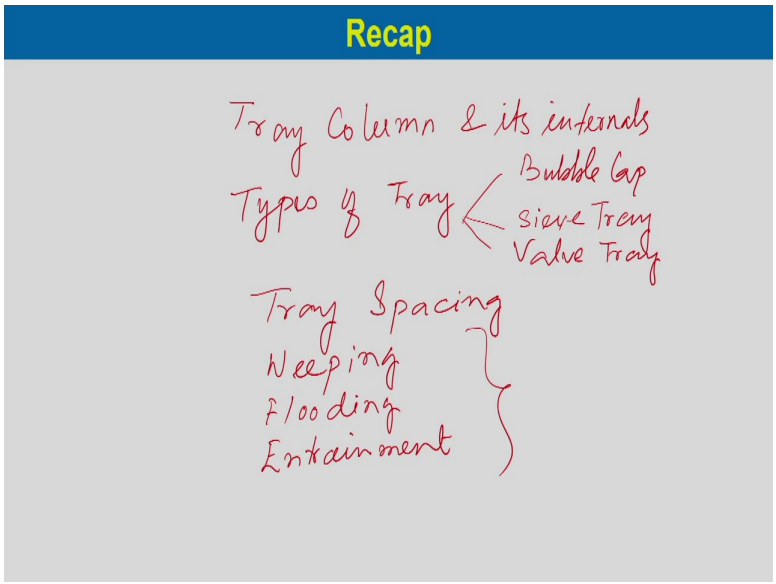
Mass Transfer Operations-I
Prof. Bishnupada Mandal
Department of Chemical Engineering.
Indian Institute of Technology, Guwahati

Lecture – 19
Sieve Tray

Welcome to the third lecture on module 3 on Mass Transfer Operation. In this module, we are discussing equipment for gas liquid operations. So, before going to the next lecture let us have recap on our previous lecture. In our previous lecture, we have mostly considered the tray column and its different internals.

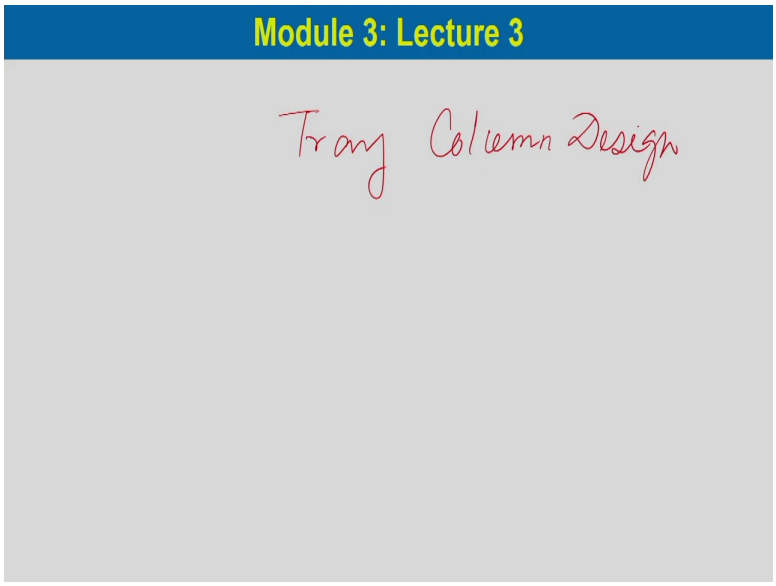
(Refer Slide Time: 01:01)



So, we considered tray column and we have seen how the tray column looks like, its different types of tray and under which we have seen there are three different types of tray generally used one is bubble cap, then sieve tray and then valve tray.

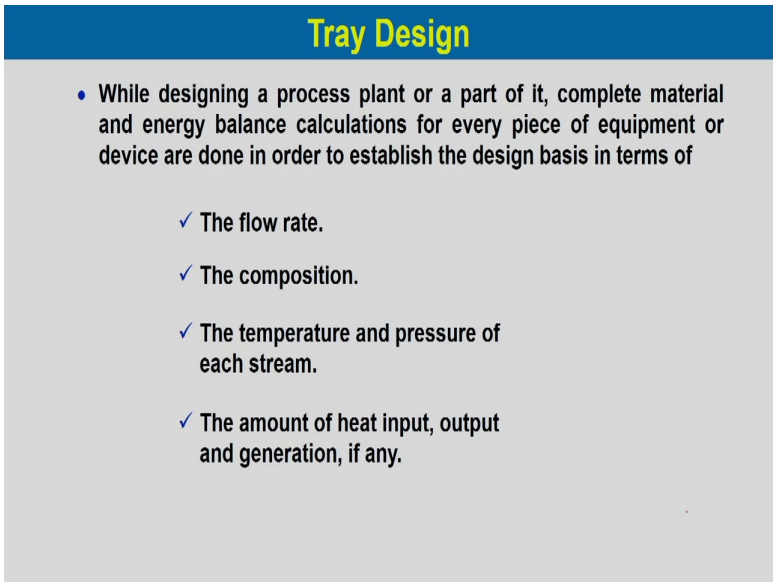
So, valve tray is a proprietary trays which are used for tray column, but bubble cap and sieve tray they have detail information are available in the literature for their design and then we have seen what are the different conditions happens or occurs in a tray column when we change the gas and liquid flow and how the flooding, entrainment that occurs. So, we have also discussed about the tray spacing and weeping, flooding, entrainment so and we have seen how to take care of these parameters.

(Refer Slide Time: 02:59)



In this lecture module 3, lecture 3 we will continue our tray column design. So, we will see how to design a tray column. So, tray column design we will considered in under this know lecture.

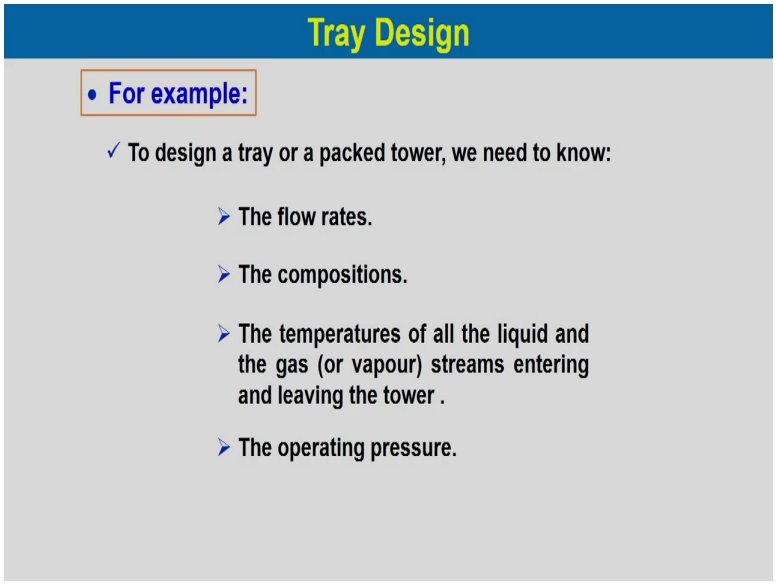
(Refer Slide Time: 03:17)



While designing a process plant or a part of it complete material and energy balance calculation for every piece of equipments are required and this can be established for the design only when we have certain parameters in our hand; one of them is the flow rate is known to us. Then we need to know the composition of the mixture both for the liquid

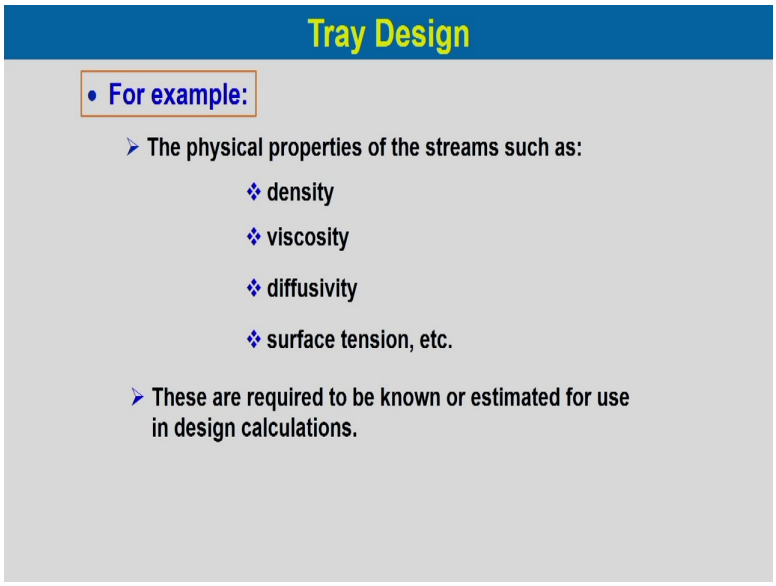
phase composition and the gas phase composition. The temperature and pressure of each stream both the gas and the liquid stream, each stream we should know the temperature and pressure condition. The amount of heat input, output and generation if any because of any chemical reactions or so; so this parameters should be available to do the detail materials and energy balance for a particular process plants.

(Refer Slide Time: 04:19)



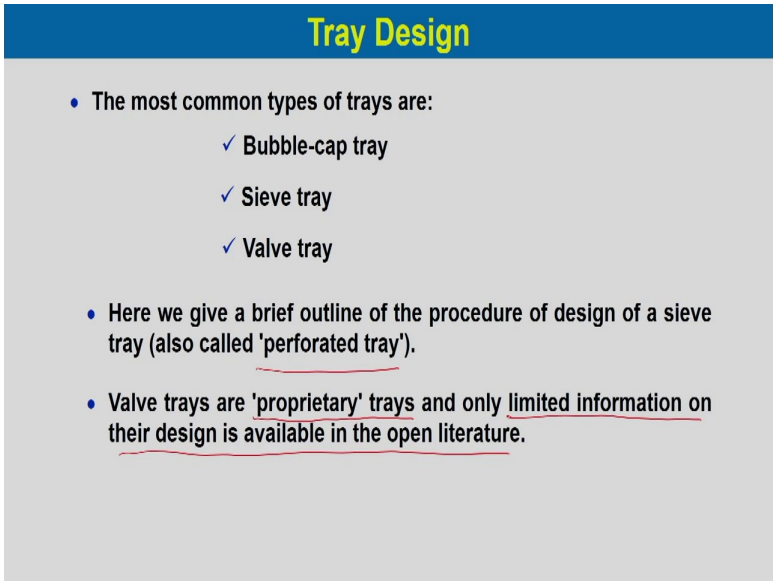
For example, if we take a tray or a packed tower we need to know the flow rates, the compositions, the temperature of all liquids and the gas or the vapour streams entering and leaving the tower and then the operating pressure; so these are required.

(Refer Slide Time: 04:43)



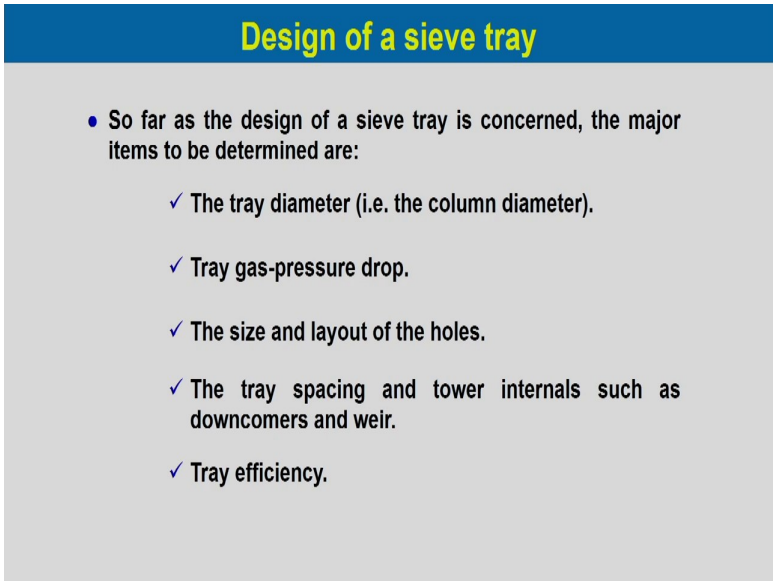
The physical properties of the stream are also required such as density, viscosity, diffusivity, surface tension etcetera. These are required to be known or estimated for use in design calculation. So, the physical properties either has to be available in the literature or has to be estimated which will be used in the design calculation. So, if it is a unknown solvent, an unknown gas, unknown liquid mixture this properties has to be measured or a know estimated using certain empirical correlations.

(Refer Slide Time: 05:23)



The most common type of trays are bubble cap tray, sieve tray and valve tray. So, these we have already introduced in the last class. So, under this trays; we give a brief outline of the procedure of design of sieve tray which is called the perforated tray. Valve tray as you said it is a proprietary trays and only limited information on their design is available in the open literature as far as the design is concerned we will outline on the sieve tray because the design parameters for the proprietary trays like valve trays are not much available in the open literature.

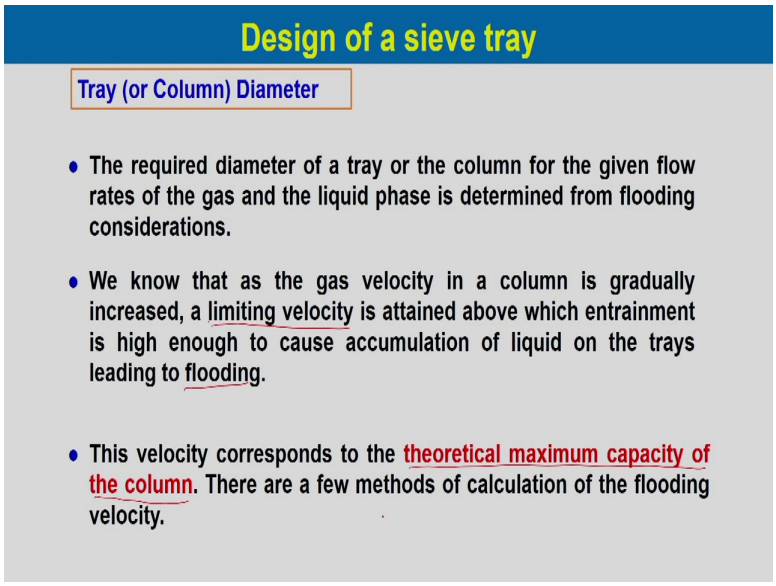
(Refer Slide Time: 06:07)



So, far the design of sieve tray is concerned the major items to be determined are the tray diameter. So, we need to know what would be the tray diameter or that is the column diameter column internal diameter. So, that has to be determined. The tray gas pressure drop so how much pressure drop because of the flow of the gas through the know from one trays to the other through the liquid.

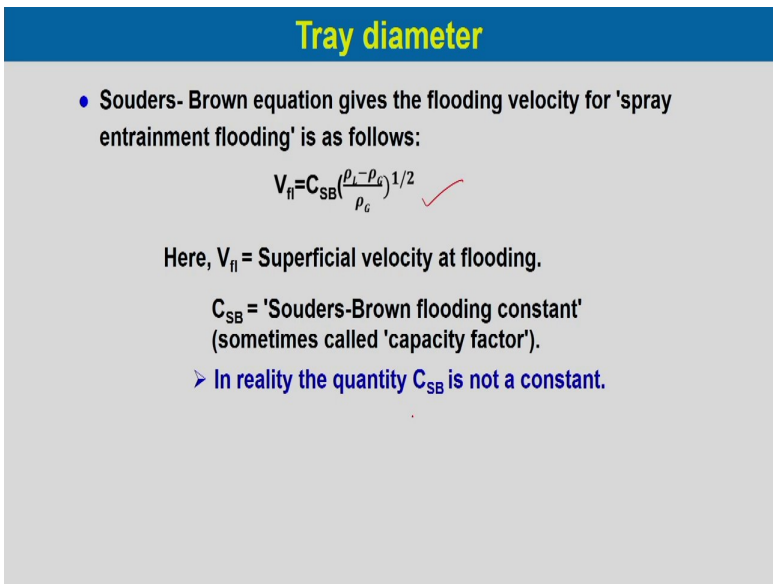
The size and layout of the holes; hole layout and size; the tray spacing and tower internal such as down comers and weir and tray efficiency. All this we will discuss briefly in this lecture, but mostly the detail design of the plate columns or the sieve tray are available in your design course or you will learn in future. So, we will just briefly highlight to give the basic understanding on the sieve tray design.

(Refer Slide Time: 07:15)



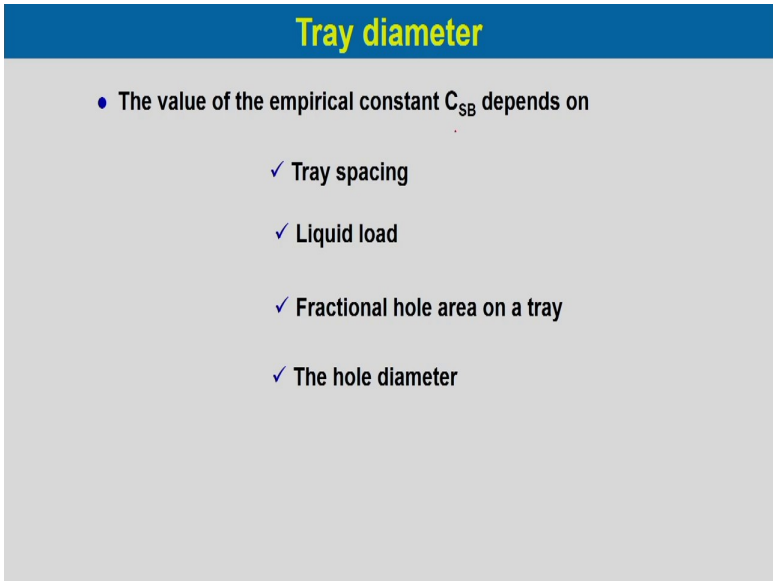
Tray or column diameter the required diameter of a tray of column for a given flow rates of the gas and the liquid phase is determined from the flooding conditions. We know that, the gas velocity in a column is gradually increased. So, if we increase the gas velocity in a column there is a limiting velocity above which entrainments is high enough to cause accumulation of the liquid on the trays leading to flooding after a certain velocity or we call the limiting velocity, so under such circumstances the column will floods. The velocity corresponding to the theoretical maximum capacity of the column that limiting velocity will correspond to the theoretical maximum capacity of the column.

(Refer Slide Time: 08:13)



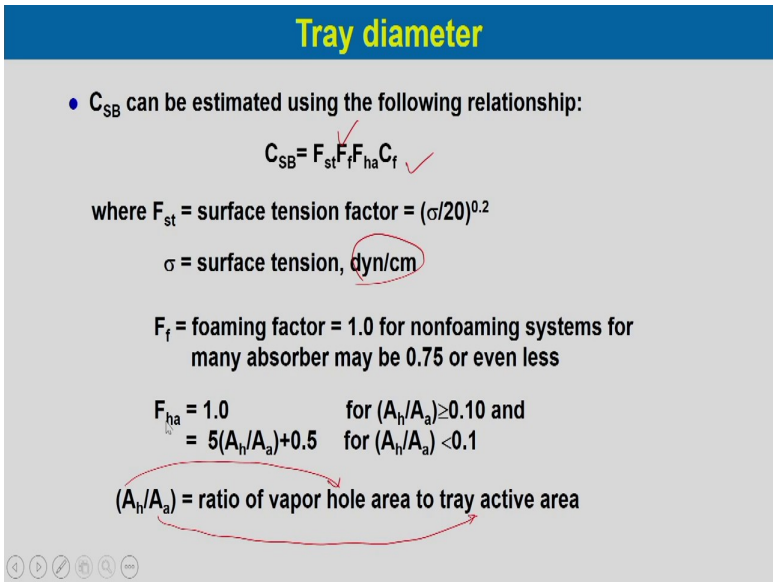
There are few methods of calculation of the flooding velocity. Souders-Brown equation gives the flooding velocity for spray entrainment flooding and which is given as follows V fl would be equal to C SB rho L minus rho G divided by rho G to the power half, where v l is the superficial velocity at flooding and C SB is the Souders-Brown flooding constant sometimes called capacity factor and rho L and rho G they are the density of the liquid and the gas although C SB is called the capacity factor and the Souder-Brown flooding constant, but actually this quantity C SB is not a constant.

(Refer Slide Time: 09:01)



The value of empirical constant C SB depends on different parameters like tray spacing, liquid load, fractional hole area on a tray and the hole diameter. So, these are the 4 parameters which will influence the empirical constant values of C SB of the Souder-Brown constant.

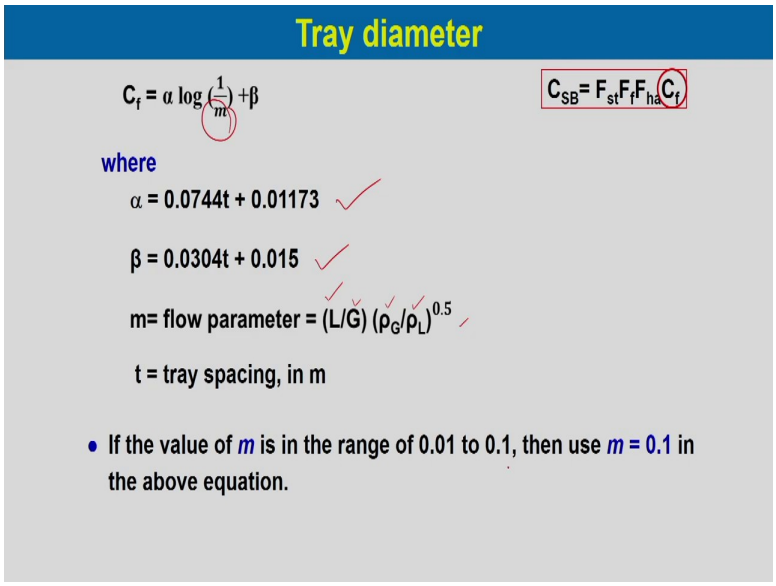
(Refer Slide Time: 09:27)



C SB can be estimated using the following relationship; C SB equal to F st into F f F into F ha into C f where F st is the surface tension factor and which is defined by sigma by 20 to the power 0.2 sigma is the surface tension.

So, which is in know unit of dynes per centimetre and then F f is the foaming factors and it is usually one for non foaming systems. For many absorber it maybe 0.75 or even less and F ha is 1 for A h by A a greater than equal to 1.0 and it would be equal to 5 into A h by A a plus 0.5 where for A h by A a less than 0.1. This A h by A a is the ratio of vapour hole area to tray active area. So, A a is the tray active area and A h is the vapour hole area. So, vapour hole area divided by tray active area this ratio is related with the F ha another factor hole to tray area and which is used over here to calculate C SB.

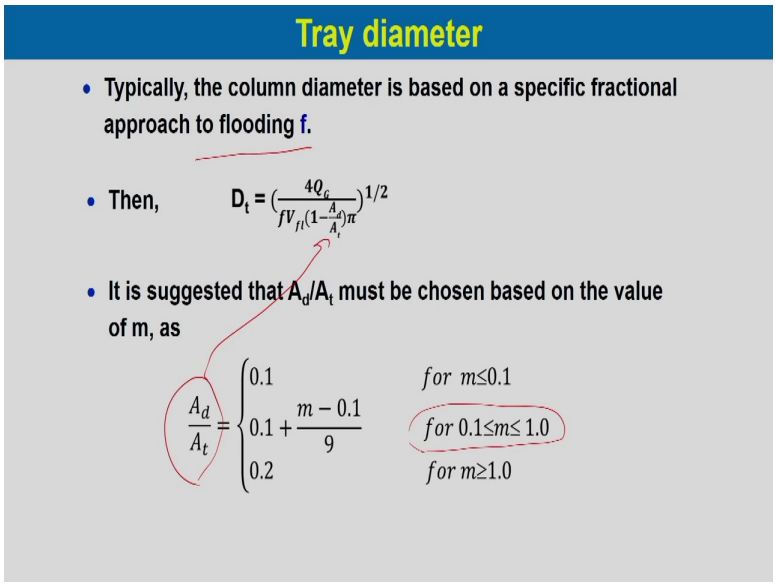
(Refer Slide Time: 11:09)



Now, C f which can be related with know alpha log 1 by m plus beta. This alpha a can be related term with 0.0744t plus 0.01173 with this equation and then beta is also a constant can be related with 0.0304 into t plus 0.015. So, with this two relations alpha and beta are related and then we can have m is the flow parameter which you also depends on liquid and gas flow and their density.

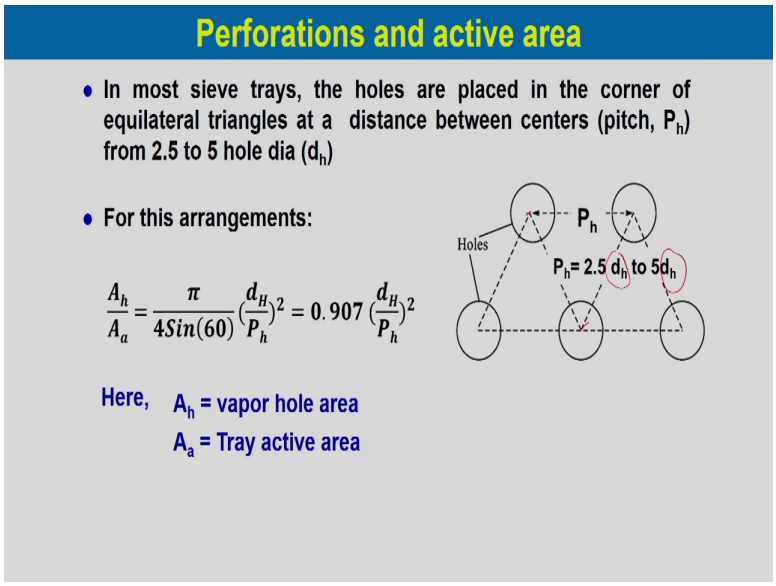
So, L is the flow rate of the liquid, G is the gas flow rate and then rho is the density of the gas rho G and rho L is the density of the liquid. So, L by G into rho G by rho L to the power 0.5, t is the tray spacing over here in equation of alpha and beta tray spacing which is in metre and the value of m over here is in the range of 0.01 to 0.1 then use m is equal to 0.1 in the above equation. So, we can use as 0.1 at the extreme case.

(Refer Slide Time: 12:45)



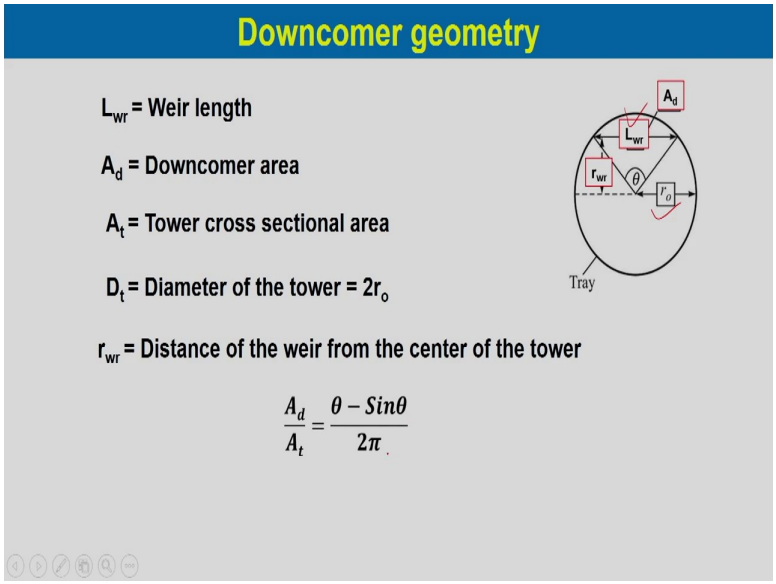
Typically the column diameter is based on a specific fractional approach to flooding. So, fractional approach to flooding means fractional flooding is f and then we can write D t column diameter would be equal to 4Q G divided by f into V fl 1 minus A d by A t into pi to the power half. So, it is suggested that A d by A t must be chosen based on the values of m as A d by A t would be 0.1 when, m is less than 0.1 A d by A t would be 0.1 plus m minus 0.1 divided by 9 for this range when m is no greater than equal to 0.1 and it is less than equal to 1 and it would be 0.2 for m greater than 1.0. So, we can use this values over here and V fl and given a particular flooding conditions with a volumetric flow rate we can calculate the tower diameter ok or column diameter.

(Refer Slide Time: 14:07)



Now, in most sieve trays the holes are placed in the corner of equilateral triangle at a distance between centres from 0.25 d h 2.5 hole dia. So, this pitch length from here to here would be 2.5 d h to 5 d h that is the hole dia. So, it would be in this cases in most of the sieve trays. For this arrangement we can write A h by A a would be equal to pi by 4 sin 60 d H by P h whole square which is equal to 0.907 d H by P h square. So, A h is the vapour hole area and A a is the tray active area.

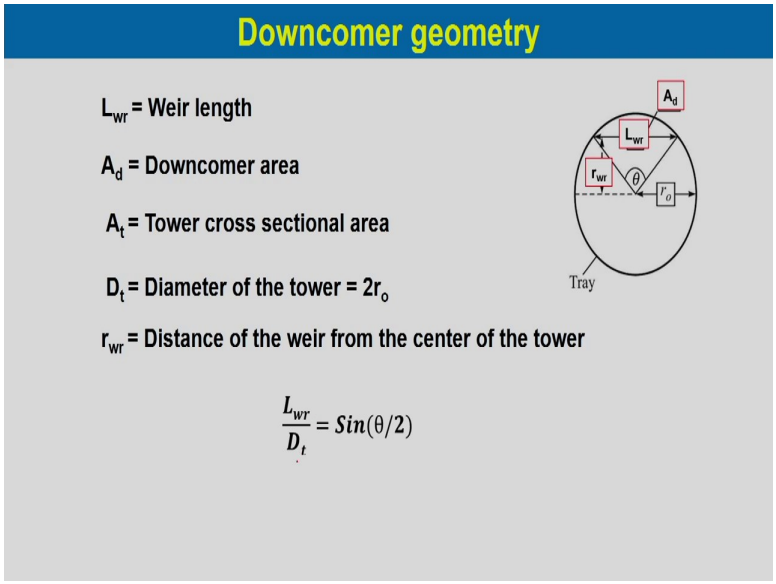
(Refer Slide Time: 15:11)



Now, we need to know the down comer geometry. L wr is the weir length which is given over here this is the weir length and A d is the down comer area here A t is the tower cross sectional area A t and D t is the diameter of the tower which is equal to twice r o here, r wr is the distance of the weir from the centre of the tower.

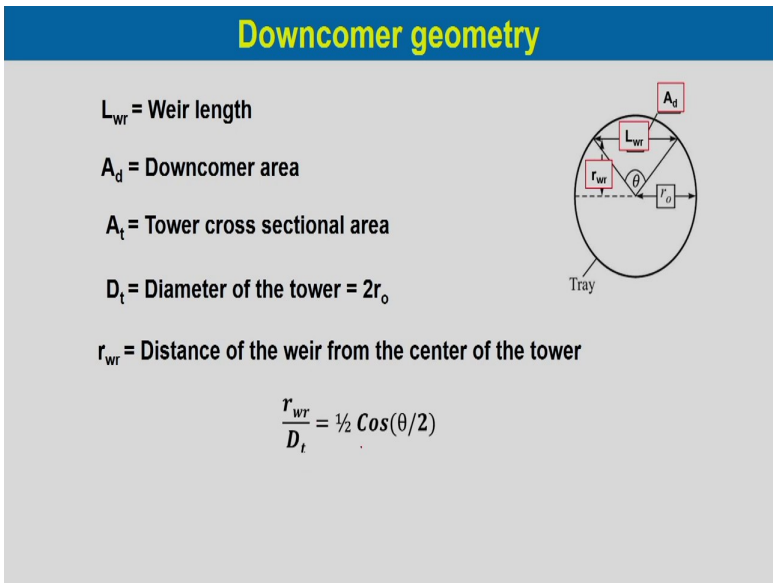
So, we can calculate A d by A t would be equal to theta minus sin theta by 2 pi.

(Refer Slide Time: 16:05)



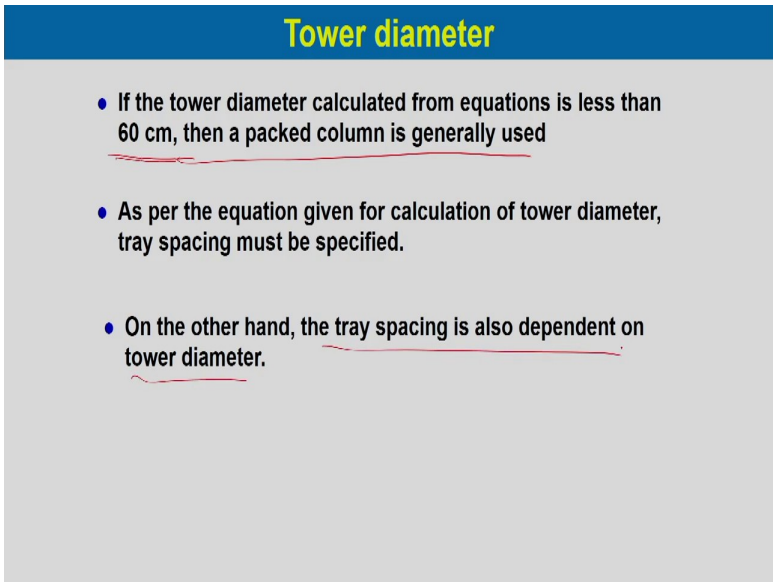
So, here L wr by D t would be equal to sin theta by 2.

(Refer Slide Time: 16:13)



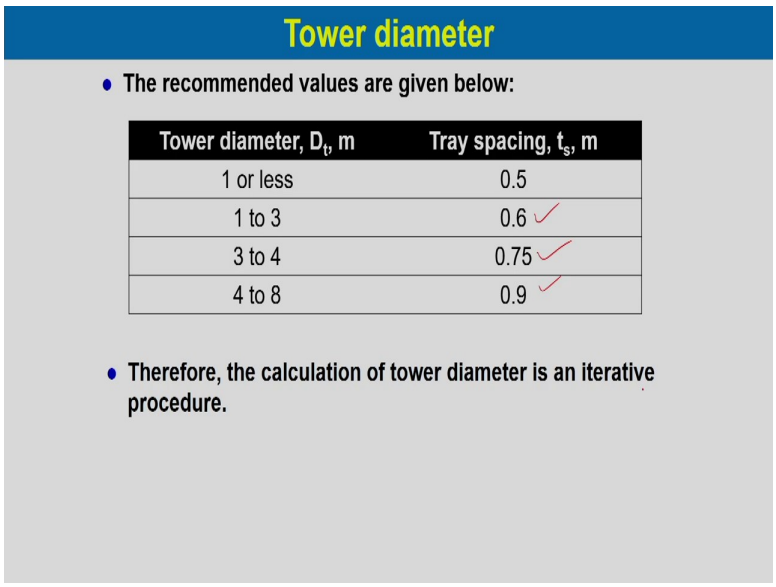
And r wr by D t we can write half into cos theta by 2.

(Refer Slide Time: 16:19)



If the tower diameter calculated from the equation is less than 60 centimetre then, a packed column is generally used. As per the equation given for the calculation of the tower diameter, tray spacing must be specified. On the other hand, the tray spacing is also depend on the tower diameter.

(Refer Slide Time: 16:43)

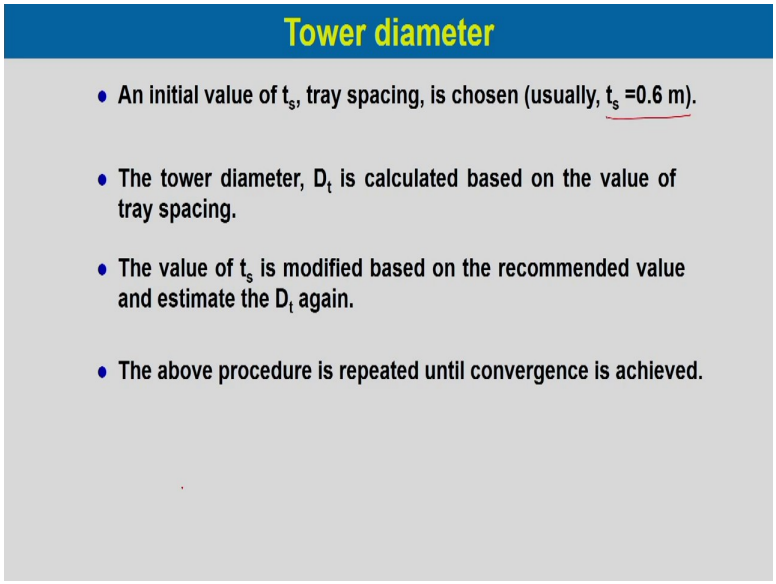


So, these are the recommended values for the tower diameter and you can see over here the tower diameter which is in metre is 1 or less when the tray spacing you can set as 0.5

metre and when it is between 1 to 3, the tower diameter between 1 to 3 the tray spacing is 0.6 metre and it between 3 to 4 metre tower diameter the tray spacing is 0.75 metre and 4 to 8 metre the tray spacing is 0.9 metre.

So, these are the recommended values for the tower diameter of which need to be used for the design; therefore, the calculation of tower diameter is an iterative procedures.

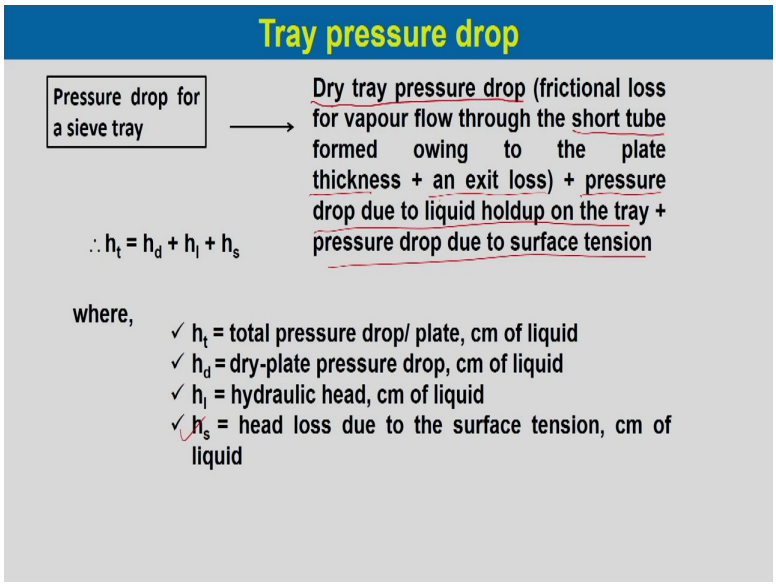
(Refer Slide Time: 17:41)



So, we have to use the iterative procedures and an initial value of t s that is tray spacing is chosen when t s is 0.6 m at their lower values and then gradually we can iterate with the higher values of tray spacing.

The tower diameter D t is calculated based on the values of tray spacing. The value of t s is modified based on the recommended values and estimate the D t again. This above procedure is repeated until the convergence is achieved.

(Refer Slide Time: 18:21)



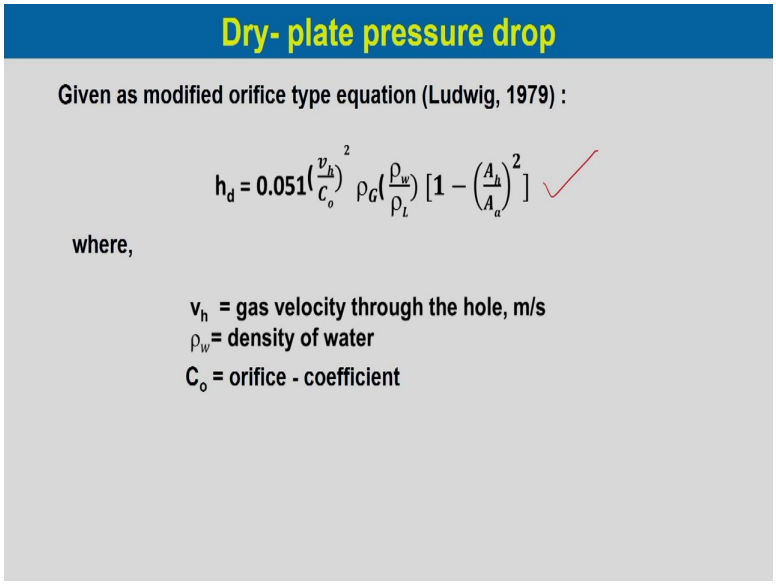
Now, there is a pressure drop in the tray. So, pressure drop of a sieve tray we can calculate tray pressure drop fractional loss of vapour flow through the short tube formed owing to the plate thickness and an exit loss. So, this know short tube means when we make a hole with a particular thickness of the tray there will be a sort no tube like arrangement.

So, owing to that when the vapour flow is through that, you consider a vapour flowing through a short tube due to the thickness of the plate plus an exit loss plus pressure drop due to the liquid holdup on the tray and plus the pressure drop due to surface tension. So, all this has to be accounted for dry tray pressure drop, then we have to consider pressure drop due to liquid holdup and pressure drop due to surface tension. Under dry tray pressure drop, we have two types due to the frictional loss which is due to the forming the tube short tube due to the plate thickness another one is an exit loss. So, these has to be consider under the dry tray pressure drop.

So, we can write the equation h t is equal to h d plus h l plus h s where h t is the total pressure drop per plate of centimetre of liquid it is in centimetre of liquid and h d is the dry plate pressure drop centimetre of liquid and h l is the hydraulic head of that is centimetre of liquid. So and h s is the head loss due to the surface tension that is centimetre in of liquid; so, total would be the drive plate, pressure drop, hydraulic head

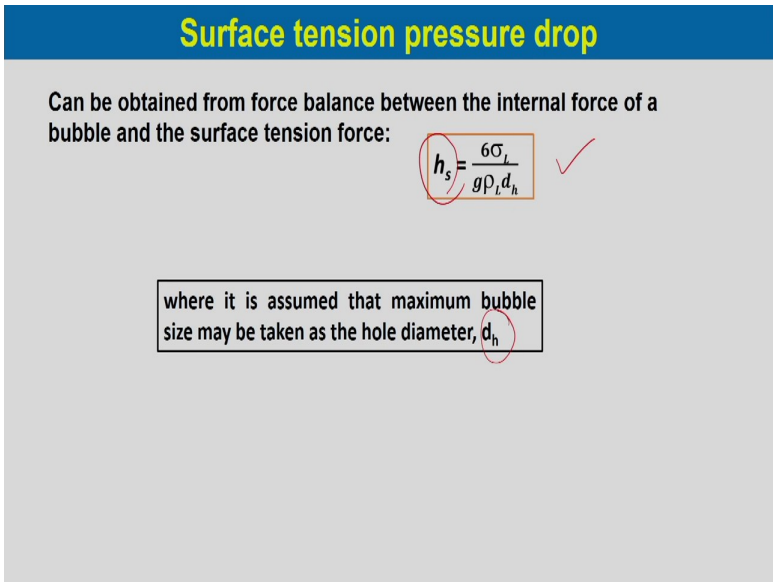
and the head loss due to the surface tension, this 3 pressure drop are added to get the total pressure drop in a sieve tray.

(Refer Slide Time: 20:45)



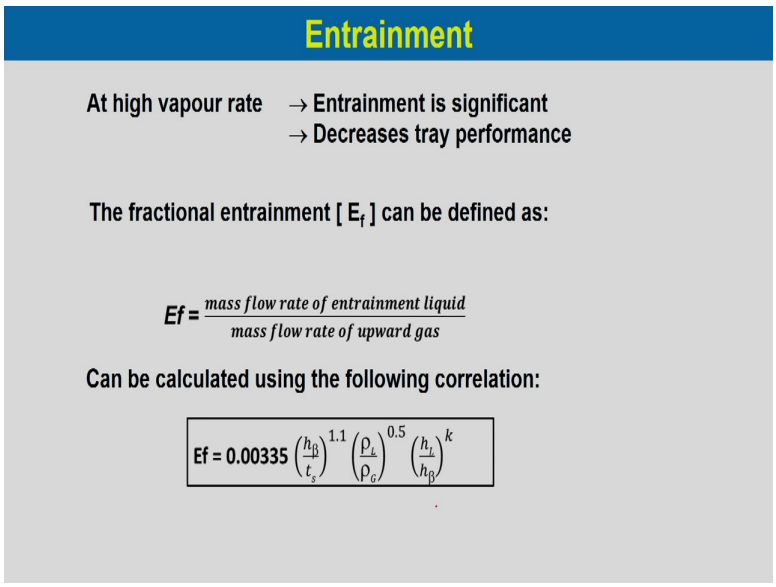
Now, given as modified orifice type equation, Ludwig in 1979 this is the equation h d would be equal to 0.051 into v h by C 0 to square into rho G into rho w by rho L whole into 1 minus A h by A a whole square. So, with this we can calculate h d where, v h is the gas velocity through the holes in metre per second, rho w is the density of water, c naught is the orifice coefficient and A h and A a is already mentioned earlier it is a hole area A h and A a is the active tray area. The rho G, rho w and rho L are conventionally used.

(Refer Slide Time: 21:49)



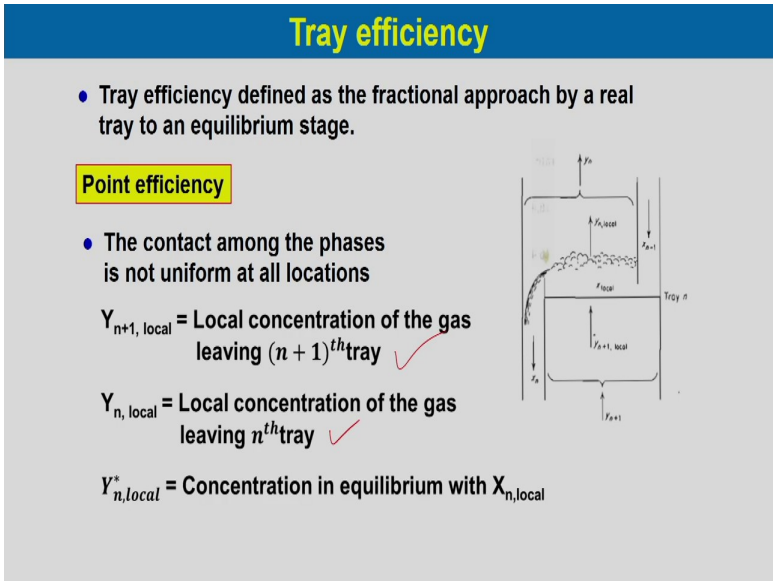
Then surface tension pressure drop we can obtain from the force balance between the internal force of bubble and the surface tension force. So, from this h s would be equal to 6 sigma L by g rho L by d h; so using these we can calculate the surface tension force where it is assumed that maximum bubble size may be taken as the hole diameter. So, this is the assumptions if you wanted to calculate the pressure drop due to surface tension force and where we consider d h is the maximum bubble diameter which can be achieved.

(Refer Slide Time: 22:39)



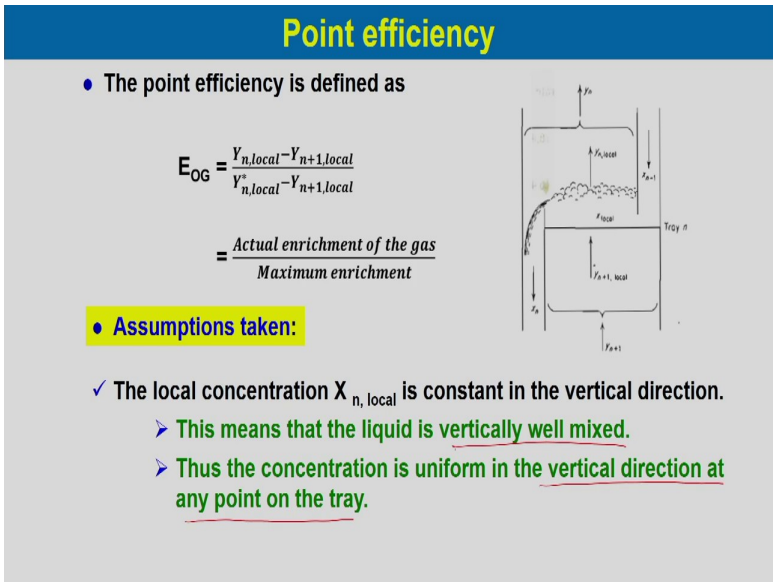
Now, at very high vapour rate entrainment is significant that we know. So, decreases tray performance and the fractional entrainment E f can be defined as mass flow rate of the entrainment liquid divided by the mass flow rate of upward gas. So, it can be calculated using the correlation E f would be equal to 0.00335 h beta by t s to the power 1.1 rho L by rho G to the power 0.5 h L by h beta to the power k.

(Refer Slide Time: 23:19)



The tray efficiency which is defined as the fractional approach by a real tray to an equilibrium tray. So, we need to know the tray efficiency. So, in tray efficiency we will discuss few terms one is point efficiency. You can see in this case the contact among the phases is not uniform at all locations. So, the point efficiency will vary Y n plus 1 local is the local concentration of the gas leaving n plus oneth tray and Y n local is the local concentration of the gas living at nth tray. So, this 2 are local concentration and Y n star local is the concentration in equilibrium with x n local. So, this y n star local is in equilibrium with X n local.

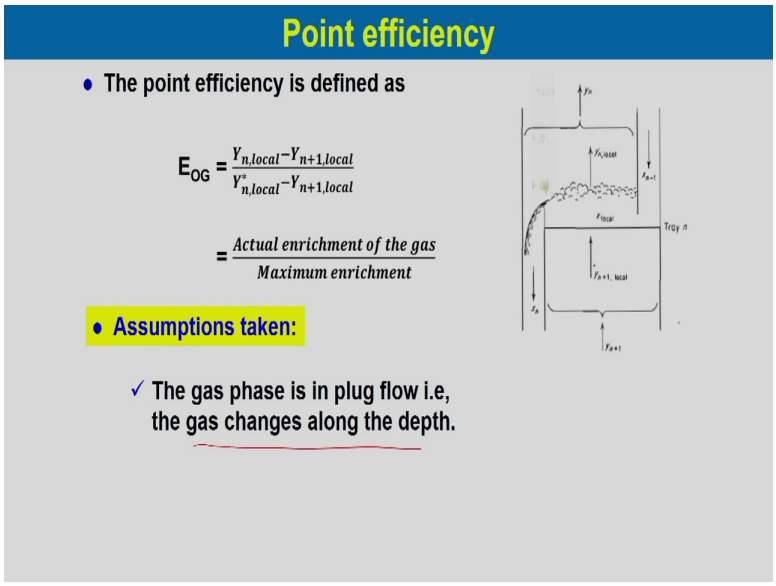
(Refer Slide Time: 24:27)



So, with this no nomenclature we can write the point efficiency as E OG equal to Y n local minus Y n plus 1 local divided by Y n star local minus Y n plus 1 local, numerator is the actual entrainment of the gas divided by the maximum entrainment possible. So, this will give the point efficiency of that particular tray.

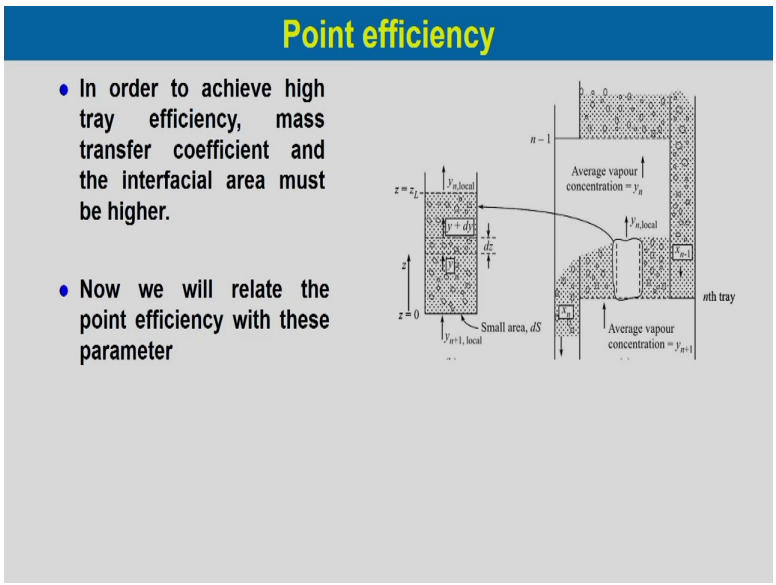
Now, what are the assumptions taken over here, the local concentration X n local is constant in the vertical direction. This means that, the liquid is vertically well mixed. Thus the concentration is uniform in the vertical direction at any point on the tray. So, this local concentration X n is constant in the vertical direction and then uniform throughout the tray.

(Refer Slide Time: 25:31)



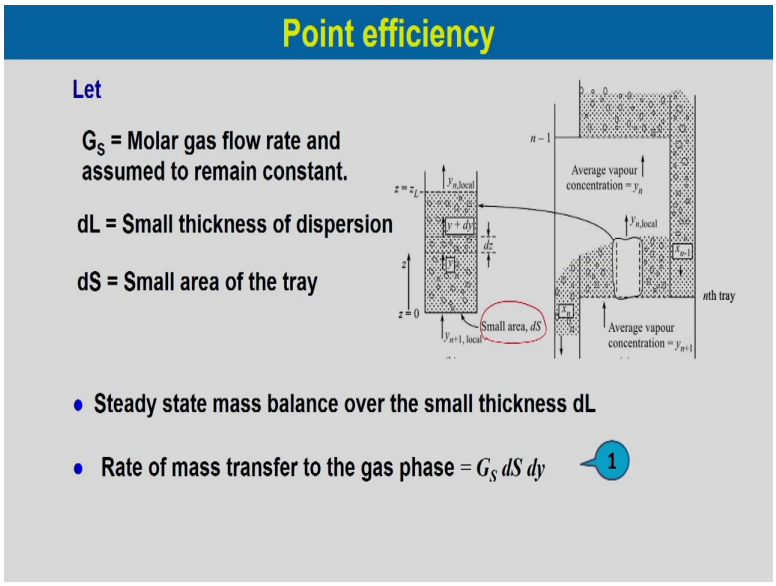
The gas phase is in plug flow, that is the gas changes along the depth it is a plug flow. So, its concentration will change along the depth of the flow.

(Refer Slide Time: 25:49)



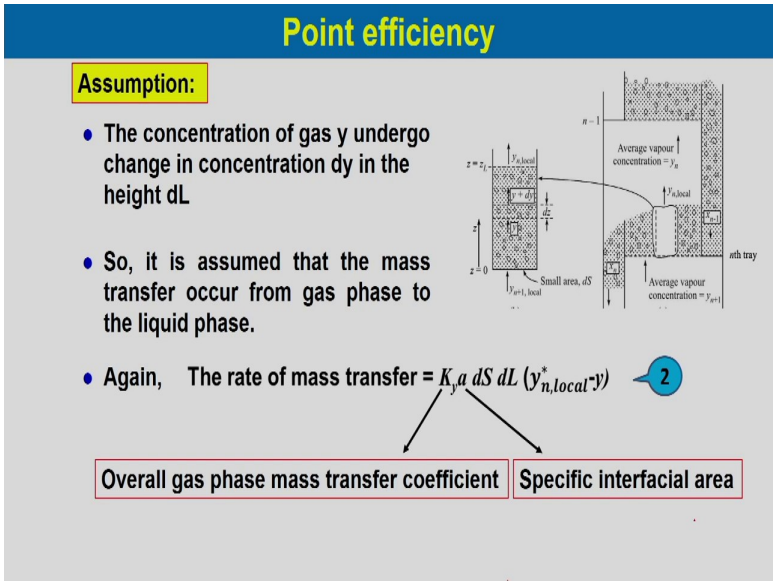
In order to achieve high tray efficiency, mass transfer coefficient and interfacial area must be higher. Now we will relate the point efficiency with this parameters interfacial area and the mass transfer coefficient.

(Refer Slide Time: 26:07)



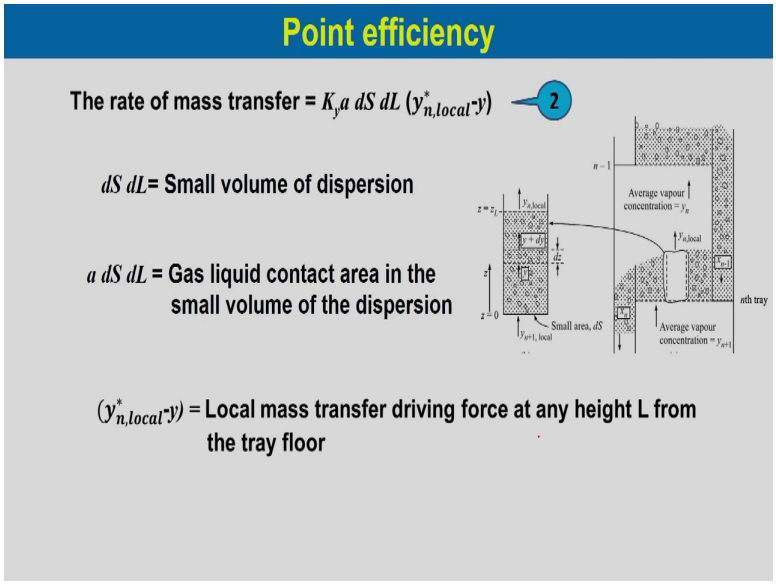
Let G s is the molar gas flow rate and assume to remain constant, dL is the small thickness of dispersion, dS is the small area of the tray which is shown over here. Steady state mass balance over the small thickness dL, then we can write the rate of mass transfer of gas would be equal to gas flow rate into area into thickness. So, this is the rate of mass transfer G s is the molar flow rate into the differential area of the tray into the change of concentration dy.

(Refer Slide Time: 26:51)



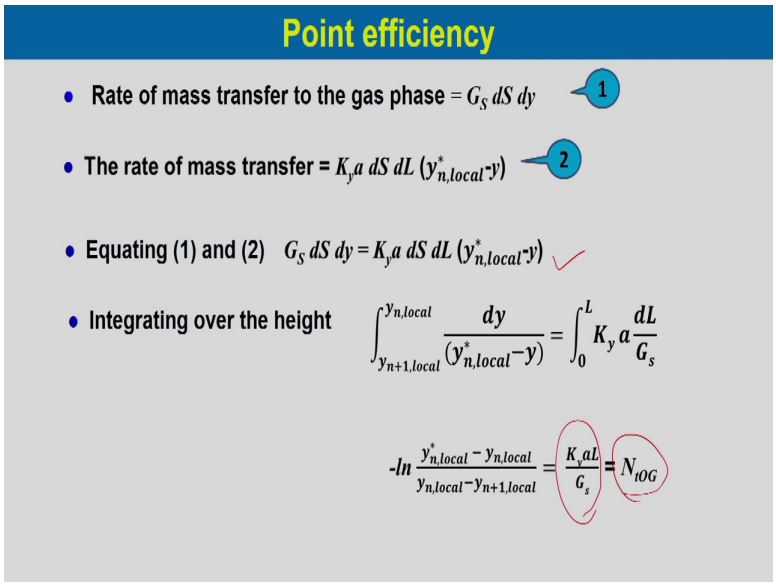
Now, assumptions the concentration of gas y undergo change in concentration dy in the height dL. So, it is assumed that the gas mass transfer occur from gas phase to the liquid phase and again the rate of mass transfer we can write K y a in to dS into dL and Y n star local minus Y. So, capital K y a is the overall gas phase mass transfer coefficient and a is the specific interfacial area it is area per unit volume of the liquid.

(Refer Slide Time: 27:33)



The rate of mass transfer as we have no defined earlier. So, this is over here and dS into dL is the small volume of dispersion a dS dL is the gas liquid contact area in the small volume of the dispersion and Y n star local minus Y is the local mass transfer driving force at any height L from the tray floors.

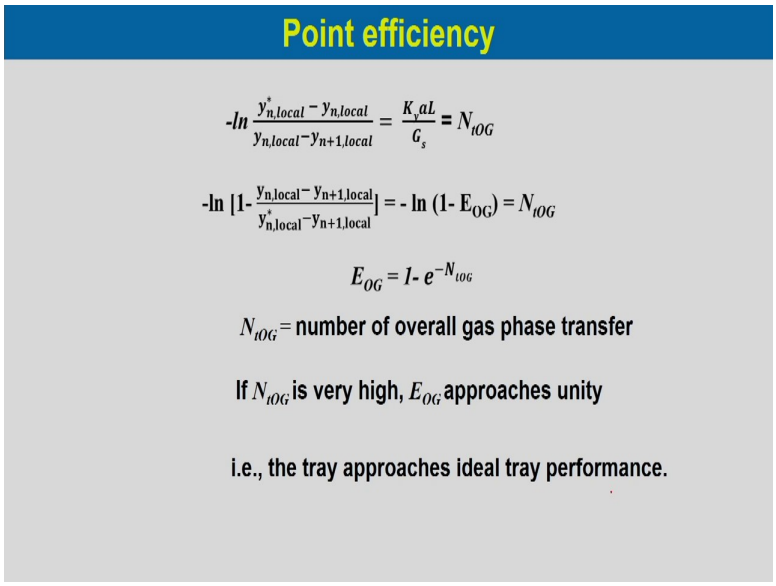
(Refer Slide Time: 27:59)



The rate of mass transfer to the gas phase is this one which is already mentioned and then rate of mass transfer we can also correlate with this equation and then if we equate equation 1 and 2, we can get G s into dS into dy would be equal to K y a dS dL into the concentration gradient Y n star local minus Y. So, if we integrate over the height. Then we will get integral Y n plus 1 local to Y n plus n local dy by Y n star local minus Y would be equal to integral 0 to L K y into a dL by G s.

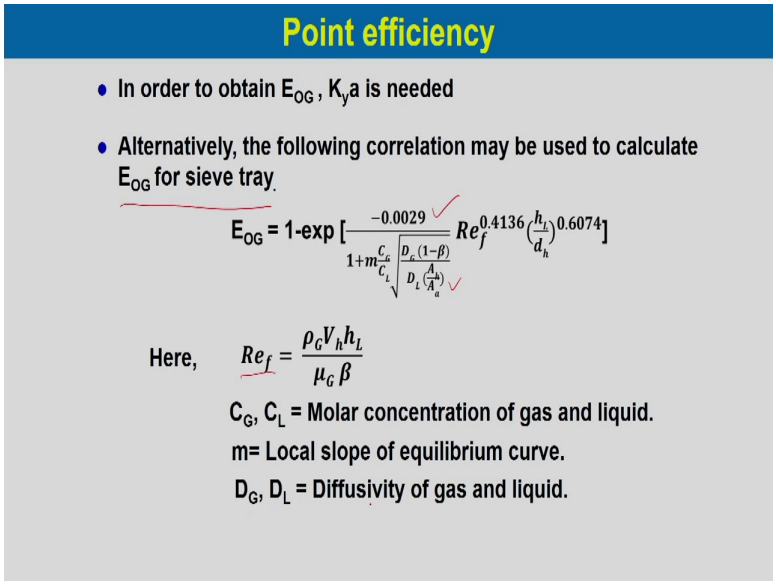
So, from here we can get ln Y n star local minus Y n local divided by Y n local minus Y n plus 1 local would be equal to K y aL by G s. So, this is defined as N tOG number of transfer unit of the gas phase N tOG.

(Refer Slide Time: 29:19)



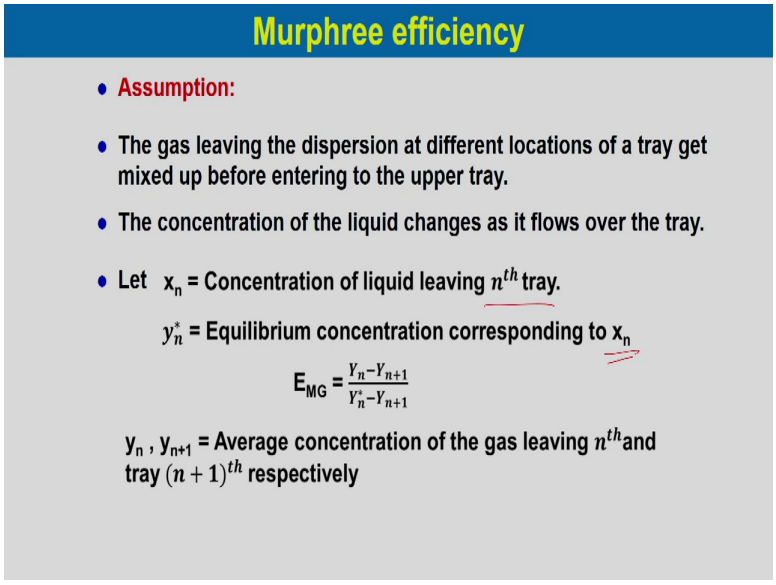
So, if we just subtract both sides with minus 1 and then we can write this equation minus ln 1 minus Y n local minus Y n plus 1 local divided by Y n star local minus Y n plus 1 local would be equal to minus ln 1 minus E OG would be equal to N tOG. So, E OG we can write would be equal to 1 minus e to the power N tOG, N tOG as we said number of overall gas phase transfer unit and if N tOG is very high, E OG approaches unity that is; the tray approaches ideal tray performance when N tOG approaches infinity.

(Refer Slide Time: 30:15)



In order to obtain E OG, K y a is needed. Alternatively the following correlations may be used to calculate the E OG for sieve tray. So, one of them is E OG would be equal to 1 minus exponential minus 0.0029 divided by 1 plus m C G by C L in to root over D G into 1 minus beta divided by D L into A h by A a whole into R e f to the power point 0.4136 into h L by d h to the power 0.6074 here, R e f is the Reno's number of the fluid which is defined as rho G V h into h capital L divided by mu G beta. C G and C L is the molar concentration of the gas and liquid, m is the locals slope of equilibrium curve and D G and D L are the diffusivity of the gas and liquid.

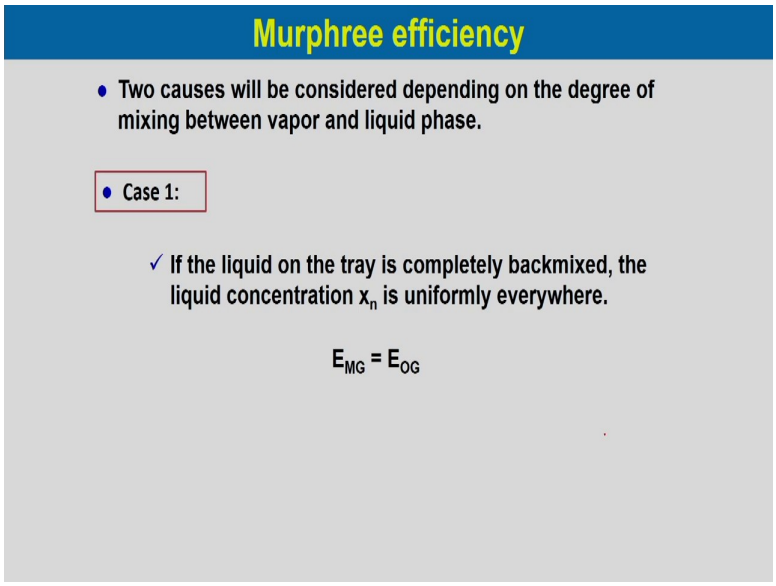
(Refer Slide Time: 31:47)



Now, there is another efficiency is called the Murphree efficiency, define Murphree efficiency these are the following assumptions taken the gas living the dispersion at different locations of a tray get mixed up before entering to the upper tray. So, the concentration of the liquid changes as it flows over the tray. Let x n is the concentration of the liquid leaving of the nth tray and y n star is the equilibrium concentration co corresponding to x n.

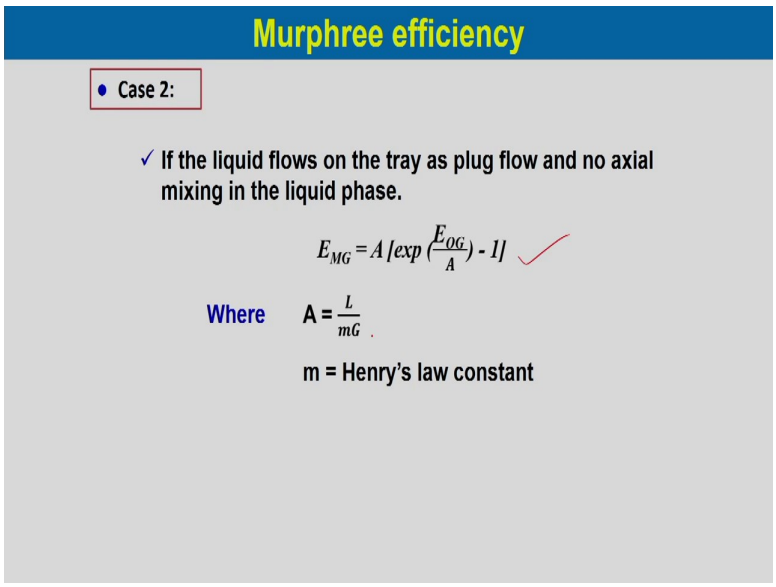
So, E MG is defined as Y n minus Y n plus 1 divided by Y n star minus Y n plus 1. Here, Y n and Y n plus 1 is not the local concentration it is the average concentration of the gas leaving nth and n plus oneth tray respectively. So, in case of the point efficiency we have considered the local concentration, but in this case we have consider the average concentration in case of Murphees tray efficiency.

(Refer Slide Time: 33:11)



Cases will be considered depending on the degree of mixing between vapour and liquid phase. Case 1, if the liquid on the tray is completely back mixed, the liquid concentration x n is uniform everywhere. So, know for complete back mixing sys systems the liquid concentration x n will be uniform throughout the tray. So, E MG would be equal to E OG. So, point efficiency would be equal to the Murphree efficiency.

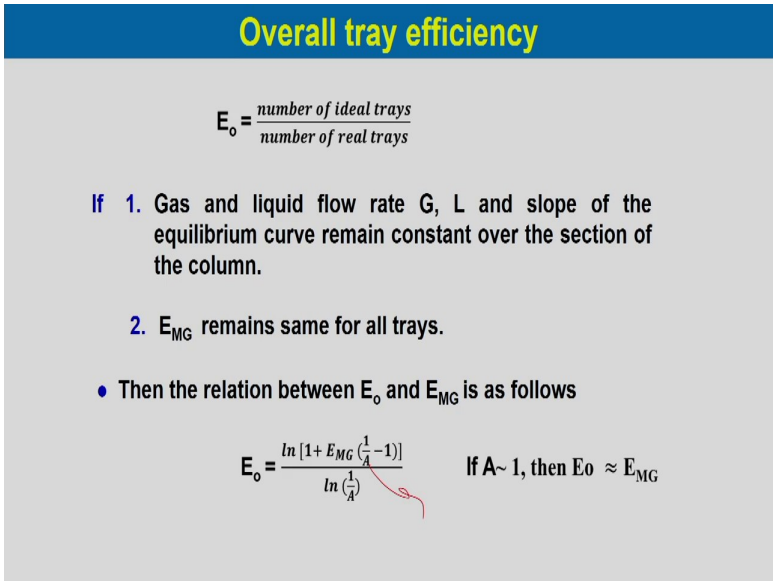
(Refer Slide Time: 33:49)



Now, for case 2, if the liquid flows on the tray as plug flow and no axial mixing in the liquid phase, in this case, E MG would be equal to A into exponential E OG by A minus

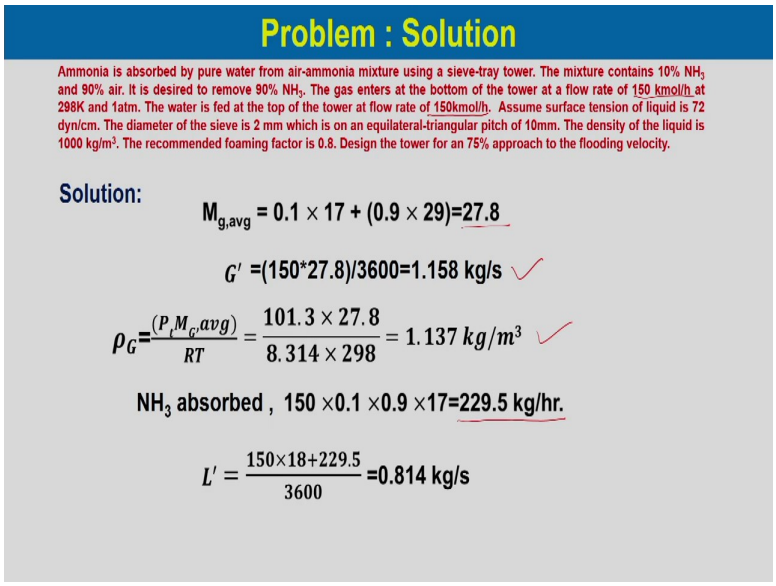
1 where, A is L by mG it is absorption factor m is the Henrys law constant and L is the liquid flow rate and G is the gas flow rate.

(Refer Slide Time: 34:25)



So, overall tray efficiency E O is the number of ideal trays divided by the number of real trays. If no point 1, if gas and liquid flow rates G and L and the slope of the equilibrium curve remain constant over the section of the column, E MG remains same for all trays. So, then the relation between E O and E MG is as follows E O would be equal to ln into 1 ln 1 plus E MG into 1 by A minus 1 divided by ln 1 by A here, A if A tends to 1 then E O would be equal to no approximately equal to E MG. So, when this absorption factor tends to 1 then, the overall tray efficiency would be equal to the Murphree stage efficiency or tray efficiency.

(Refer Slide Time: 35:35)



Now, let us consider a small problem to look after the design aspect which we have discussed for the tray column. Ammonia is absorbed by pure water from air ammonium mixture using a sieve tray tower. The mixture contains 10 percent ammonia and 70 percent air. It is desired to remove 90 percent ammonia.

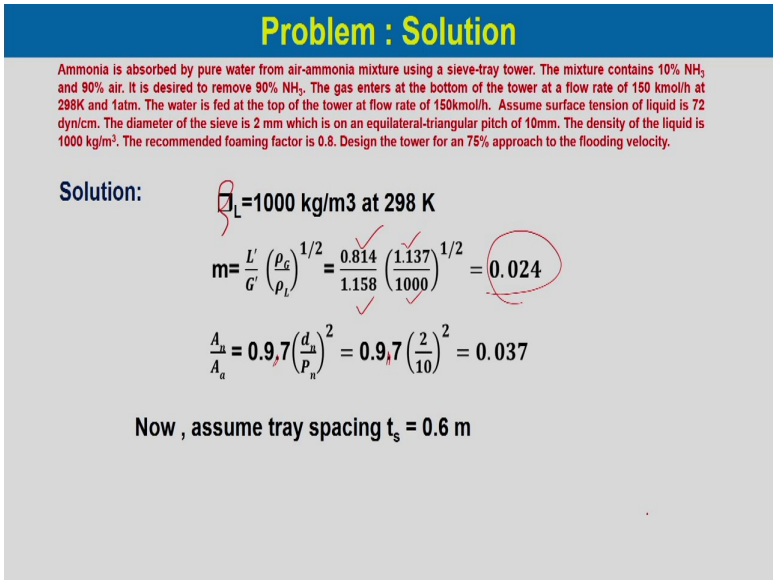
The gas enters at the bottom of the tower at a flow rate of 150 kilo mole per hour at 298 Kelvin and 1 atmosphere pressure. The water is fed at the top of the tower at flow rate of 150 kilo mole per hour. Assume surface tension of liquid is 72 dynes per centimetre. The diameter of the sieve tray is given 2 millimetre which is on an equilateral triangular pitch of 10 millimetre. The density of the liquid is 1000 kg per metre cube. The recommended foaming factor is 0.8. Now design the tower for an 75 percent approach to the flooding velocity.

Now, let us move forward to solve this problem step by step. So, average molecular weight we can calculate for the no gas mixtures which are given. We have 10 percent ammonia, 90 percent air; so, 0.1 into 17 the molecular weight of ammonia plus 0.9 into 29. So, it is 27.8. Now, G dash gas flow rate which is given 150 kilo mole per hour. So, we can calculate in terms of kg per second G dash would be no 150 into average molecular weight 27.8 divided by 3600 seconds. So, it would be 1.158 kg per second. Now rho G would be equal to P t M G average divided by RT. So, it is 101.3 total

pressure into the average molecular weight divided by R into T so, which is coming around to be 1.137 kg per metre cube.

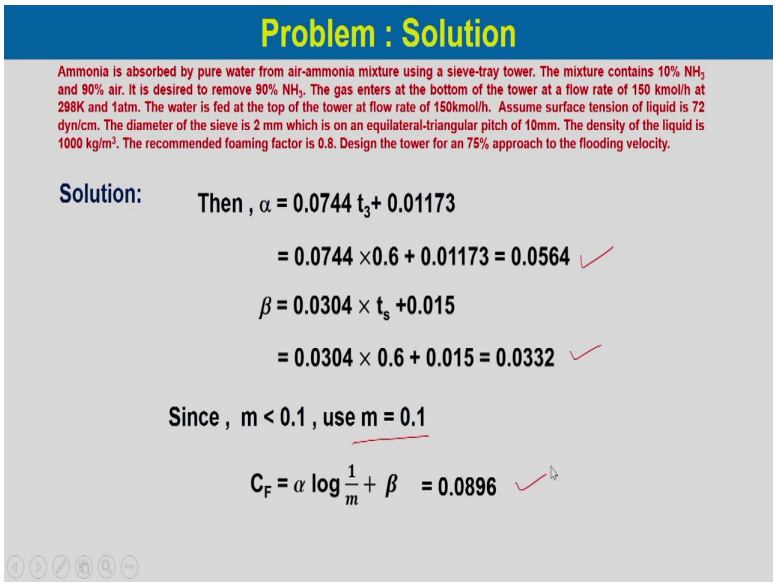
Now, ammonia absorbed. So, we have a gas flow rate of 150 kilo mole per hour. So, 10 percent of that is 150 into 0.1 and out of that 90 percent has to be absorbed so into 0.9 into the molecular weight of the ammonia. So, would be 229.5 kg per hour. So, L dash is also over here is 150 kilo mole per hour for water which is fed at the top. So, it would be 150 into 18 plus 229.5 divided by 3600. So, the water flow rate would be point 1 dash would be 0.814 kg per second.

(Refer Slide Time: 39:03)



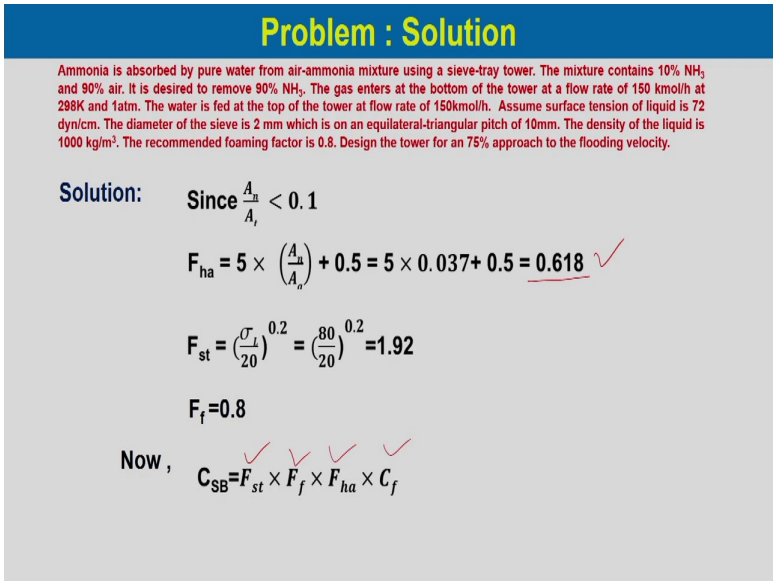
The density rho L is 1000 kg per metre cube at 298 Kelvin, m would be equal to L dash by G dash into rho G by rho L to the power half. So, if we just substitute of values of L dash then G dash into rho G 1.137 which we have calculated and then the density of no liquid which is given 1000 kg per metre cube to the power half. So, will get is around 0.024. A n by A h would be equal to 0.97 d n by P n whole square which is equal to 0.97 2 by 10 whole square. So, which is coming out to be 0.037.

(Refer Slide Time: 40:05)



Now, assume tray spacing t s is 0.6 meter, then we can calculate alpha would be equal to 0.0744 into 0.6 plus 0.01173 would be equal to 0.0564. So, alpha we can calculate. Then we can calculate beta using the e r relations which are provided in the lecture; so which will be around 0.0332. Since, m is less than 0.1, use m is equal to 0.1 as we have said no earlier. So, C F would be equal to alpha log 1 by m plus beta. So, beta and alpha we have calculated m which we can use 0.1. So, C F we can calculate is about 0.0896.

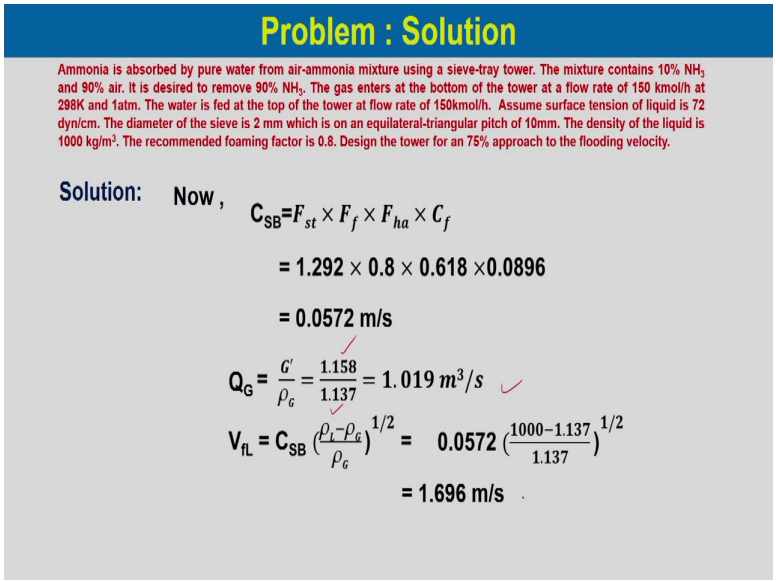
(Refer Slide Time: 41:09)



Now, since A n by A t is less than 0.1, we can use the relation of F ha which is 5 into A n by A a plus 0.5 which is equal to 5 into 0.037 plus 0.5 which is equal to 0.618. So, F ha we can calculate and then F st would be equal to a sigma L divided by 20 to the power point 2. So, sigma L which is given over here is taken as 80 times per second. So, 80 divided by 20 to the power 0.2 which is equal to 1.92.

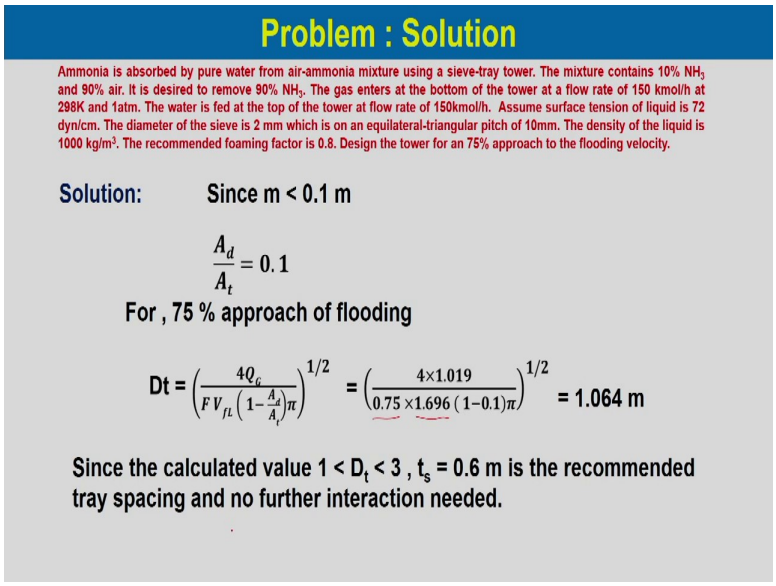
F; F f is the you know factor flooding factor F f which is equal to 0.8 which is given and C SB we can calculate using this relation. So, all the parameters F st, F f, F ha and C f are known.

(Refer Slide Time: 42:23)



So, we can calculate the no values of C SB which is 0.0572 meter per second. Now Q G would be equal to G dash by rho G, rho G we have calculated rho G we are given then, G dash we have calculated. So, Q G would be equal to 1.019 metre cube per second. So, volumetric flow rate of the gas we can calculate. V fL we can calculate using this relation which is 0.0572 into rho L minus rho G divided by rho G to the power half which is 1.696 meter per second; so V L fL we can calculate.

(Refer Slide Time: 43:15)



Since m less than 0.1, m we can take A d by A t is equal to 0.1. For 75 percent approach of flooding we can calculate Dt which is equal to 4Q G divided by F V fL into 1 minus A d by A t into pi to the power half. So, if you substitute the values then we can see 4 into 1.019 divided by 0.75 into 1.696 into 1 minus 0.1 into pi to the power half. So, then we will get no the values of Dt is around 1.064 meter.

Now, since the calculated values of diameter is between 1 and 3. So, it is in between 1 and 3 metre and we assume t s is equal to 0.6 meter which is recommended tray spacing. So, no farther iteration is needed. So, that is within the acceptable limit. So, this way we can do the tower design for the plate towers and with this discussion we will complete our tray tower design discussion and thank you for hearing this lecture and we will continue our design of the towers for packed column in the next lecture.