**Mass Transfer Operations I**
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Module - 3
Equipment for gas liquid operations
Lecture - 2
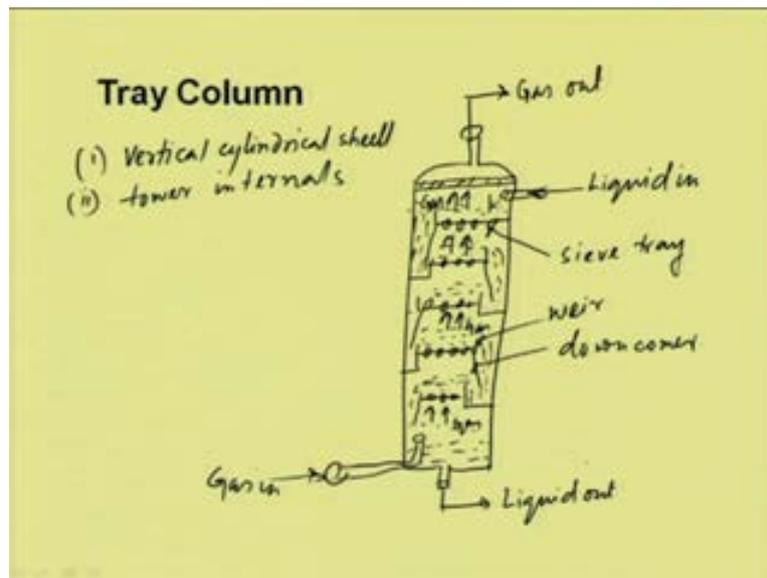**Tray Column (Part 1)**

Welcome to the second lecture of module three. The module three is on equipment for gas liquid operations. In the previous lecture, we have classified the gas liquid equipments into two categories; one is the gas dispersed equipments, and another one is liquid dispersed equipments.

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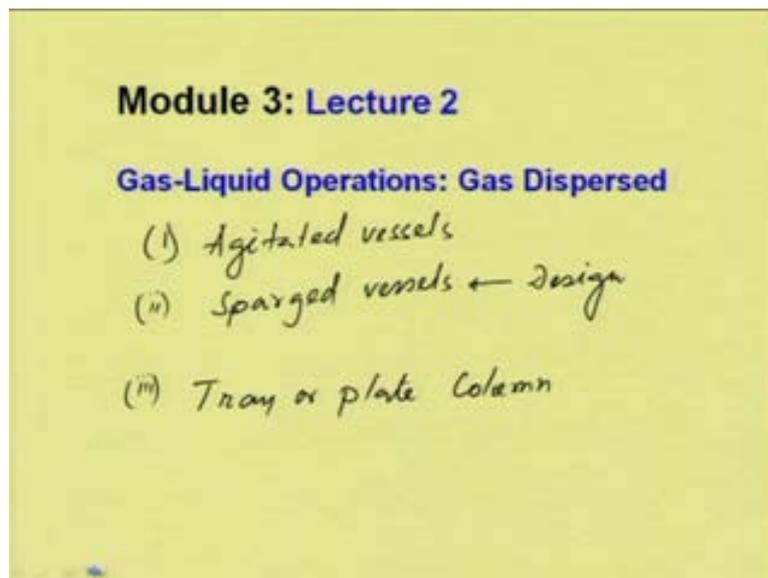
We have discussed in the previous lecture gas dispersed equipment, so particularly we have discussed the agitated vessels and we have also discussed the sparged vessels, and we have seen how to design the sparged vessel. And third equipment under gas dispersed conditions we will discuss the tray column, tray or plate column.

A tray column basically consists of two parts; one is vertical cylindrical shell vertical cylindrical shell and second one is the tower internals tower internals. Let us see the design as we have also discussed earlier in module two, the gas absorption equipment. So, this is a shell where there is a liquid out at the bottom and at the top gas out, so gas inlet is generally at the bottom, gas in. And you have liquid in at the top, so this liquid there is a plate, this is the design for the sieve tray we will discuss soon, so these are the different holes on the sieve plate.

So, this is the liquid in and this is here so this the sieve tray corporated hole and there are there is a pool of liquid and the gas gas is flowing out from each tray and liquid coming down through the down comer, this is known as down comer; these are weirs weir and these are different sieve tray so this is a multi tray towers or we can get cascade system inside the tower tray towers; and there are nozzles through which the liquid and gas are spread to the towers so the in each tray the gas and the liquid are finely dispersed and then they the gas disengaged and flow through the upper tower and the liquid flows through the down comer and comes to the down tray, lower to the tray.
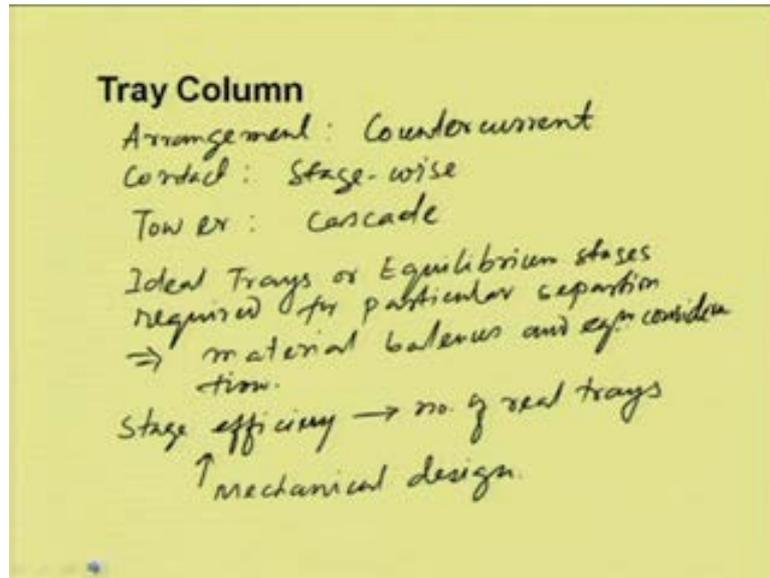
This way the arrangement is counter current; and the contact of the liquid and gas- stage wise and overall it is a tower is cascade arrangement. Now the equilibrium stage for particular tray towers required for a particular separations or the ideal trays or equilibrium stage stages required for particular separation can be obtained from the material balance material balances and equilibrium consideration. So, if we know the stage efficiency then we can calculate the stage efficiency then we can calculate the number of real trays, so the number of real trays we can obtain if we know the stage efficiency and this is obtained by mechanical design, so we will discuss design part.
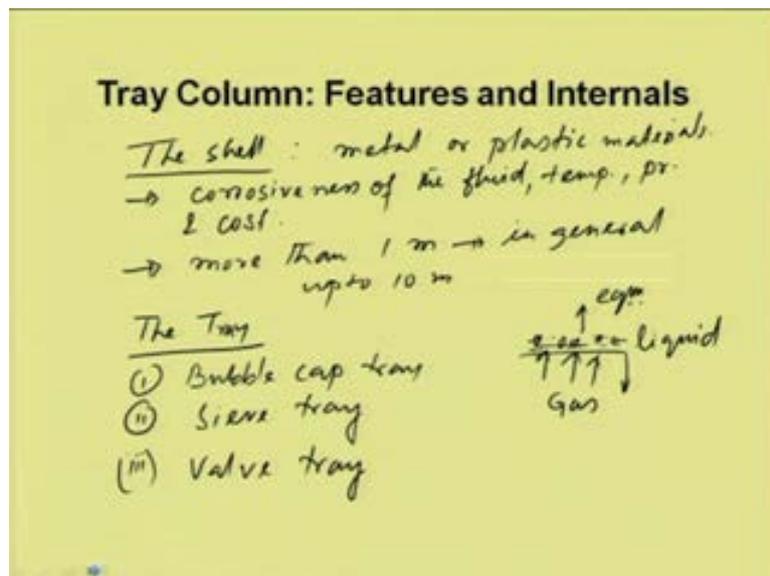
Let us see the different parts of the column which we have discussed, what are their features? First thing is the shell, it is generally made of metal or plastic plastic materials; it is selected based on the properties like corrosiveness of the fluid, temperature, pressure and cost. The diameter of the tower is generally more than 1 meter in general and it is up to 10 metres. There are trays, the tray serve the purpose of the intimate contact between gas and liquid and it acts as a stage, so in each stage the gas and liquid come in intimate contact and so gas bubbles through the liquid and they come in intimate contact; and the liquid out from the tray and the gas out from the tray are in general it is in equilibrium. So there are different types of tray used one is bubble cap bubble cap tray and second type is the sieve tray and third one is the valve tray.

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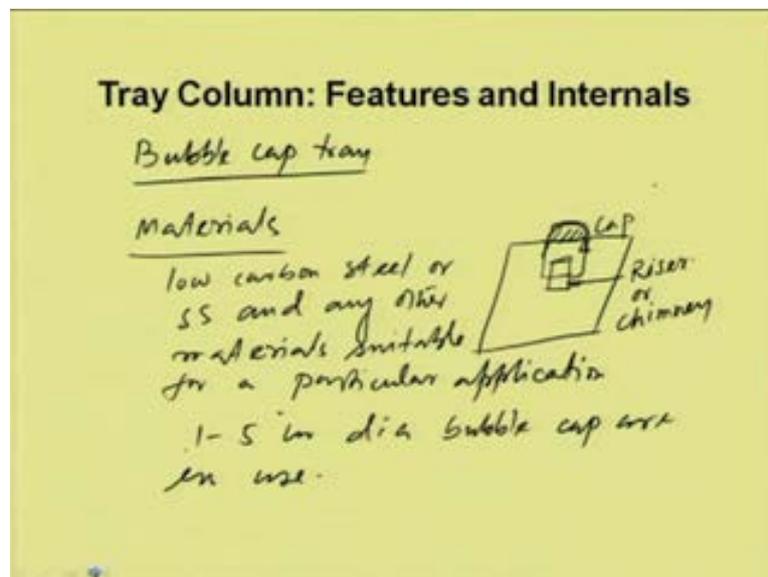
Bubble cap tray, this has two parts- one is this is the plate on which, this is the cap and this is the riser or we call chimney; materials is made of low carbon steel or stainless steel or any other materials suitable for this purpose; the cap diameters are generally 1 to 5 inch dia bubble cap are in use.
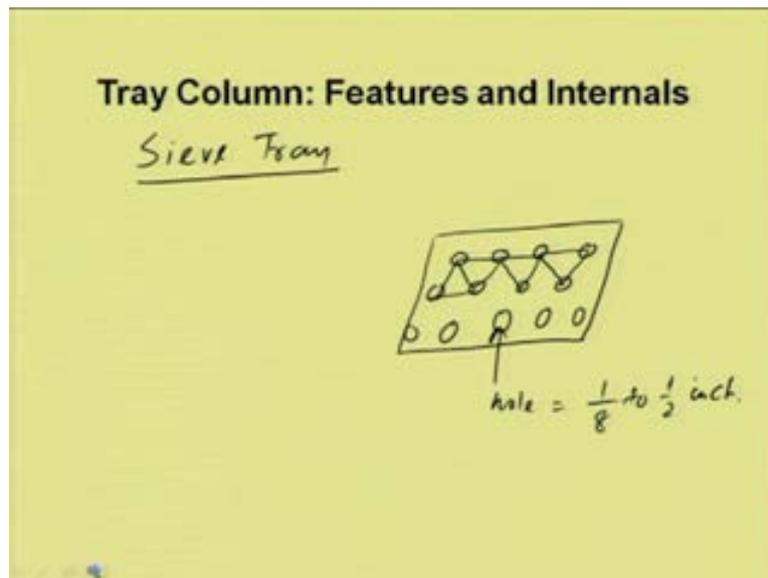
Now another type of tray which is called sieve tray, it is the simplest type of tray; on the plate it is perforated plate and the perforations are usually the triangular shape which are generally used. So this is the perforation hole, this hole diameter is generally 1 8 to half inch; these are very simple design and in common use.
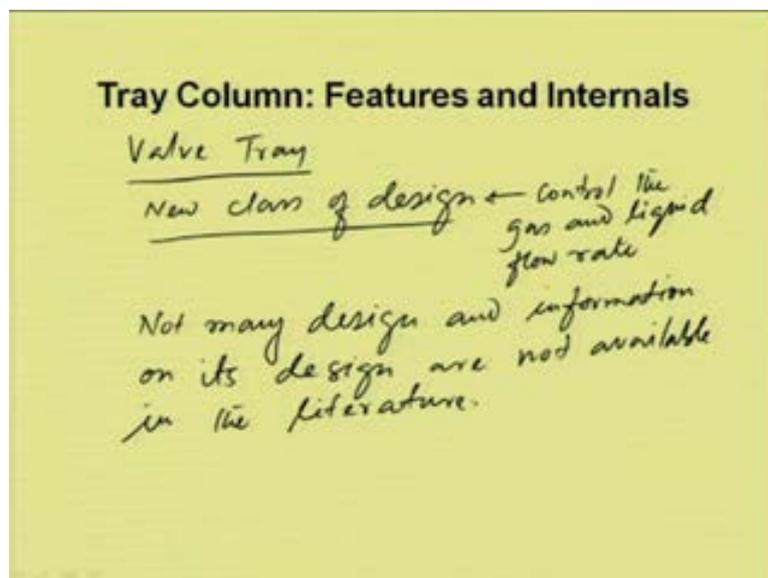
Another type of tray is the valve tray. The valve tray basically is a new class of design and it can control the gas and liquid flow gas and liquid flow rate by appropriate opening of the valve; so these are preparatory items and not many designs are available; design and information on its design are not available in the literature.

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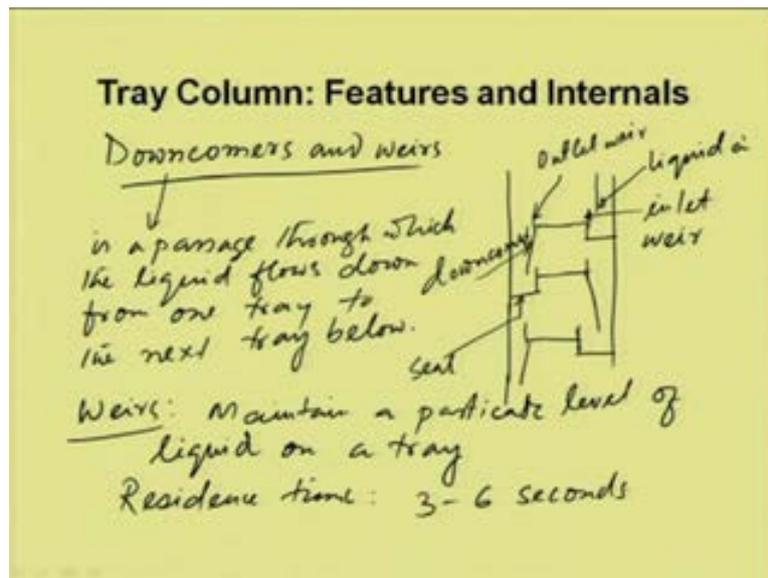
Another important thing for the tray column design is the downcomers and weirs, so as we have seen weirs, so this you say liquid inlet we call liquid in and this is known as the inlet weir, this is outlet weir and this is the downcomer and this one is the seal, liquid seal; so the downcomer basically is a passage through which the liquid flows down from one tray to the next tray below; and the depth weir, basically we use the weir, this maintain a particular level of liquid on a tray, so that the gas bubble through the liquid and there is intimate contact between the gas and liquid; and the residence time of contact between the gas and liquid residence time is maintained between 3 to 6 seconds.
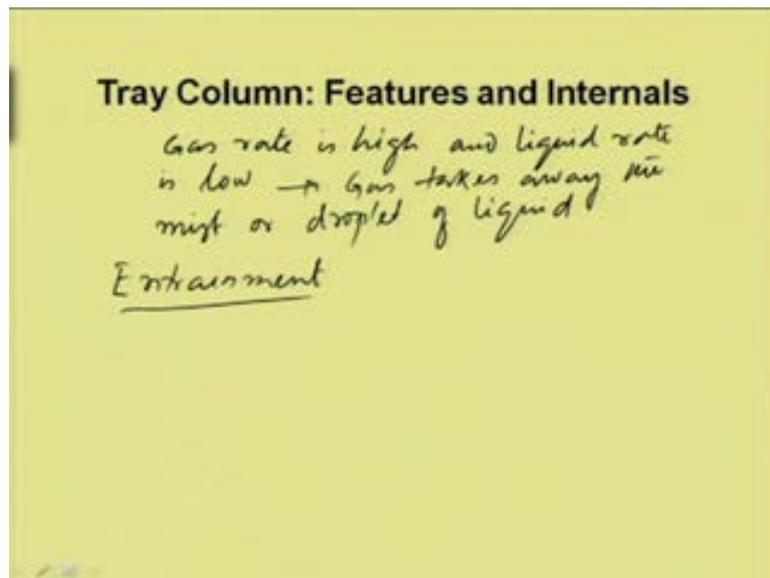
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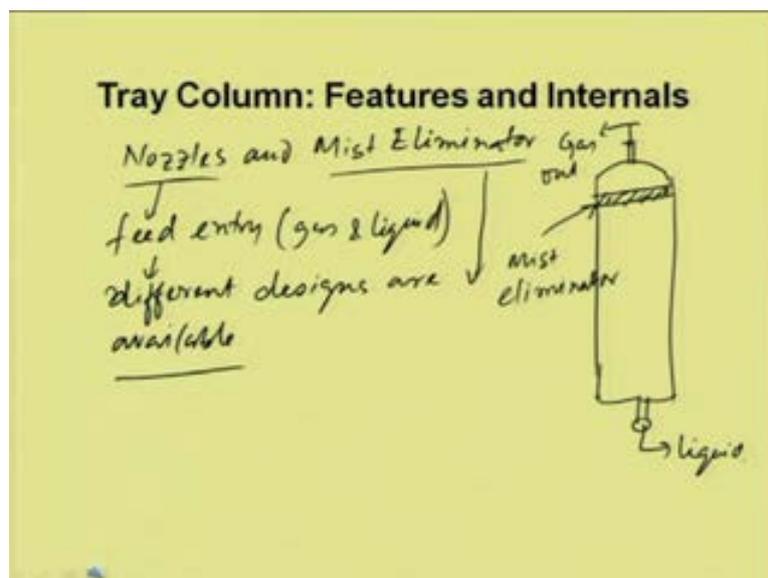
There are some nozzles and mist eliminator; nozzles and mist eliminators. So, nozzles are provided for the feed entry, gas and liquid and there are different types of nozzle designs are available, and as we have seen at the top of the column where the gas gas out. We have above the liquid inlet, there is a little opening where when gases goes through the liquid it takes away some of the mist which will form gas liquid contact in a particular tray and that mist has to be eliminated, so there is a mist eliminator at the top of the column.
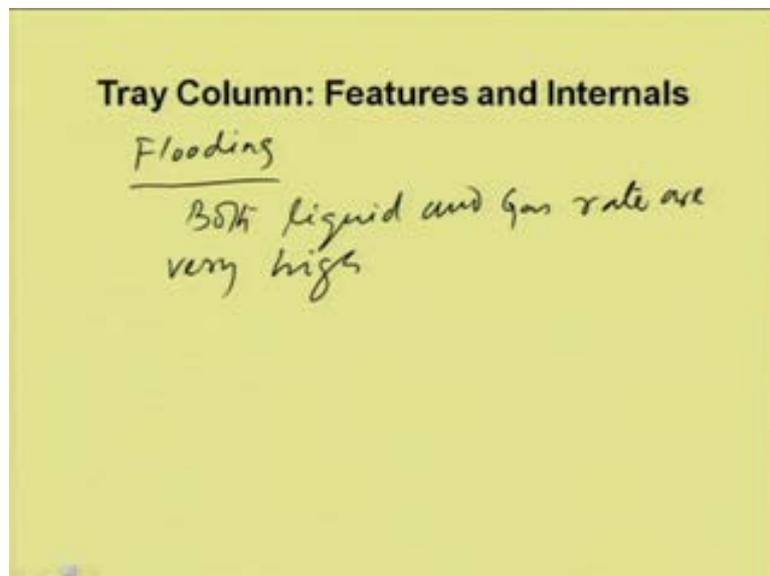
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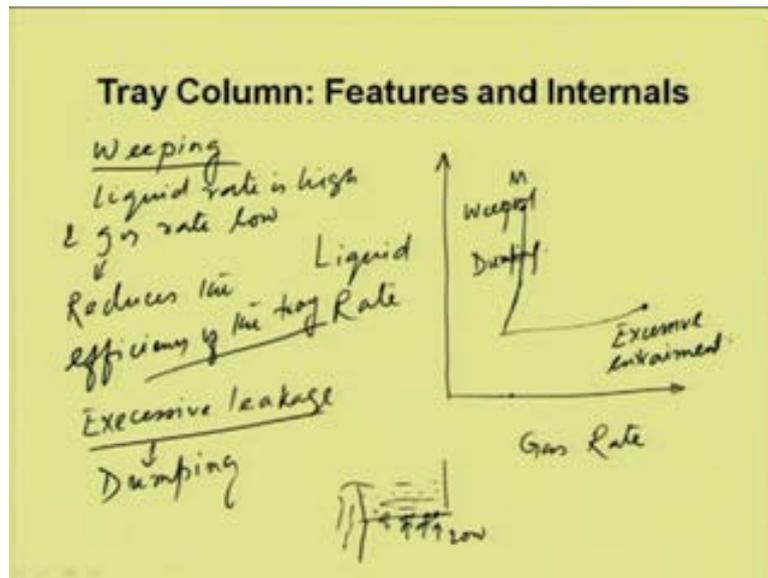
There are some operational problems in case of or features in case of tray columns, so depending on the gas and liquid rate we plot gas rate and liquid rate; for a particular plate if the gas rate is low and liquid rate is high some of the liquid will channel or pass through the holes, in that case we call it is weeping, so suppose this location m so weeping, when liquid rate is high and gas rate is low; and then this reduces the efficiency of the column reduces the efficiency of the tray, because there some of the liquids are not in intimate contact with the gas. Now if there is excessive leakage then we call it dumping we call it dumping, so this is the region we call weeping and this is the region we call dumping.

Tray Column: Features and Internals

Gas rate is high and liquid rate is low → Gas takes away the mist or droplet of liquid

Entrainment

Now if the gas rate is high high and liquid rate is also liquid rate is low low, in that case we have seen the gas takes away the mist or droplet of liquids then we call it entrainment, so the entrainment occurs when the at this location entrainment.

Tray Column: Features and Internals

Flooding
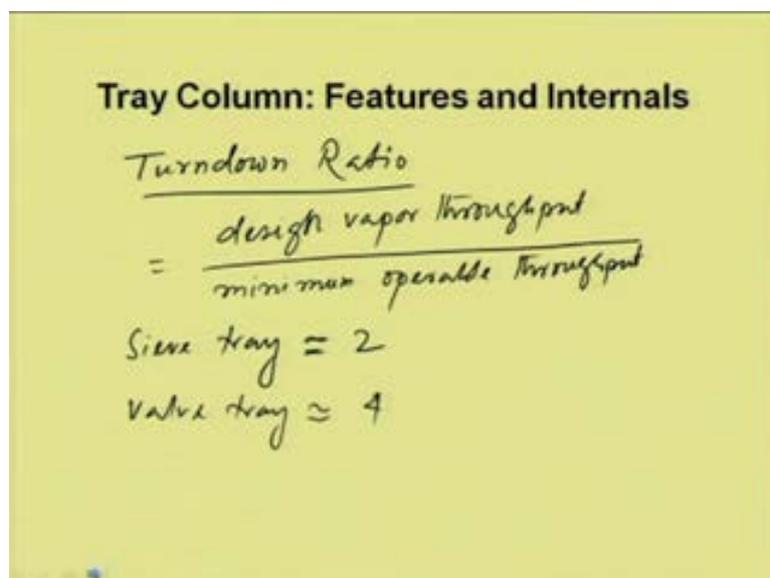
Both liquid and Gas rate are very high

Flooding, when both liquid and gas rate are very high.

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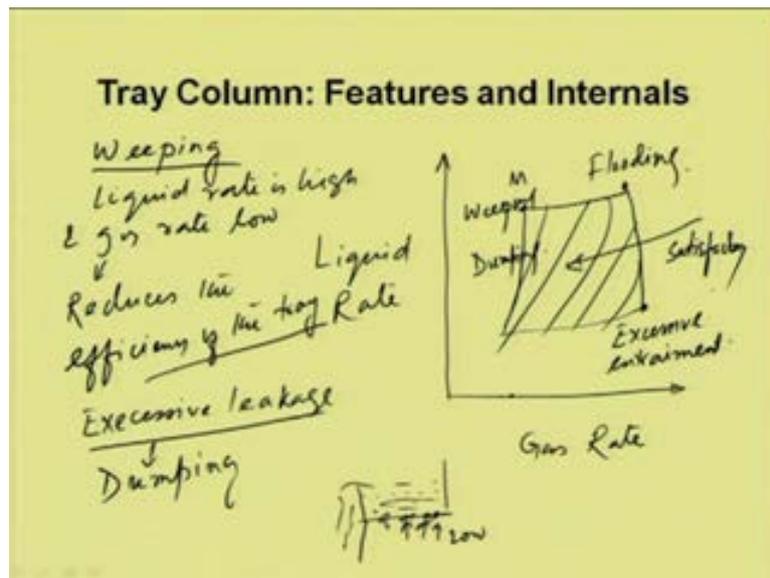
So in that case we can see, so this is the region of flooding, so this is the region were we can operate the column; in this gas flooded region we can operate in the satisfactory region.

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So another important thing of tray tower design is the turn down ratio turn down ratio so this is required to maintain the capacity of operations for a particular tower is depending on our requirement we can increase or reduce the load or capacity of plant; so make it flexibility we defined it on turndown ratio which is equal to the design vapor throughput divided by the minimum operable throughput; sieve tray generally have low turndown ratio is around 2 and in case of valve tray it is around 4.
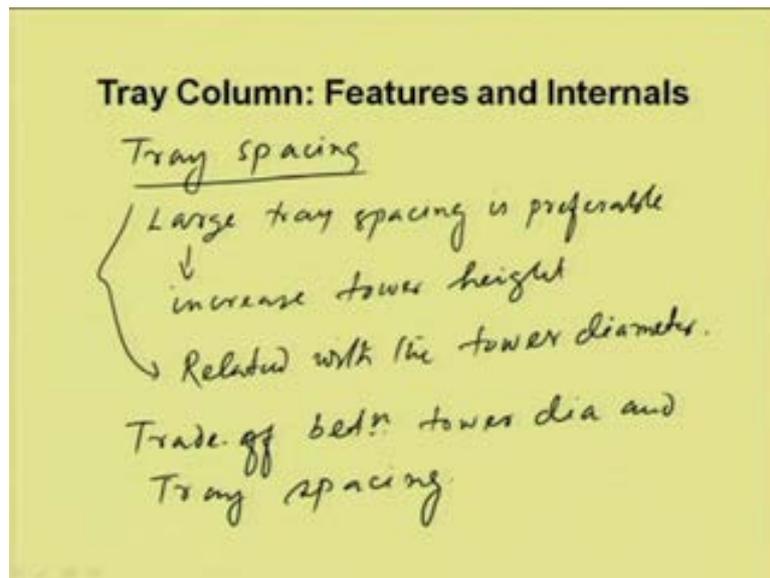
The tray space spacing is an important requirement to operate the column successfully; more tray spacing more tray spacing is better for the space which will be provided for the gas to flow and it is easy to operate or the gas can disengaged from the liquid droplets and the free gas or saturated gas can enter into the next tray, so larger spacing is better; but in this case if we provide large tray spacing is preferable, but increase tower height so there is a trade-off between the, and this tray spacing also related with the tower diameter, so there is a trade-off between tower dia and tray spacing. So we will discuss the recommended values for the tower diameter and the tray spacing in the design part, in the next design part of the tower.
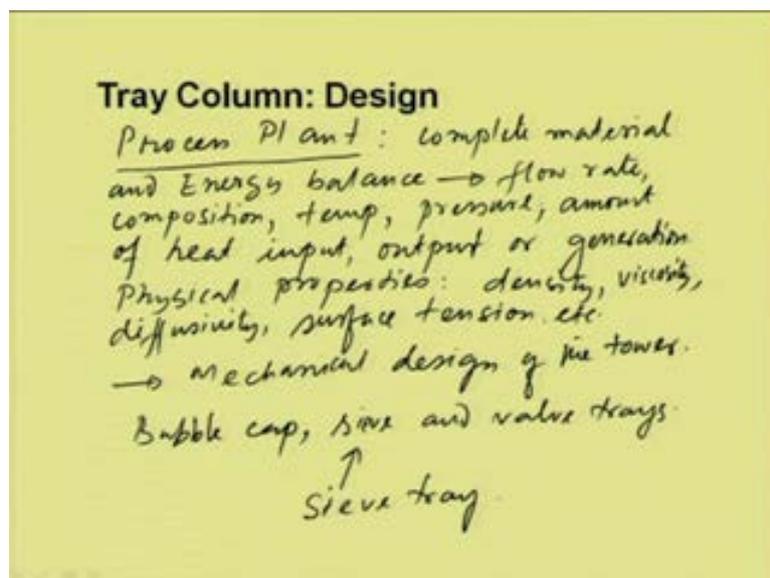
Now we will discuss the design of tray columns; so in a process plant process plant design we need to know complete material and energy balance for this we need the flow rate, composition of the gas and liquid, temperature, pressure, amount of heat input, output or generation; and also we need the physical properties like density, viscosity, diffusivity, surface tension etcetera. So with these values we can design the we can do the mechanical calculations as well. As we discussed there are three types of trays: bubble cap, sieve and valve. So here we will discuss the design of sieve tray which is very simple, sieve tray design.

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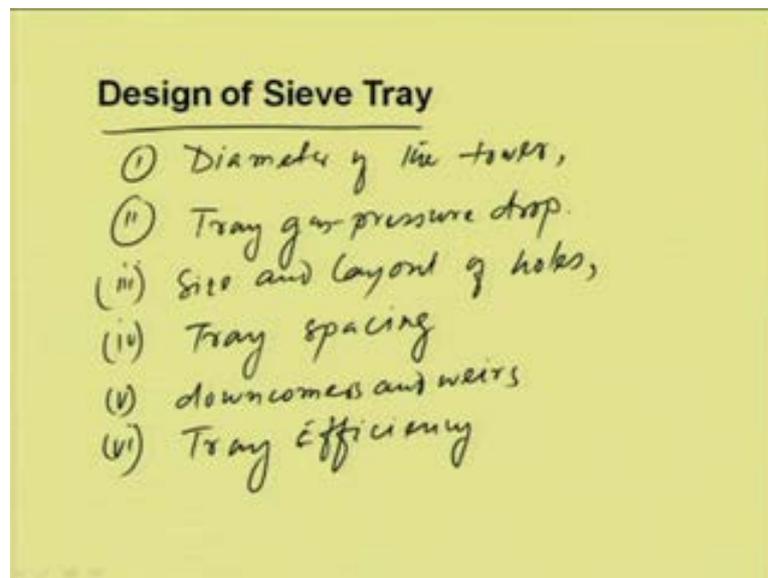
So the important part for the sieve tray design we need to know diameter of the tower, second thing we need to know the tray gas pressure drop, then size and layout of holes, tray spacing, downcomer and weirs, and tray efficiency; this we will discuss one by one.
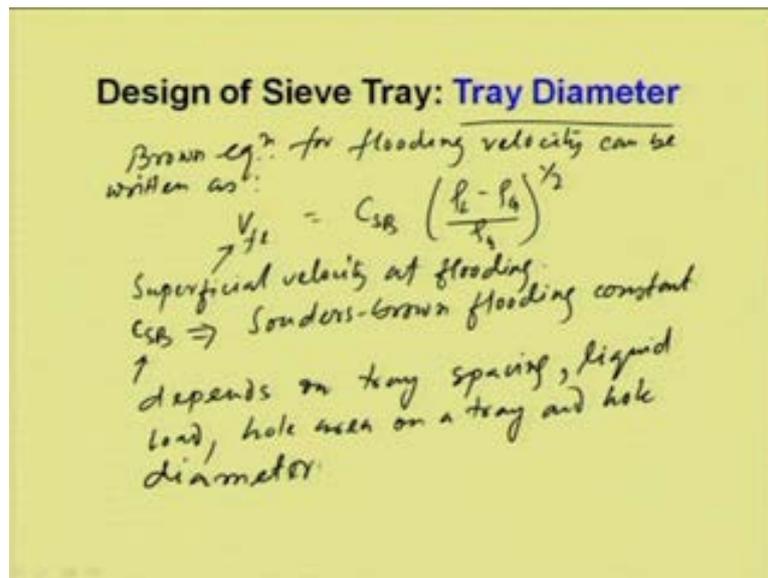
Let us consider how to design the diameter of a particular column. Tray diameter can be calculated based on the floodings considerations and the Brown equation for flooding velocity can be written as V f l is equal to C s B rho L minus rho G by rho G to the power half; this is the superficial velocity at flooding. C s B this is the souder-brown flooding constant, in general this is not the constant it depends on tray spacing, liquid load, hole area on a tray and hole diameter.
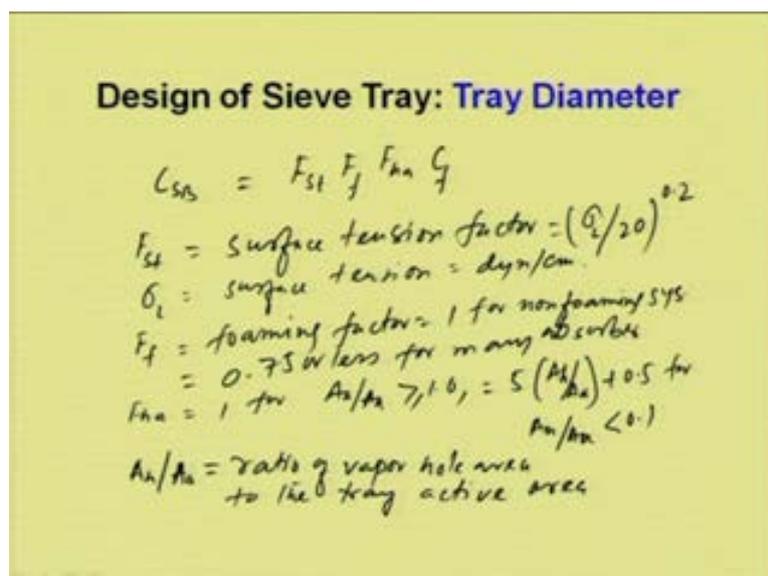
This C s B the empirical constant we can calculate, C s B is equal to F s t capital F f F h a and C f, where F s t is equal to surface tension factor which is equal to sigma L divided by 20

to the power 0.2; sigma L is the surface tension it is in dyn per centimetre; F f is the foaming factor which is equal to 1 for non foaming system and equal to 0.75 or less for many absorber; F h a is equal to 1 for A h by A a greater than equal to 1.0 and it is equal 5 A h by A a plus 0.5, for A h by A a less than 0.1; so A h by A a is equal to ratio of vapour hole area to the tray active area.

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Design of Sieve Tray: Tray Diameter

$$c_f = \alpha \, \log\!\left(\frac{1}{m}\right) + \beta$$

$$\alpha = 0.0744 \, t_s + 0.01173$$

$$\beta = 0.0304 \, t_s + 0.015$$

$$m = \text{flow parameter} = \left(\frac{L'}{G'}\right)\left(\frac{\rho_L}{\rho_G}\right)^{0.5}$$

$$t_s = \text{tray spacing, } m$$

$$D_t = \left(\frac{4\,Q_G}{f\,v_{fl}\left(1 - \frac{A_d}{A_t}\right)\pi}\right)^{1/2}$$

$$\frac{A_d}{A_t} = \begin{bmatrix} = 0.1 & \text{for } m \le 0.1 \\ = 0.1 + \frac{m - 0.1}{9} & \text{for } 0.1 < m < 1.0 \\ = 0.2 & \text{for } m \ge 1.0 \end{bmatrix}$$

And then we can calculate c f is equal to alpha log 1 by m plus beta; alpha is equal to 0.0744 t s, t s is the tray spacing plus 0.01173; and beta is 0.0304 t s plus 0.015; and m is equal to flow parameter which is equal to L dash by G dash into rho L by rho G to the power 0.5; and t s is the tray spacing in meter, if value of m is in the range of 0.01 to 0.1 then it is recommended that m is can be used as point 1 in the above equation. So, then we can calculate the diameter of the tower as 4 Q G, Q G is the volumetric flow rate of the gas, f v f l into 1 minus A d by A t into pi to the power half and it is suggested that A d by A t is equal to is equal to 0.1 for m less than equal to 0.1, is equal to 0.1 plus m minus 0.1 by 9 for m greater than equal to 0.1 and less than 1.0 and it will be 0.2 for m greater than equal to 1.0.

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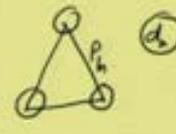
Now in most of the sieve tray the holes are placed in a equilateral triangular pitch, so this is the pitch length and the diameter of each hole is d h, then A h by A a we can write pi by 4 sine 60 d h by P h to the power square, so this will be equal to 0.907 d h by P h square.

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Now for downcomer geometry we have said, this is the r is equal to d t by d 2 and this is length of the weir L w r and this is the angle theta and this is the height between the weir from the centre of the tower this is r w r; so l r L w r is the weir length, A d as we said down spot area tower cross-sectional area; rwr is the distance of the weir from the centre of the

tower. Then we can write A d by A t is equal to theta minus sin theta by twice pi and L w r by D t tower diameter is sin theta by 2 and r w r by D t is equal to half cos theta by 2.

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Design of Sieve Tray: Tray Diameter

Less than 60 cm → Generally packed col^n

Dia, D_t, m	Spacing, t_s, m
1 or less	0.5
1 to 3	0.6
3 to 4	0.75
4 to 8	0.9

If the diameter calculated from the given equations is less than 60 centimetre, then generally packed column may be in use. So as we said there is a relations between tower diameter and the tray spacing so dia, dt in meter and spacing, t s in meter if it is 1 or less than 0.5; if it is 1 to 3 then it is 0.6; if it is 3 to 4 then it is 0.75 and 4 to 8 it is generally 0.9, so these are the recommended values for the tray spacing and tower diameter.

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Design of Sieve Tray: Tray Diameter

Calculation Procedure

(i) Guess t_s = Say 0.6 m

(ii) Calculate, D_t

(iii) Check the value in the table for D_t and t_s ⇒ modify and repeat the calculation to obtain new D_t

(iv) Repeat the procedure untill the convergence according recommed values in Table is achieved.

So the calculation procedure, it is an iterative procedure first we have to guess t s, that is tray spacing say 0.6 meter and then calculate D t tower diameter and then check the value in the table for D t and t s; modify and repeat the calculation to obtain new D t value. And then repeat this procedure until the convergence according to the recommended values in the table is achieved. So, this iterative process has to be done until unless we receive achieve the recommended values given in the table. So this we will discuss with an examples how to calculate by the iterative procedure in the next class.

Thank you.