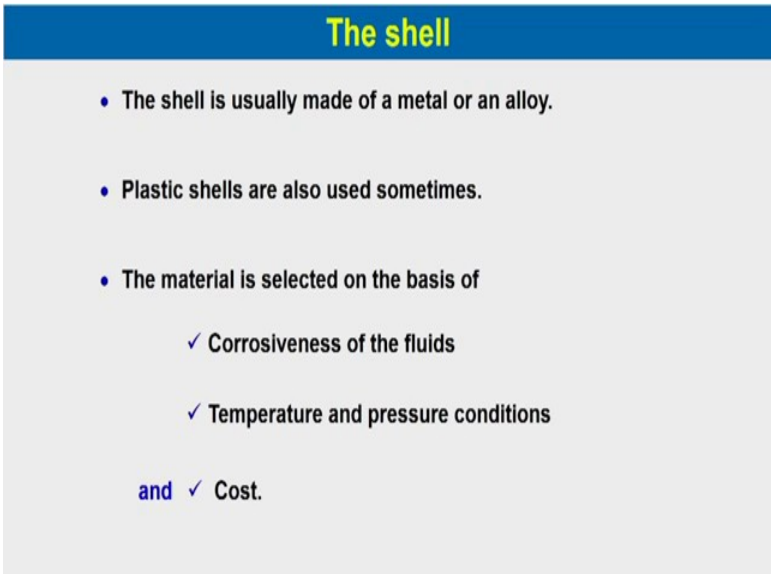

The shell is usually made of metals or an alloy ah. The materials of construction anyway we learn in another know course or another subjects. So, here we will mostly just highlight what are the materials used, plastic shells are also used sometimes. The material is selected on the basis of corrosiveness off the fluids temperature and pressure conditions and the cost.

So, based on these three factors the materials are selected and then, which are usually among the plastic metals or alloys.

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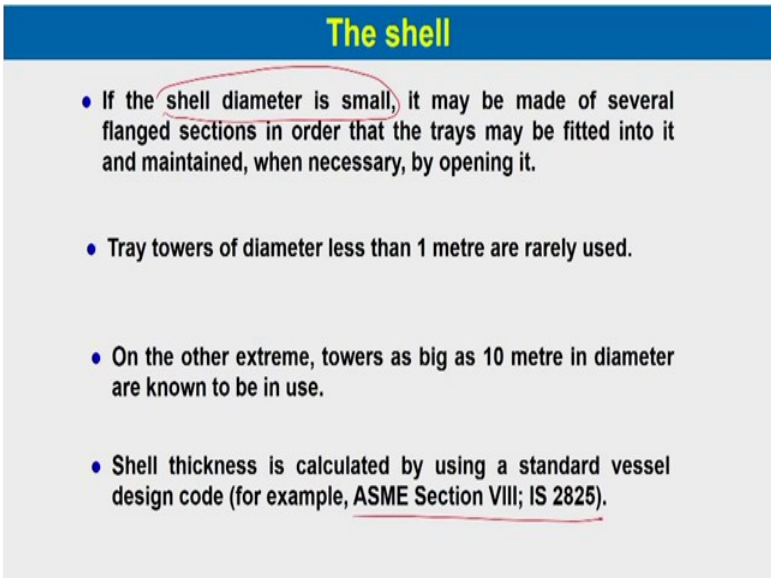


If the shell diameter is small, it may be made of several flanged sections in order that the trays may be fitted into it and maintained when necessary by opening it this is for. So, the small diameter tray, so we need to have several flanged sections and it is very easier to maintain whenever it is necessary tray towers of diameter less than 1 metre are rarely used on the other extreme towers as big as 10 metre in diameter are known to be in use. So, in industry you would find very know bigger diameter tower is generally varies between 7 to 10 metre diameter.

Shell thickness is calculated by using a standard vessel design code. So, that would be available in this you know in this references you can use where the thickness of the shell can be calculated.

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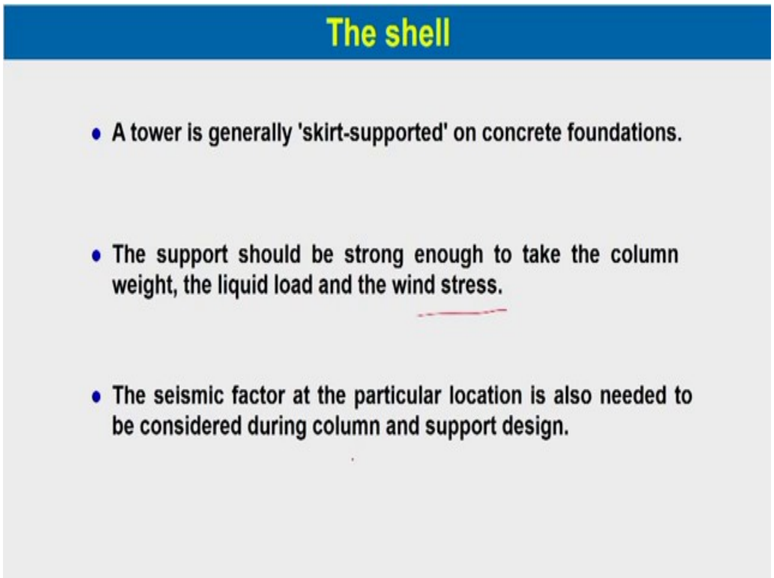


A tower is generally skirt-supported on concrete foundation. As you have shown you on the figure there is skirt-foundation or support which is made of concrete. So, to keep the tower the support should be strong enough to take the column weight, the liquid load and the wind stress. Generally the columns are very tall close to 50 metre in the height. The seismic factor at the particular location is also needed to be considered during column and support design.

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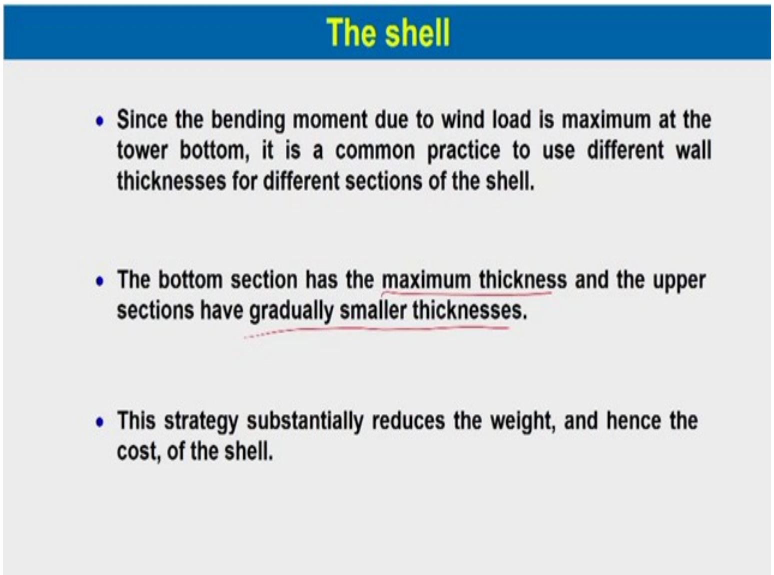

Since the bending moment due to wind load is maximum at the tower bottom, it is a common practice to use different wall thickness for different sections of the shell. So, depending on the bending moment or due to the wind load and several other accepts the thickness of the sections or of the wall, of the tower maybe different.

The bottom section has the maximum thickness where as the upper section has gradually smaller thickness. This strategy substantially reduces the weight and hence, the cost of the shell. So, these are very much required instead of making the uniform thickness throughout its better to design as per the requirement can be made accordingly.

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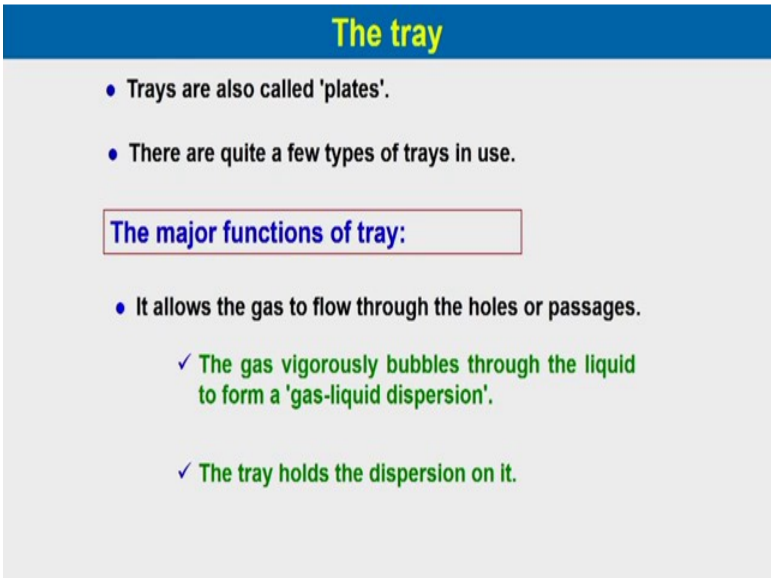


Trays are also called plates. So, either we can call it tray columns or plate columns. There are quite a few types of trays in use. Major function of tray is basically it allows the gas to flow through the holes or passages. So, the tray will allow the gas to pass through the holes on the tray. The gas vigorously bubbles through the liquid to form a gas liquid dispersion.

When the liquid comes down from the down comer of the upper tray if there is a liquid height maintained and the gas which is passes through the perforation of the plate, it bubbles through the liquid. So, while doing so it make a gas liquid dispersion and it know create a turbulence and hence, increase mass transfer coefficient and gas liquid interfacial area. So, the tray holds the dispersion on it. So, these are the major functions of a tray.

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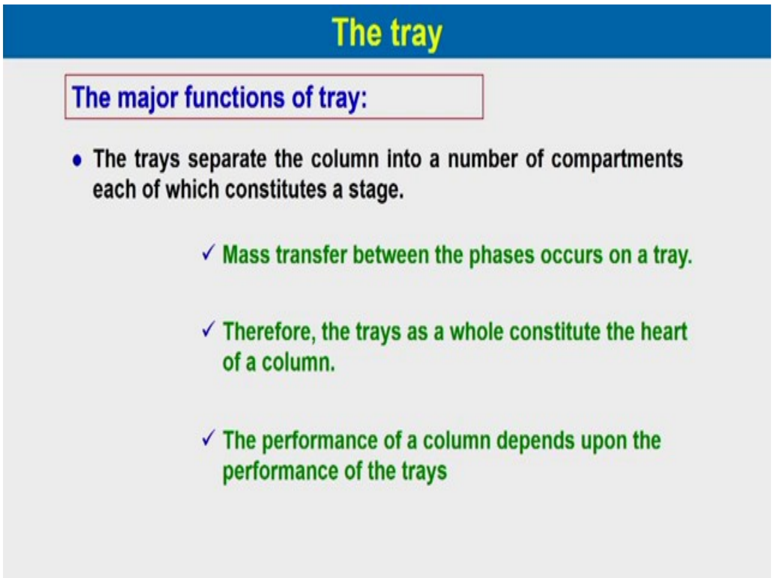


The tray separates the column into a number of compartments each of which constitutes a stage. So, that is why we call stagewise contact. So, what happens mass transfer between the phases occur on a tray. Therefore, the trays as a whole constitute the heart of a column. The performance of a column depends upon the performance of the trays. So, that is why tray has to be designed properly.

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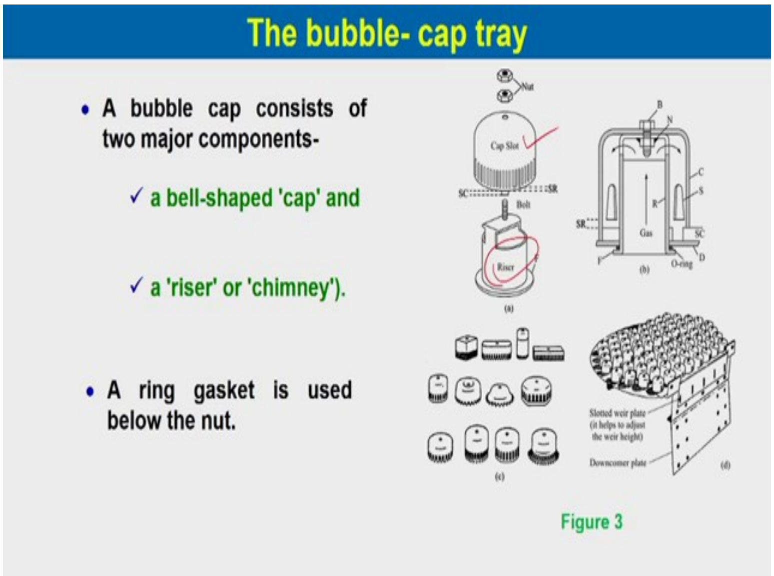


There are different kind of trays and now we will discuss on the bubble cap tray. The bubble cap tray consist of two major components. One is know cap slot a bell shaped cap you can see over here bell shaped cap and then, there is a riser or chimney so which is given over here. A ring gasket is used below the nut. So, there is a gasket which is used over here below the nut.

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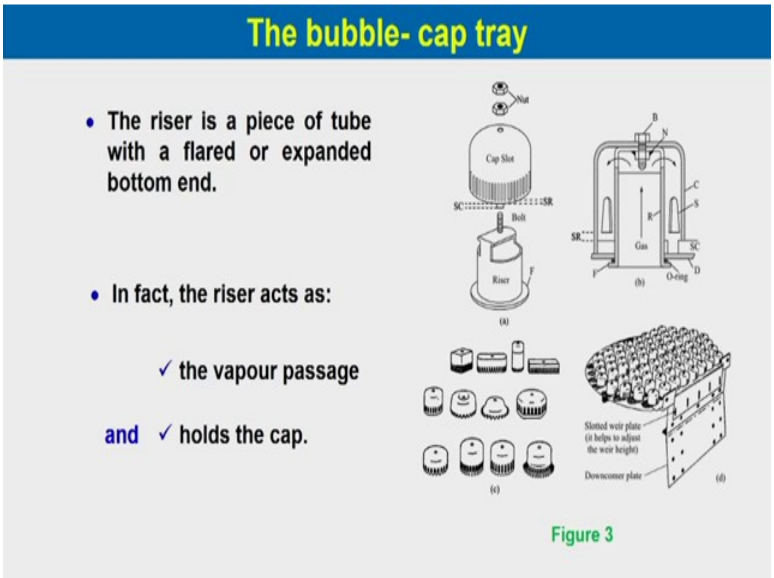


The riser is a piece of tube with a flared or expanded bottom end, so, you can see here. So, the bottom is a little expanded are flared. It is a know tube like arrangements and then the riser acts as the vapour passage and holds the cap. So, this riser when you put you know cap over here when there is a flow from the bottom, so cap will go up and the opening from the riser will also go up. So, the vapour will go out. It controls the vapour passage and it also holds the know cap over it.

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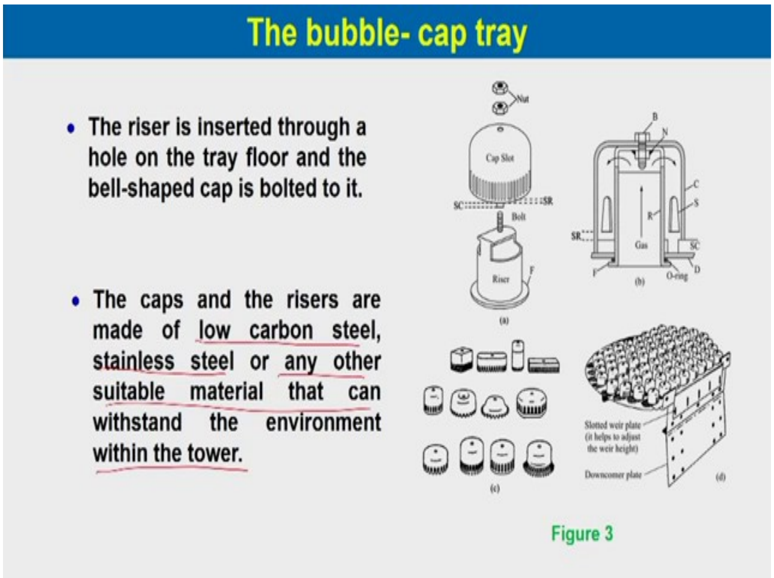


The riser is inserted through a hole on the tray floor and the bell shaped cap is moulded to it. Now, the cap and the riser are made of low carbon steel. So, here its materials of construction usually is low carbon steel or stainless steel or any other suitable materials that can withstand the environment within the tower. So, depending on the application the materials maybe changed.

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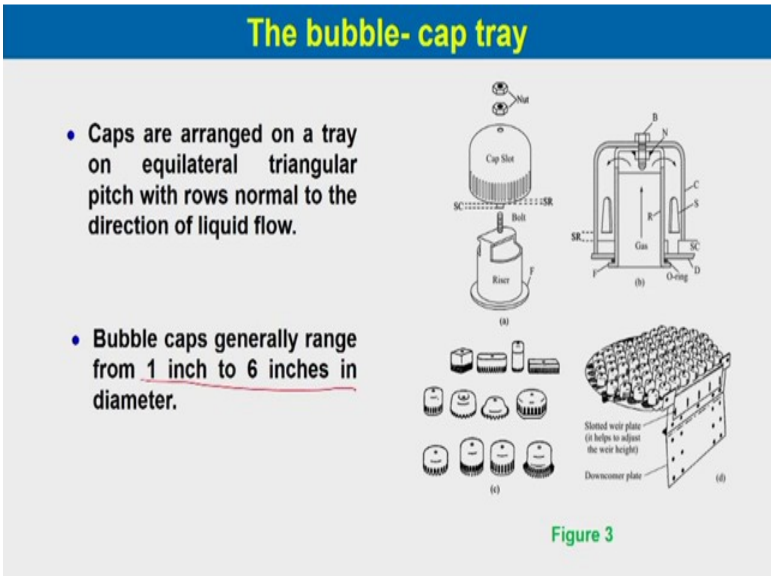

Caps are arranged on a tray on equilateral triangular pitch with row normal to the direction of the liquid flow. Bubble caps generally range from 1 inch to 6 inches in diameter.

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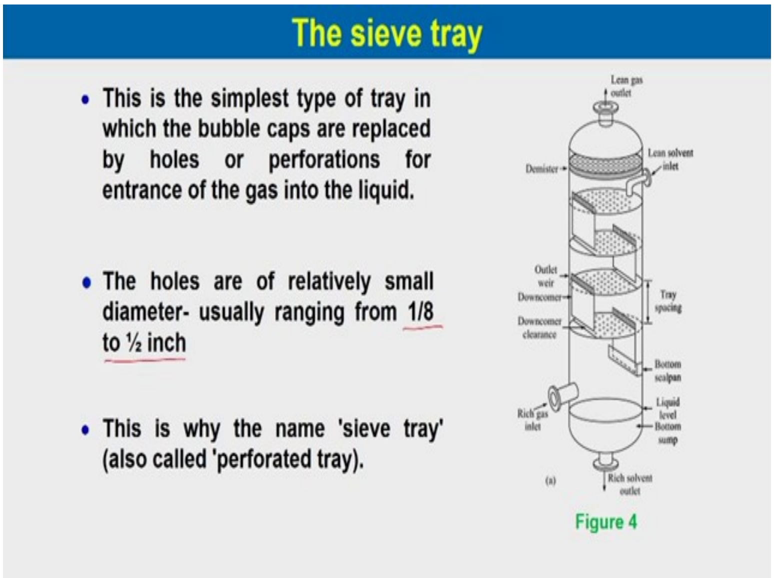


Now, we will discuss about the sieve tray. In this figure you can see this is the simplest type of tray in which the bubbles caps are replaced by holes or perforations for entrance of the gas into the liquid.

So, instead of giving a know cap and making a riser through which the gas used to pass, this can be replaced with the normal holes on the tray and which will give the passage of the gas into the liquid. The holes are of relatively small diameter usually ranging from one-eighth to half inch. This is why the name is sieve tray and also called perforated tray.

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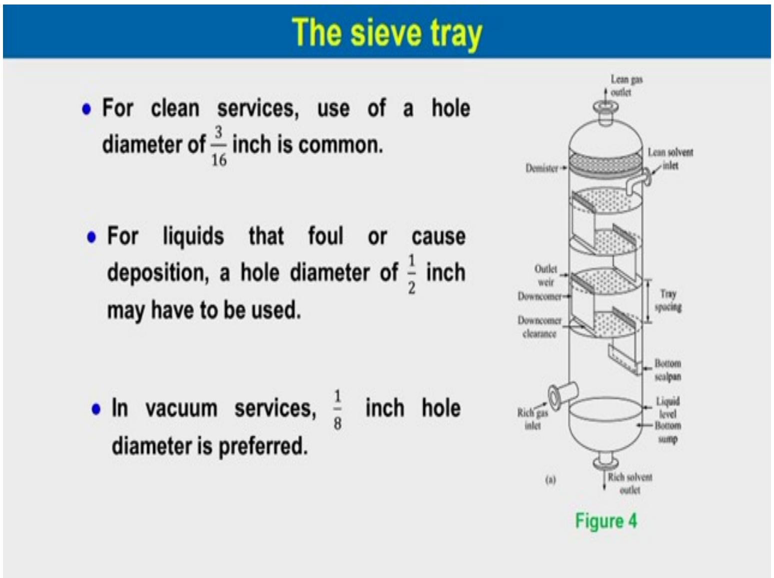


For clean services we use of hole diameter of 3 by 16 inch is common, very common 3 by 16 inch. For liquid that foul or cause deposition hole diameter of half inch maybe may have to be used. So, if the liquid which will know may clot or foul the tray holes, then in that case the larger size holes may be used in vacuum services one-eighth inch hole diameter is preferred.

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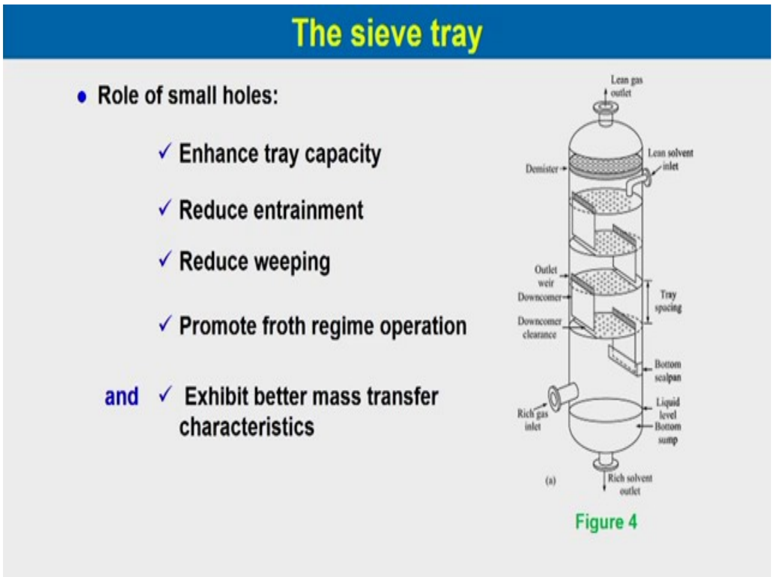


The role of a small holes enhance tray capacity reduce entrainment, it also reduce weeping. We will discuss you know all these know entrainment and weeping phenomena how it happens based on the gas liquid flows, promote froth regime operation and also exhibit better mass transfer characteristics. So, if the holes are of small, it helps in this manner.

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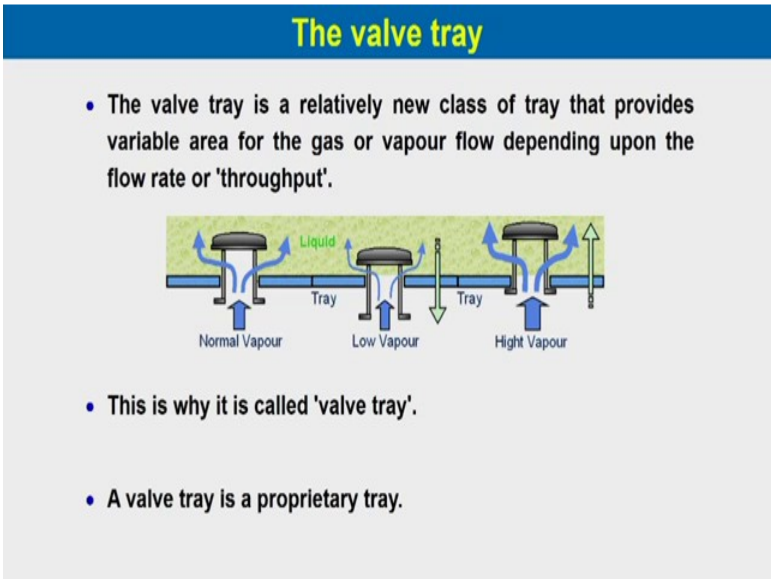


Now, we will discuss the valve tray. The valve tray is a relatively new class of tray that provides variable area for the gas and vapour floor depending upon the flow rate or throughput you can see over here there is a normal vapour which is coming to this and then, you have a tray, then there is a particular height of liquid it maintains. When vapour flow rate is low, opening is less. When vapour flow rate is more, opening is more. Then this is why it is called a valve tray.

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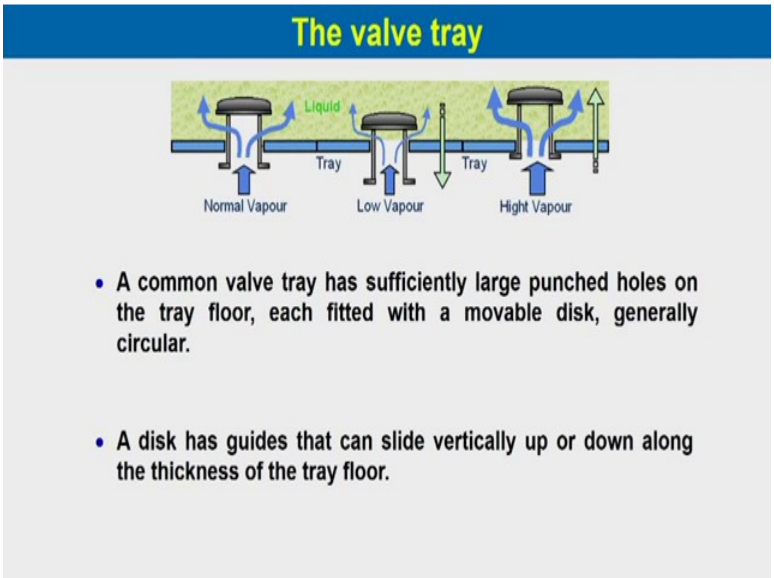


A valve tray is preparatory tray and a common valve tray has sufficiently large punched holes on the tray floor each fitted with a movable disk. Generally circular disk a disk has guides that can slide vertically up or down along the thickness of the tray floors.

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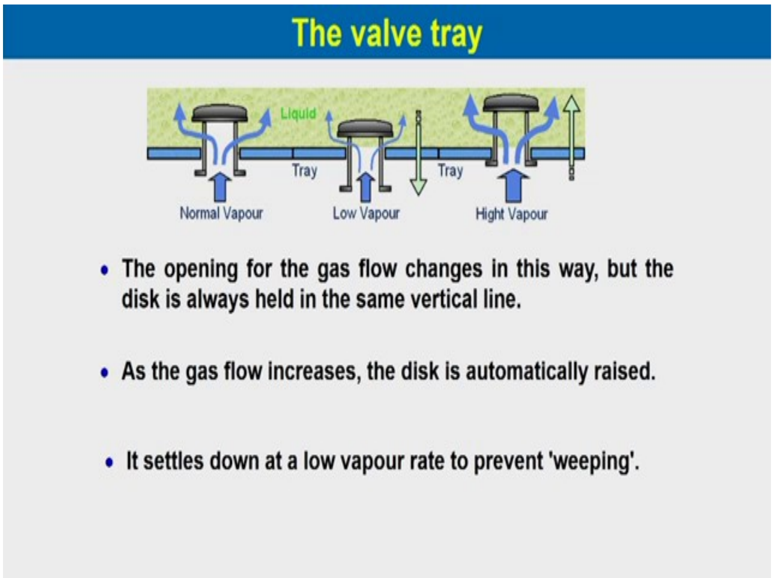


The opening for the gas liquid changes in this way, but the disk is always held in the same vertical line. As the gas flow increases, the disk automatically rises. It settle down at low vapour rate at know to prevent weeping. Weeping means the liquid drops which will flow know very slowly through the perforation, so that this will prevent the know weeping.

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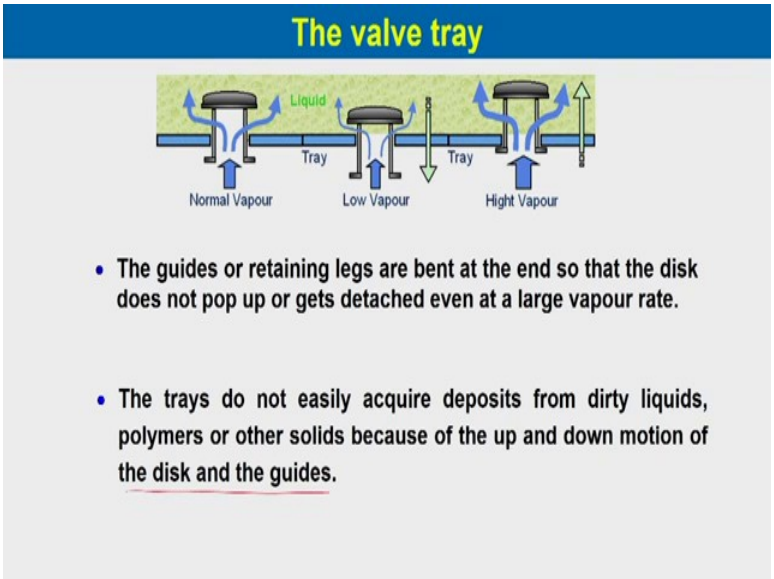


The guides or retaining legs are bent at the end, so that the disk does not pop up or gets detached even it at a very larger vapour flow rate. The trays do not easily acquire deposits from dirty liquids polymers or other solids because of the up and down motion of the disk and guides. So, this helps in this design and also you can have large number of perforations and also, it take cares different low and high viscous liquids.

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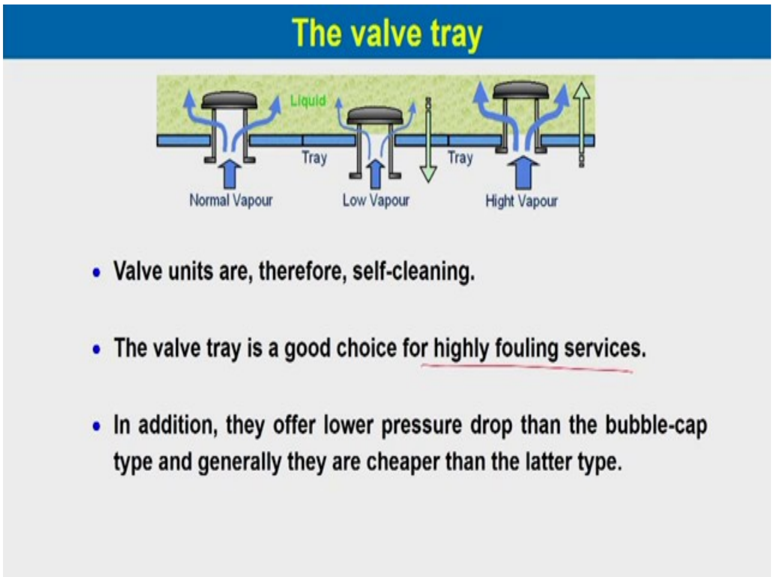

Valves units are therefore self cleaning and the valve tray is a good choice for highly fouling services. So, if some materials will foul in the know perforations this type of valve tray is generally preferred. In addition they offer lower pressure drop than the bubble cap type and generally they are cheaper than the bubble cap.

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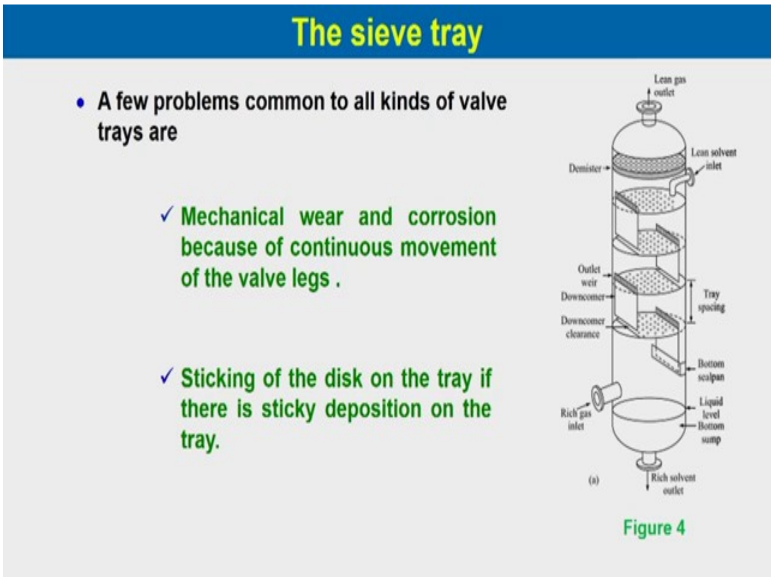


And there are few problems in case of sieve tray we usually encountered so which is also happens not only valve tray, but there are also for different sieve trays as well mechanical wear and corrosion because of continuous movement of the valve legs and sticking of the disk on the tray, if there is a sticky deposition on the tray. So, sometimes because of this there is a sticking of the disk, it may malfunction the know valve tray.

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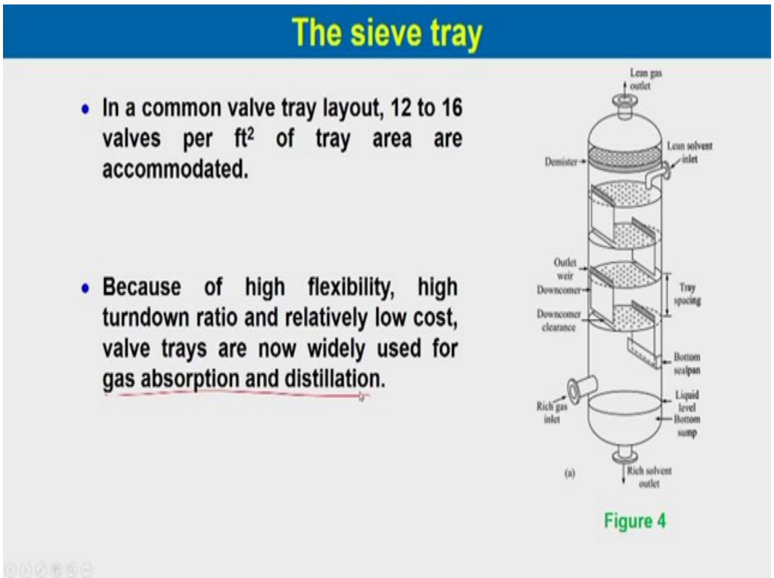


In a common valve tray layout 12 to 16 valves per square feet of tray area are accommodated and because of high flexibility high turn down ratio and relatively low cost valve trays are now widely used for gas absorption and distillation. So, these kind of trays are now widely used.

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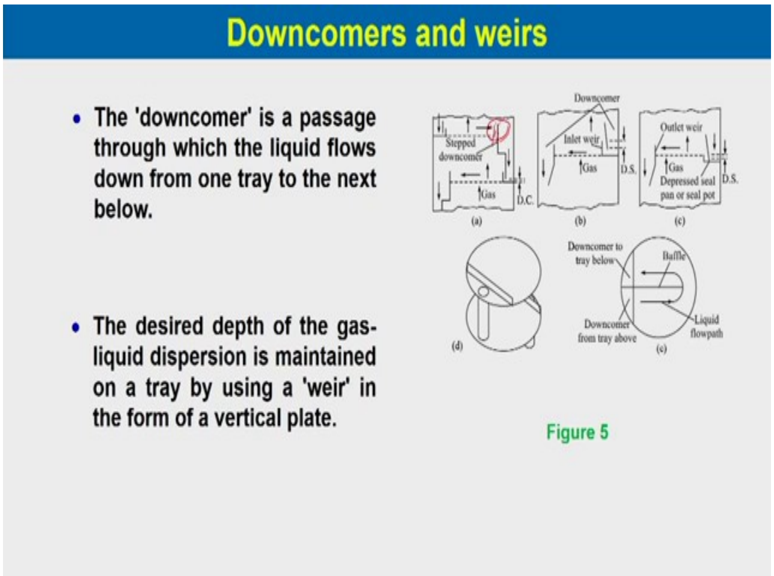


Now, we will discuss down comer and weir. The down comer is a passage through which the liquid flows down from one tray to the next. So, you can see the know over here the gas is now flowing through it and there is, so suppose this is a tray perforated tray and this is the down comer. The desired depth of the gas liquid dispersion is maintained on a tray by using a weir in the form of vertical plates. So, this is the vertical plate which is put over here. So, and this height is properly maintained, so that or the required height is maintained in a based on the liquid depth we wanted to keep.

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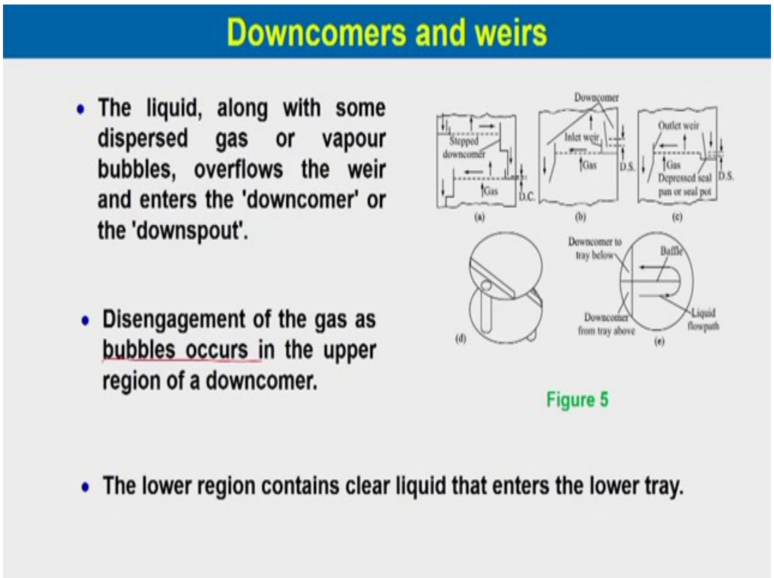


The liquid along with some dispersed gas or vapour bubbles overflows the weir and enters the down comer or the downspout. So, what happens when the liquid entered into a tray, it flows horizontally and then, you have a vertical movement of the gas through the perforation.

So, while liquid flows through the down comer, it takes some of the bubbles as well along with it and it goes to the next tray. This engagement of the gases as bubbles occurs in the upper region of the down comers, so, there is a space which are maintained. We will come later to the tray spacing and then, to the down comers when the liquid flows down with the some gas molecules along with it, gas bubbles along with it the upper part of the down comers there is a disengagement of the bubbles occurs in the lower region contains clear liquid that enters the know enter the lower tray.

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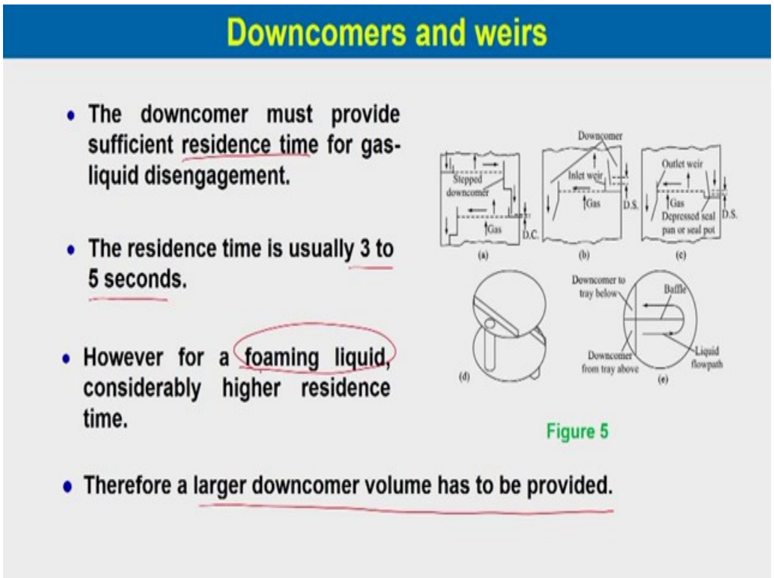


The down comers must provide sufficient residence time for gas liquid disengagement, so that the clear liquid will come to the next stage. The residence time is usually 3 to 5 seconds; however for a forming liquid considerably higher residence time is there.

So, if there is a foaming for the vapour know engagement, we need to have a higher residence time. Therefore, a larger down comer's volume has to be provided. So, for this is particularly for the know foaming liquids.

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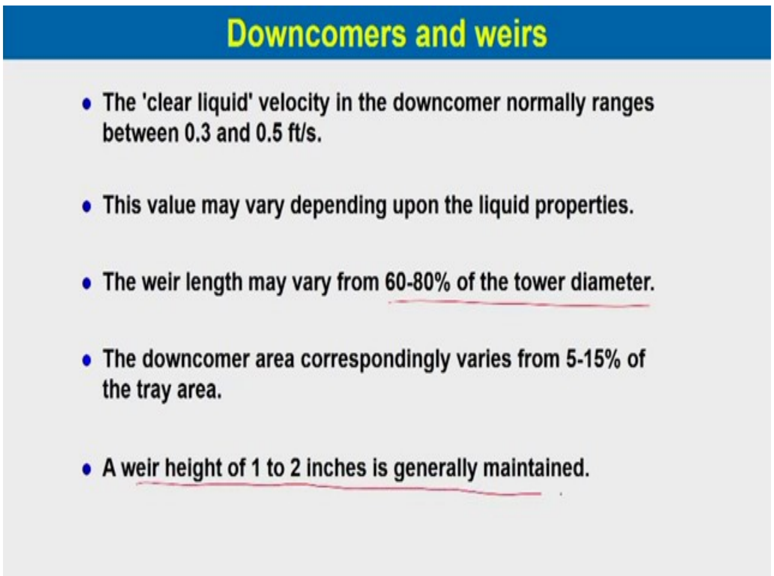

The clear liquid velocity in the down comer normally ranges between 0.3 to 0.5 feet per second. This value may vary depending upon the liquid properties. The weir length may vary from 60 to 80 percent of the tower diameter. So, as we said the tower diameter is generally upto say 10 metre in case of the industrial towers.

So, the weir length it can be as high as 6 metre. The down comer area correspondingly varies from 5 to 15 percent of the tray area. A weir height of 1 to 2 inches is generally maintained. So, it provides the know the liquid level in a particular tray.

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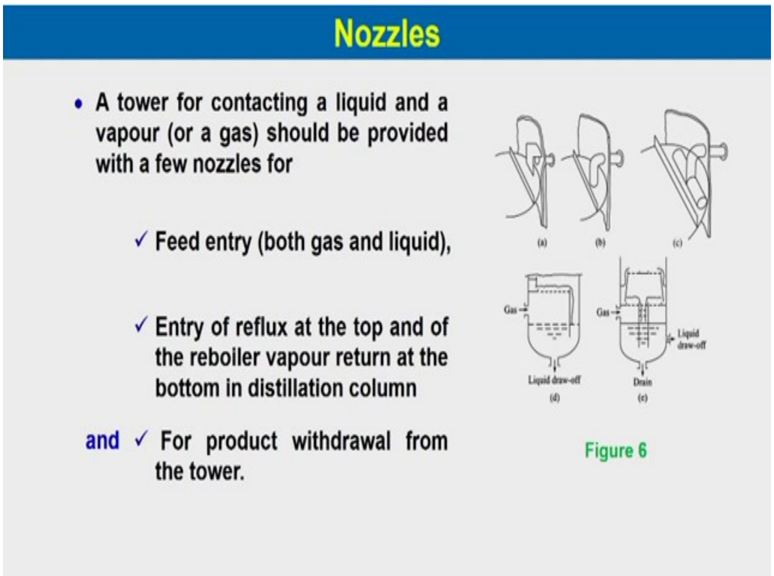


Now, nozzles a tower for contacting a liquid and a vapour or a gas should be provided with a few nozzles for feed entry both gas and liquid and then entry of reflux at the top and the reboiler vapour return to the bottom in a distillation column. So, and also for product withdrawal from the tower, so, for this places we need to have a nozzle at different locations.

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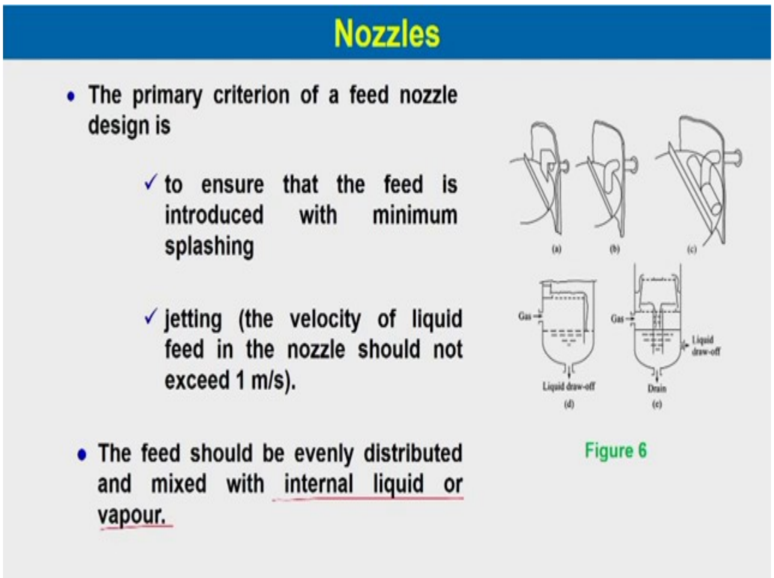


The primary criteria for a feed nozzle design is you can see to ensure that the feed is introduced with minimum splashing. So, if the splashing is more it may not properly distributed throughout the tray jetting the velocity of the liquid feed in the nozzle should not exceed one metre per second the feed should be evenly distributed and mixed with internal liquid or vapour now the velocity of the liquid and the characteristics of the liquid and vapour and the characteristics of the liquid there is a formation of mist in general.

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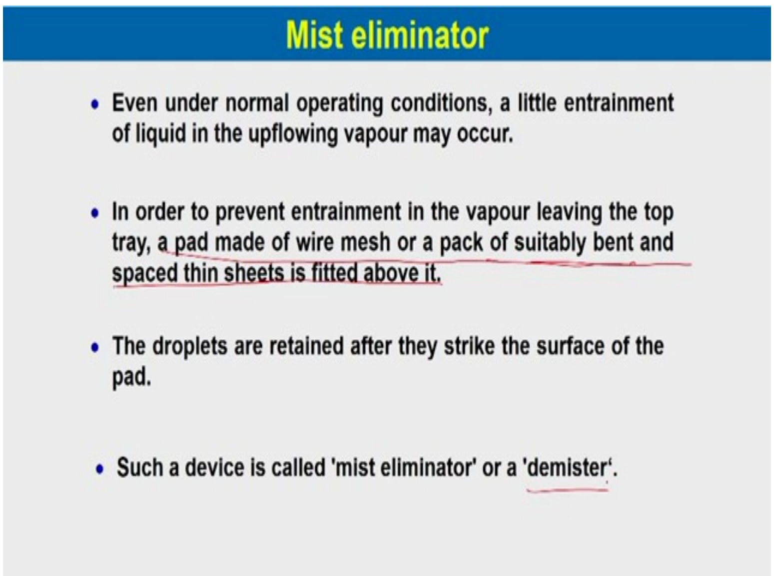

Even under normal operating conditions a little and entrainment of liquid in the up flowing vapour may not occur. So, we need to eliminate those vapour paper which is going through the as entrainment and in order to prevent entrainment in the vapour leaving the top tray a pad made of wire mesh or a pack of suitably bent and spaced thin sheets is fitted above it. So, at the top before going out to the tower there is a know mesh which is where mesh generally put which actually know eliminate the mist to going out. So, is known as mist eliminator.

The droplet are returned after this strike the surface of the pad such device is called mist eliminator or a demister now we will discuss about the operational feature of a tray column.

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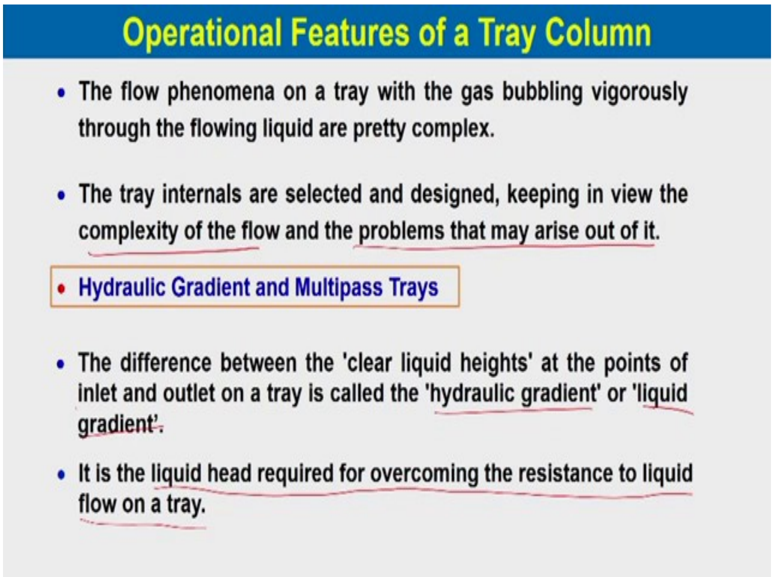


The flow phenomena on a tray with gas bubbling vigorously through the flowing liquid are pretty complex. So, know it is bubbling through the liquid the phenomena is really flow phenomena is really complex the tray internals are selected and designed keeping in view the complexity of the flow and the problems that may arise out of it. So, hydraulic gradient and multipass trays are generally used the difference between the clear liquid height at the point of inlet and outlet of a tray is called hydraulic gradient or the liquid gradient it is the liquid head which is required for overcoming the resistance to liquid flow on a tray.

So, know the liquid has to overcome the resistance and then flow through the down comer. So, there is a particular liquid head or hydraulic head maintained over it.

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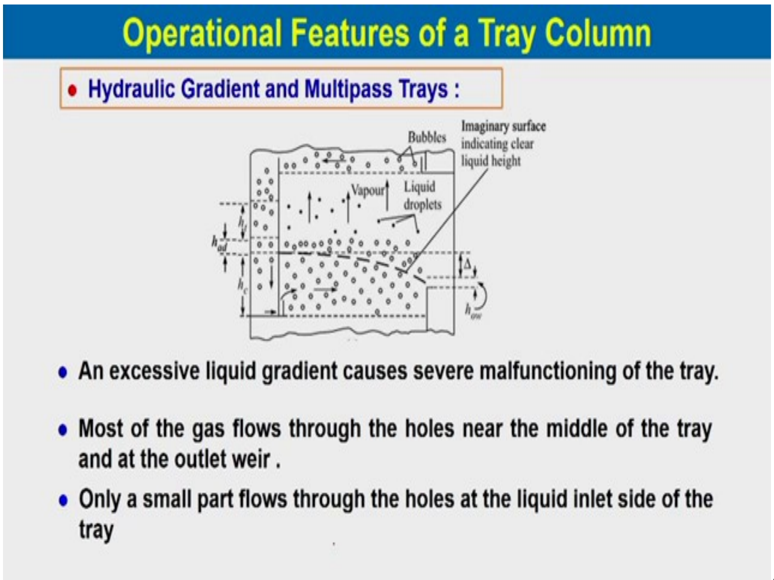


You can see over here there is a imaginary surface an excessive liquid gradient causes severe malfunctioning of the tray most of the gas flows through the holes near the middle of the tray. And at the outlet weir mostly it is through the perforation and sometimes through the weir hole also very small amount of gas flows only a small part flows through the holes at the liquid inlet side of the tray.

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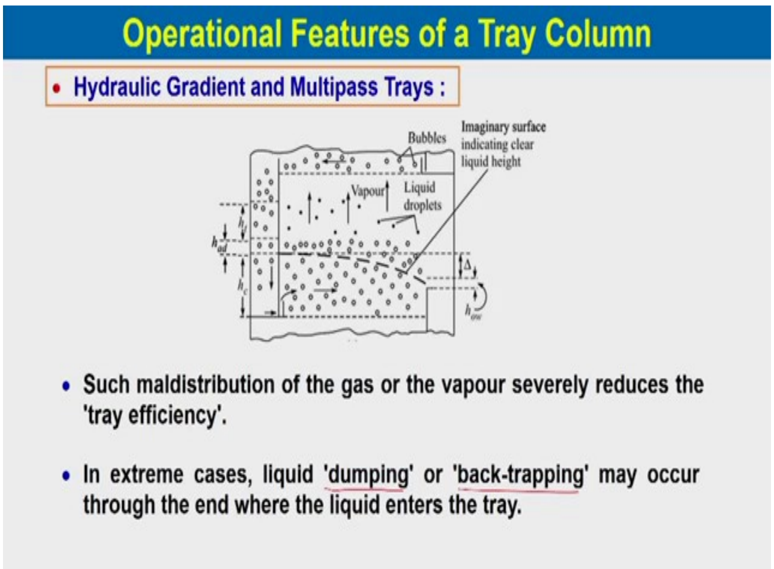

Such maldistribution of the gas or the vapour severely reduces the tray efficiency. So, we need to have a very good know tray efficiency in extreme cases liquid dumping or back trapping may occur through the end where the liquid enters the tray depending on the uneven distribution of the gas and vapour it may severely affect the efficiency and also sometimes the liquid dumping which may occur in the tray through the end where the liquid enters the tray. So, if know this dumping occurs the efficiency also reduces.

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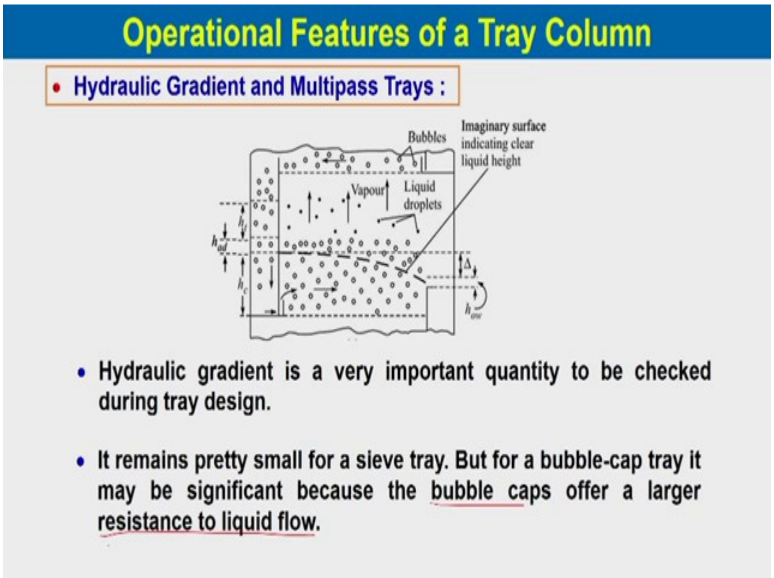


Hydraulic gradient is also very important quantity to be checked the tray design it remains pretty small for a sieve tray, but for a bubble cap tray it may be significant because the bubble caps offer a larger resistance to liquid flow. So, if the resistance is much higher in case of bubble cap tray. So, hydraulic gradient is also important over here, so, because that will severely affect the tower performance.

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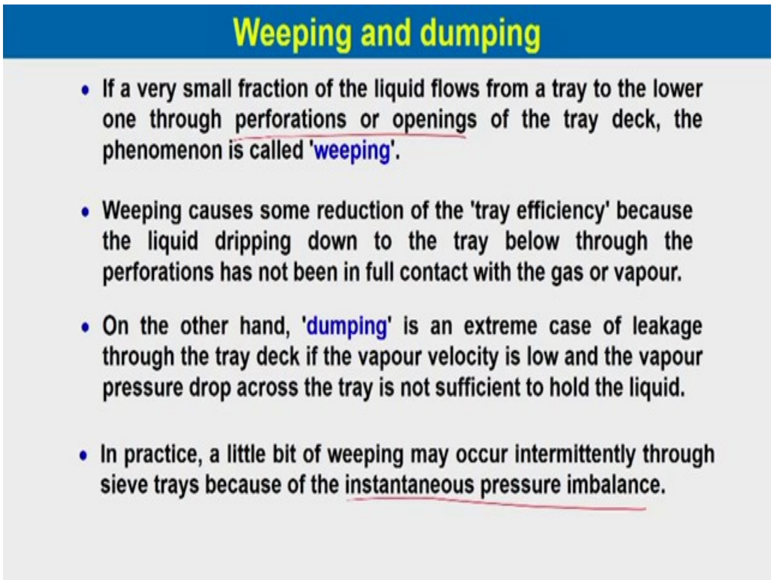


Weeping and dumping if a very small know fractions of the liquid flows from a tray to the lower one through perforation or opening of the tray deck the phenomenon is called weeping.

So; that means, know the liquid usually has to flow through the down comer. So, and liquid the vapour flow or the gas flow should be maintained in such a way that there should not be any liquid fall from the operation of the tray and only the perforation will help the vapour to go up. But if there is small fractions of the liquid flows from tray to the lower one through the perforation or the opening the phenomenon is known as weeping causes some reduction of the tray efficiency because the liquid dripping down to the tray below through the perforation has not been in full contact with the gas and vapour.

So, the intimate contact due to the agitation of the liquid and vapour which happens in a particular tray because of hydraulic gradient it maintains and if it falls down through the opening of the pores what will happen there will know the contact between the gas and liquid will not be so efficient. So, that is why it will reduce the efficiency of the tray performance on the other hand dumping is an extreme case of leakage. So, if the leakage or the liquid which is coming from the tray perforation is used or exchanged then know we call it dumping and which know if the vapour flow it happens when there is very low vapour flow rate and the vapour pressure drops across the tray is not sufficient to hold the liquid.

In practice a little bit of weeping may occur intermittently through the sieve tray because of the instantaneous pressure imbalance if there is a pressure imbalance inside the column instantaneously then intermittently where is a little bit of weeping which may occur usually in different plants or different columns.

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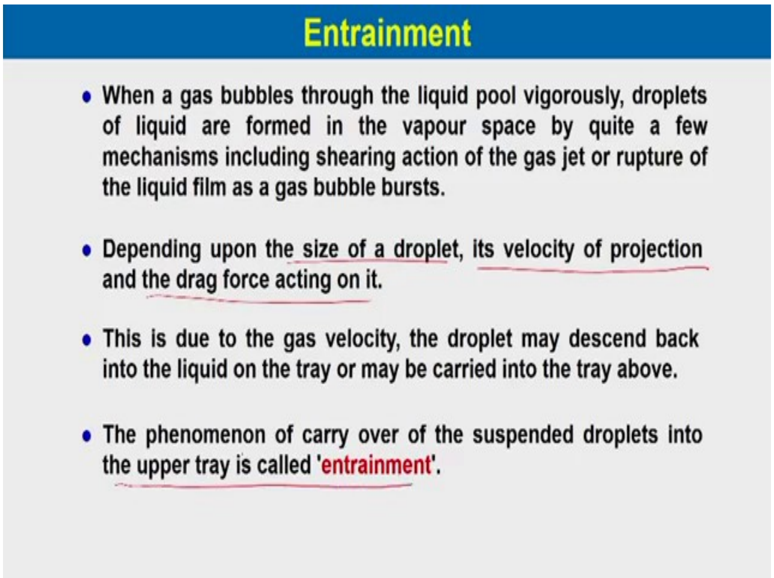


Now, entrainment when a gas bubbles through the liquid pool vigorously droplets of liquid are formed in the vapour space by quite a few mechanisms including shearing action of the gas jet or rupture of the liquid film as a gas bubble burst.

So, depending on the size of the droplet its velocity of projection and the drag force acting on it. So, the above phenomena happens depending on this size of the droplet its velocity of projection and the drag force acting on it. So, on this factors this type of actions may happen if this happens due to this the gas velocity the droplet may descend back into the liquid on the tray or may be carried into the tray above that is why when there is a know very high gas velocity entrainment occurs the phenomenon of carryover of suspended droplets into the upper tray is called the entrainment.

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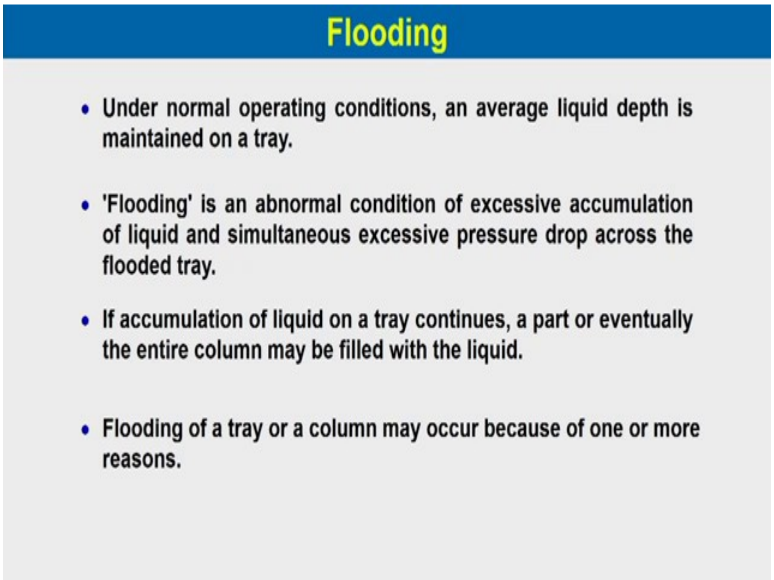


Now, we will discuss flooding. So, under normal operating condition an average liquid depth is maintained on a tray the flooding is an abnormal conditions of excessive accumulation of the liquid and simultaneous excessive pressure drop across the flooded tray.

So, this happens when we have a very low gas velocity if accumulation of liquid on a tray continuous a part or eventually the entire column may be filled with the liquid flooding of a tray or a know column may occur because of one or more reasons.

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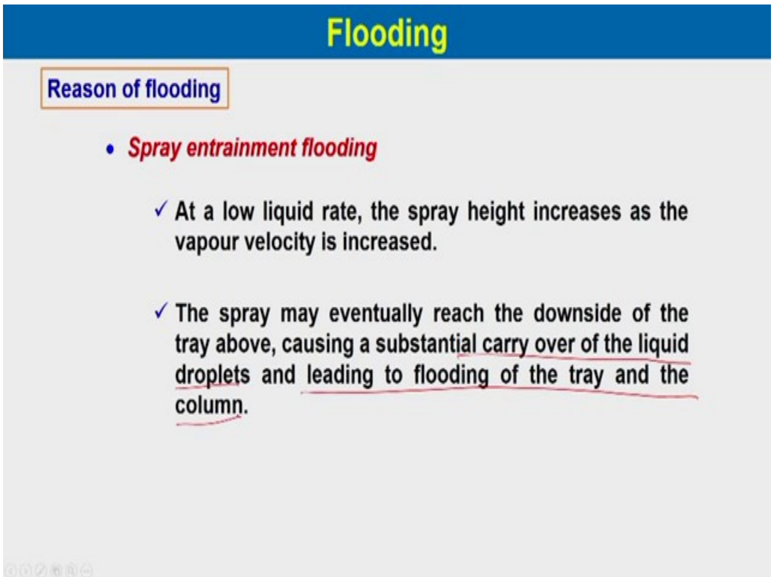

So, one of them is spray entrainment flooding. So, at a very low liquid rate as we said when you have a very low liquid rate, the spray height increases as the vapour velocity is increased. The spray may eventually reach the downside of the tray above causing a substantial carryover of the liquid droplets and leading to the flooding of the tray and the column.

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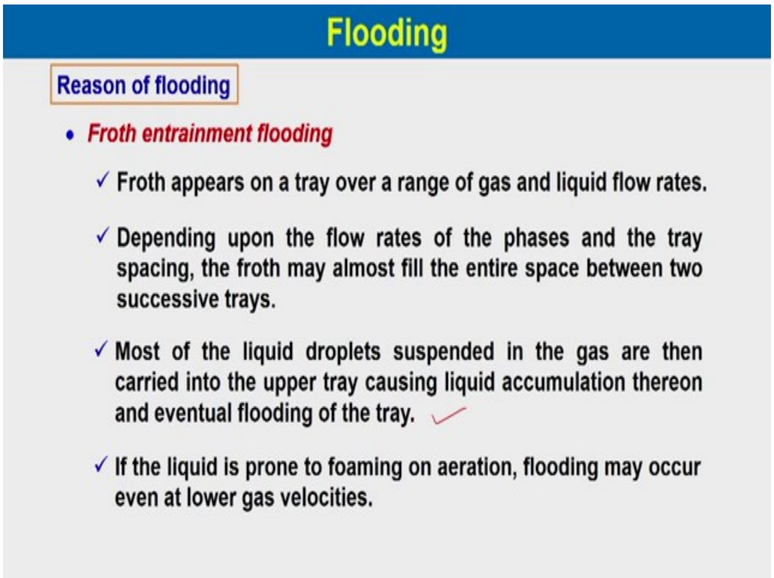


So, spray entrainment flooding may also occur. And next is the froth entrainment flooding. So, if there is no excessive froth; froth appears on a tray over a range of gas and liquid flow rates. So, depending upon the flow rate of the phases and the tray spacing the froth may almost feel the entire space between the successive trays. So, if there is a know blockage due to the froth know formation most of the liquid droplet suspended in the gas are then carried into the upper tray causing liquid accumulation there on and eventual flooding of the tray.

So, excessive know froth entrainment can also cause the flooding of the column if the liquid is prone to foaming or on aeration flooding may occur even at very lower gas velocity.

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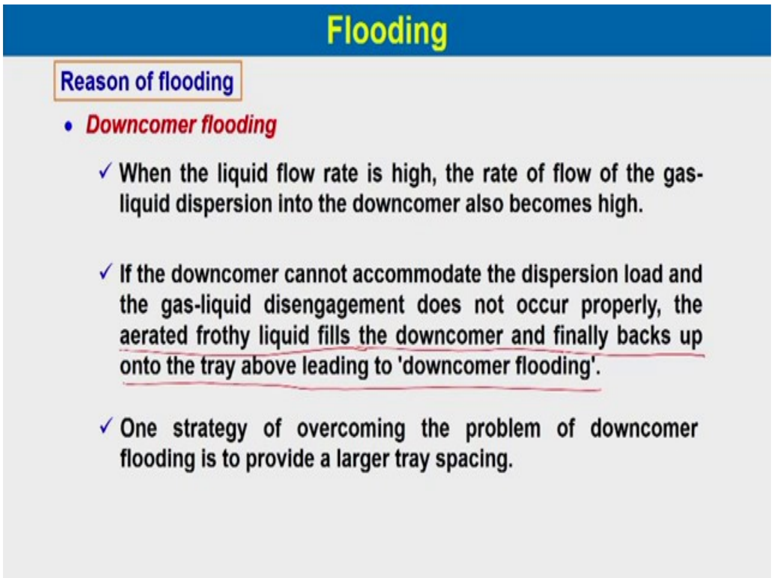


Another is the down comer flooding. So, when the liquid flow rate is high the rate of flow of the gas and liquid dispersion into the down comer also becomes high. So, because of high gas flow rate there will be know vigorous mixing in a particular column and there will be large number of bubbles and which will be carried by the liquid towards the down comer.

If the down comer cannot accommodate the dispersion load and the gas liquid disengagement does not occur properly the aerated frothy liquid fills the down comer and finally, backs up onto the tray above leading to the down comer flooding ok. One strategy of overcoming the problem of down comer flooding is to provide a larger tray spacing. So, if we increase the tray spacing probably that will eliminate the down comer flooding.

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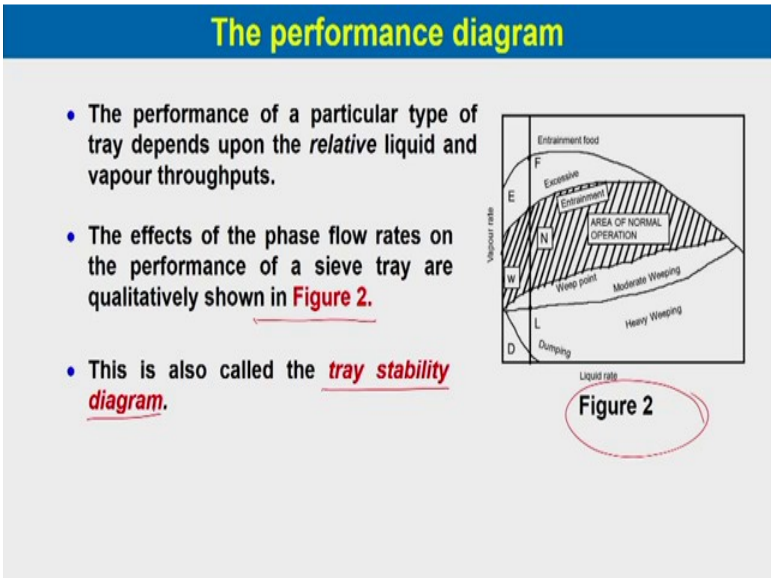


Now, let us see the performance diagram ah. Here you can see the know how the column can perform under different vapour rate and the liquid rate. The performance of a particular type of tray depends upon the relative liquid and the vapour throughput. The effects of the phase flow rate on the performance of a sieve tray are qualitatively shown in this figure over here figure 2. This is also called a tray stability diagram.

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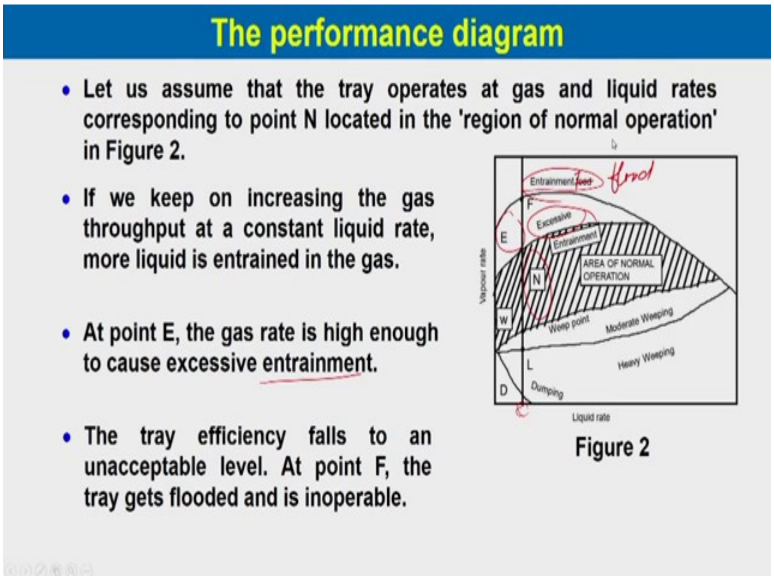


Now, let us assume that the tray operates at gas and liquid rates corresponding to point N. So, at this location in the region of normal operations, so we call it normal operation in this figure and if we keep on increasing the gas throughput at a constant liquid rate. So, let us keep the liquid know rate constant over here and we increase the gas flow rate or the vapour rate. More liquid is entrained in the gas at point E over here, the gas rate is high enough to cause excessive entrainment. So, you will have excessive entrainment over here. Now, the tray efficiency falls to a unacceptable level at point F, the tray gets flooded and is inoperable. So, you can see entrainment flooding and the column will be inoperable.

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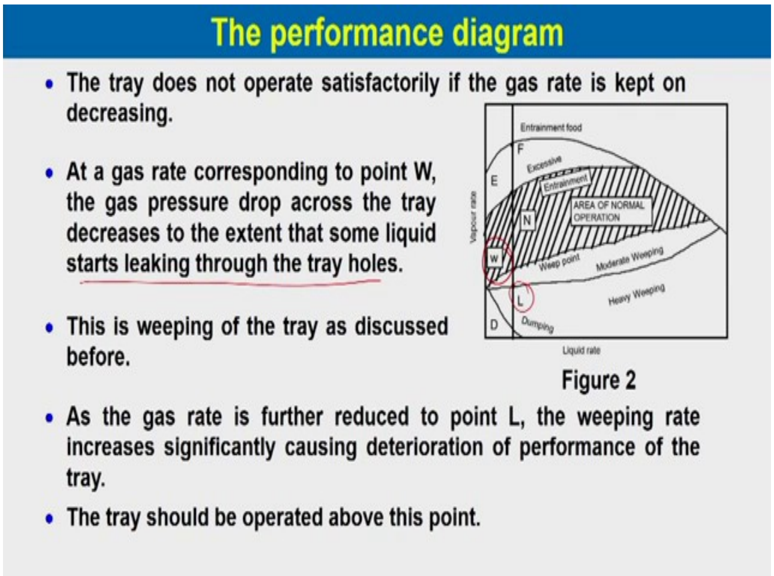


The tray does not operate satisfactorily if the gas rate is kept on decreasing. Now, if we also decrease the gas rate what happens let us see. At a gas rate corresponding to point W over here, the gas pressure drop across the tray decreases to the extent that some liquid start leaking through the tray holes. If that is happens, then we have a weeping. This weeping of the tray as discussed before will happen as the gas rate is further reduced to point L over here.

So, what happens the weeping rate increases significantly causing deterioration of the performance of the tray and the tray should be operated about this point, otherwise dumping will happen or heavy whipping will happen.

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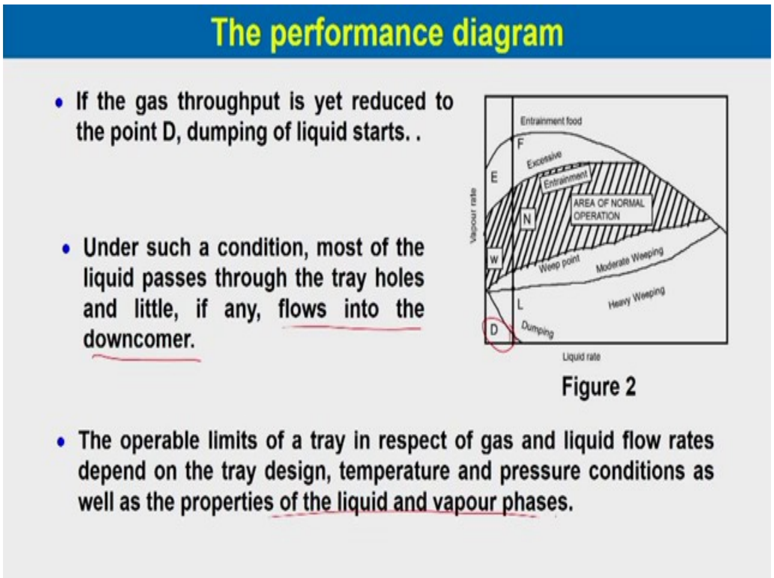


If the gas throughput is yet reduced to point D, dumping of liquid starts, ok. So, in this region so dumping will start. Under such a condition most of the liquid passes through the tray holes and little if any flows into the down comers. So, all the liquids which will come from the top tray will pass through the perforation and it will fall down directly without any flows or little flows through the down comer.

The operable limits of a tray in respect of gas and liquid flow rates depends on the tray design, temperature, pressure conditions as well as properties of the liquid and the vapour phase. So, this will know decide about the operation limit of gas and the liquid.

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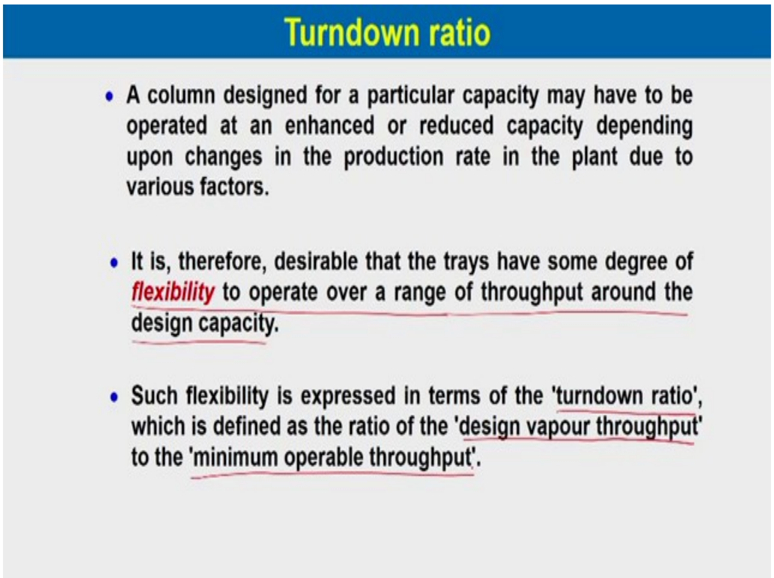


Now, another important thing is the turndown ratio. A column designed for a particular capacity may have to be operated at an enhanced or reduced capacity depending upon the changes in the production rate in the plant. So, due to know various factors, so we need to have an operational flexibility for our design. It is therefore desirable that the trays have some degree of flexibility to operate know over a range of throughput around the design capacity. Such flexibility is expressed in terms of turndown ratio which is defined as the ratio of the design vapour throughput to the minimum operable throughput.

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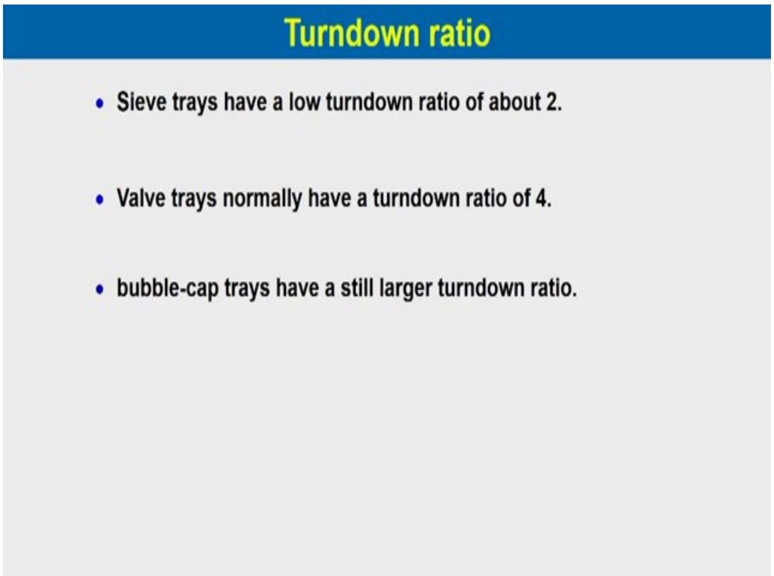

So, turndown ratio for sieve trays have a very low turndown ratio of about 2 for sieve trays, for valve trays normally have a turndown ratio of 4 and bubble cap tray have a still larger turndown ratio.

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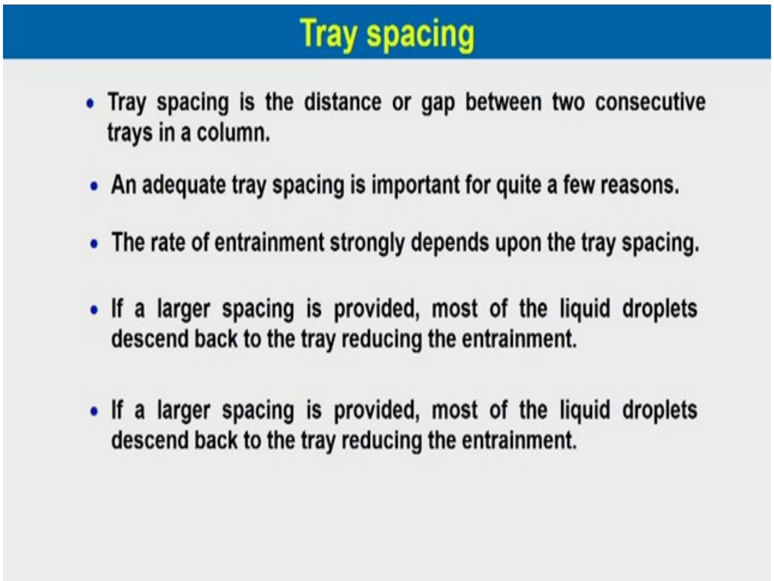


Now, the tray spacing; tray spacing is the distance or gap between the consecutive tray in a column. An accurate tray spacing is important for quite a few reasons.

The rate of entrainment strongly depends upon the tray spacing and as we know the entrainment actually reduces the performance of the tray not only that tray spacing also importance in case of the froth formation and the flooding of the column which greatly reduce to the tray efficiency. If a larger spacing is provided, most of the liquid droplets descends back to the tray reducing the entrainment. If a larger spacing is provided, most of the liquid droplets descend back to the tray reducing the entrainment.

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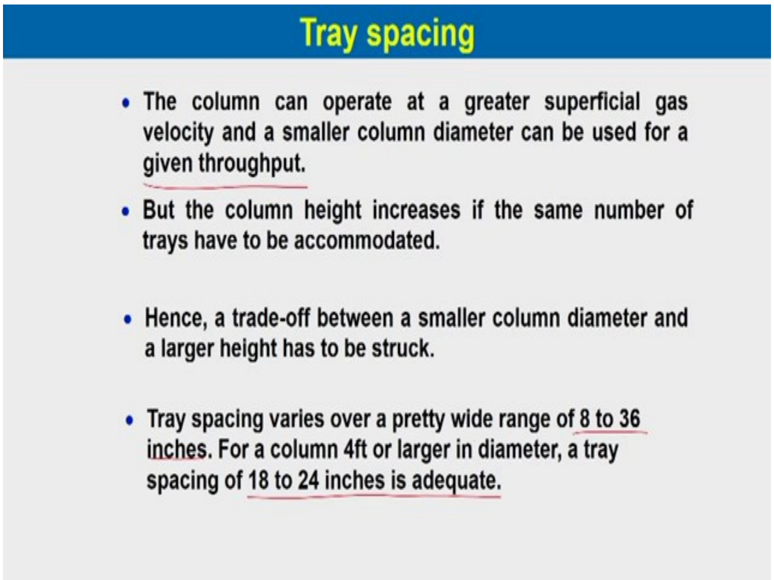


The column can operate at a greater superficial gas velocity and a smaller column diameter can be used for a given throughput, but the column height increases if the same number of tray have been accommodated. Hence a trade off between a smaller column diameter and a larger height has to be struck.

So, we have to optimise the know column diameter as well as the number of trays. The tray spacing varies over a pretty wide range from 8 to 36 inches for a column of 4 feet or larger in diameter a tray spacing of 18 to 24 inches is adequate, so, these are the typical values which is used.

With this thank you for your attention and attending to this lecture. In the next lecture, we will discuss more about the design of the tray column and we will try to solve some problems on this.