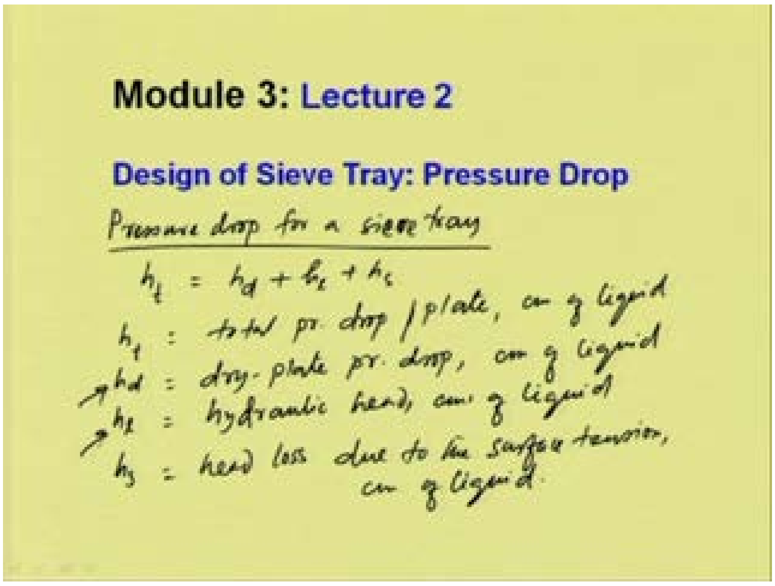
Mass Transfer Operations 1
Prof. Bishnupada Mandal
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Module - 3
Equipment for gas liquid operations
Lecture - 3
Tray Column (Part-2)

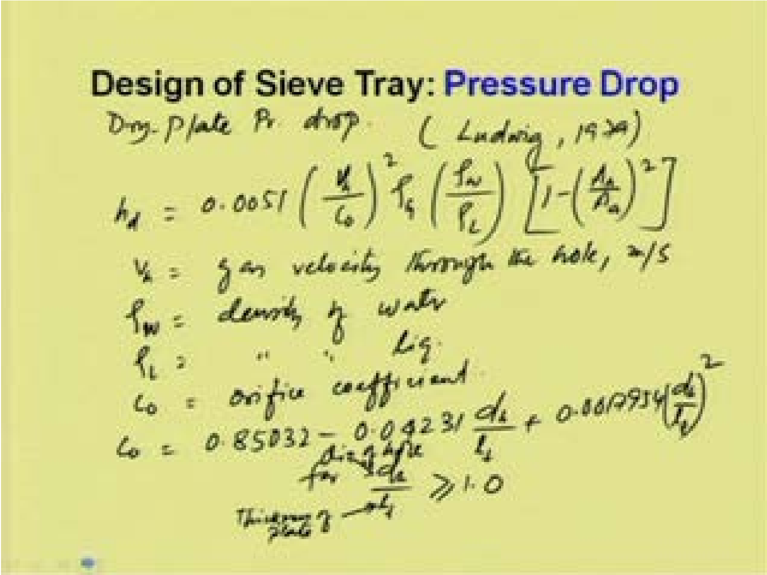
Welcome to third lecture of module three. And this lecture will be on Equipment for gas liquid operation. We are discussing the equipments for gas disperse; and we are designing the plate column; and we have seen in our previous lecture how to determine or how to design the tower diameter for a plate column. In this lecture, we will continue design of the plate column like pressure drop. We will discuss the entrainment weeping and tray efficiency. So, which are the important parameters to design for a plate column?

(Refer Slide Time: 00:34)



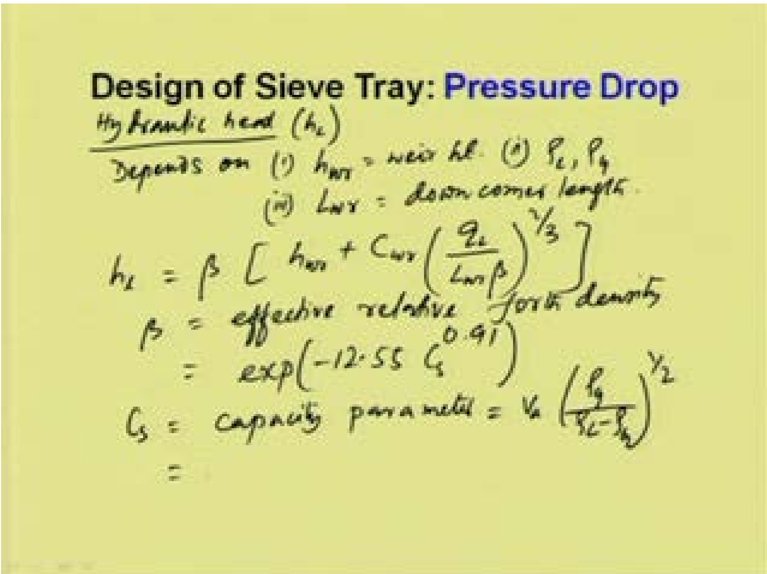
So, pressure drop for a sieve tray we can write h t is equal to h d plus h l plus h s, where h t is the total pressure drop per plate which is centimeter of liquid, and h d is the dry plate pressure drop, centimeter of liquid; h l is the hydraulic head, centimeter of liquid, and h s is the head loss due to the surface tension. And this is also centimeter of liquid. Now, how to calculate this dry plate pressure drop and h l and h s, so that we can obtain the total pressure drop, we will go one by one.

(Refer Slide Time: 03:14)



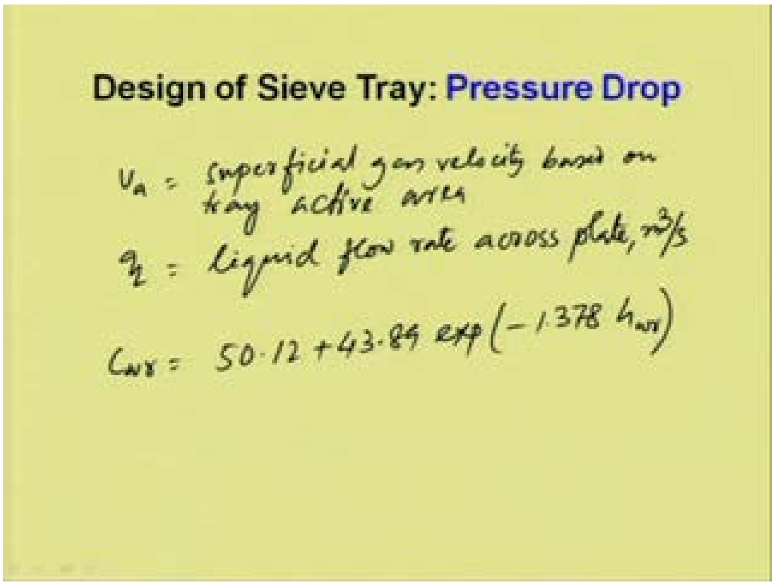
Let us consider the dry plate pressure drop and this we can obtain by a modified orifice type equation which is proposed by Ludwig. h d is equal to 0.0051 V h by c o square rho G rho w rho l into 1 minus A h by A a square. So, where V h is the gas velocity through the hole meter per second, rho w is the density of water and rho l is the density of liquid, co is the orifice coefficient and co can be obtained, c o is equal to 0.85032 minus 0.04231 d h by l t plus 0.0017954 d h by l t square, for d h is the diameter of the hole and l t is the thickness of the plate, should be this ratio should be greater than 1.0. So, l t is the thickness of the plate and diameter of the hole. From this we can calculate h d.

(Refer Slide Time: 06:12)



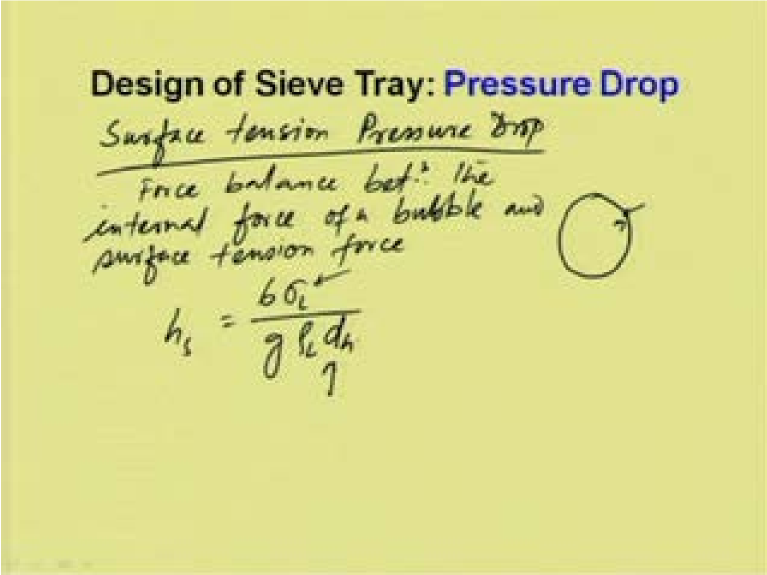
Now let us calculate the hydraulic head - h l. This depends on weir height and also it depends on liquid and gas densities, rho l and rho G and also it depends on down comer length. So, the equations which can be used is h l will be equal to beta h w r plus C w r q l by L w r beta to the power two third; where h w r is the weir height, L w r is down comer length. Now, let us consider beta; beta is the effective relative forth density and can be calculated which is equal to exponential minus 12.55 C s to the power 0.91; where C s is the capacity parameter and is equal to, we can write, v a rho G by rho L minus rho G to the power half v a, this v a is the superficial gas velocity and it is in unit of meter per second.

(Refer Slide Time: 09:08)



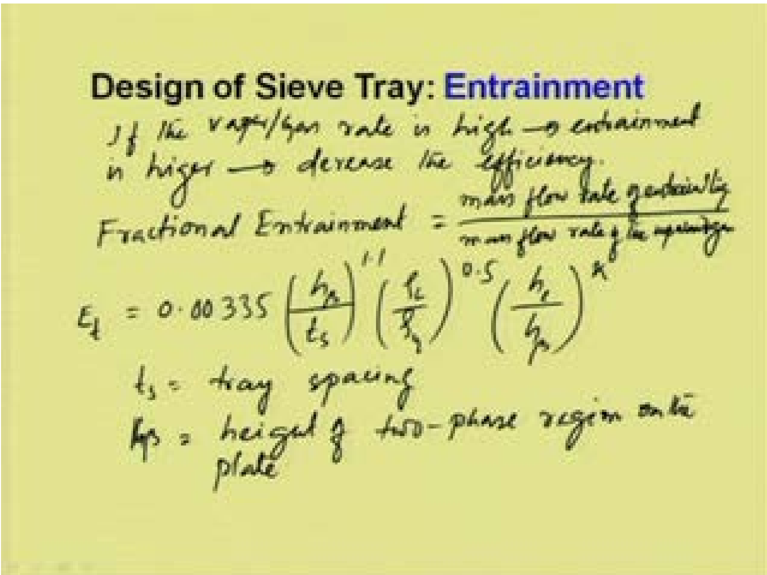
And v a which is superficial gas velocity based on tray active area and q l is the liquid flow rate across plate which is in meter cube per second, C w r we can calculate using the following equation 50.12 plus 43.89 exponential minus 1.378 h w r. This way we can calculate hydraulic pressure drop, hydraulic head; and then we can calculate the surface tension pressure drop.

(Refer Slide Time: 10:22)



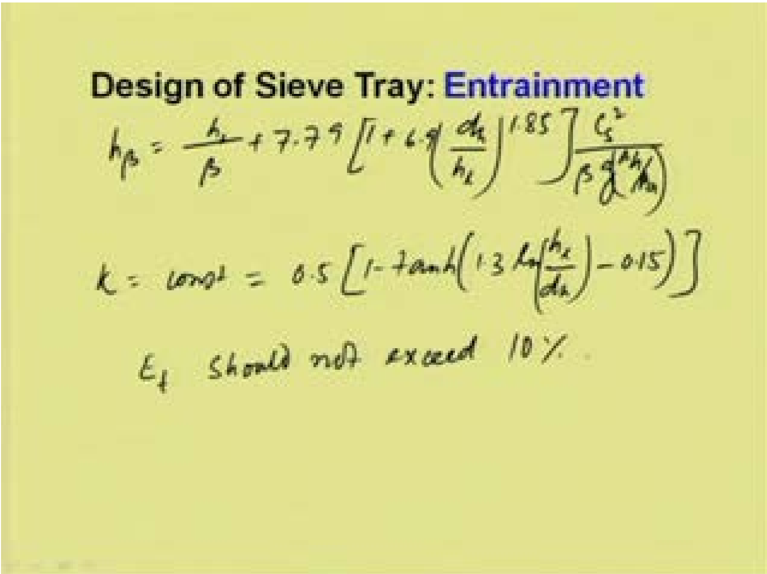
Surface tension pressure drop, this can be done by equating the force inside the bubble and outside the bubble. Outside the bubble is the surface tension force and if we do the force balance between the internal force of a bubble and the surface tension force. So, we can write h s is equal to 6 sigma L divided by G rho l d h, d h is the hole diameter and sigma L is the surface tension force of the liquid and this hole area or bubble size can be taken as hole diameter. So, we can obtain this surface tension force.

(Refer Slide Time: 11:59)



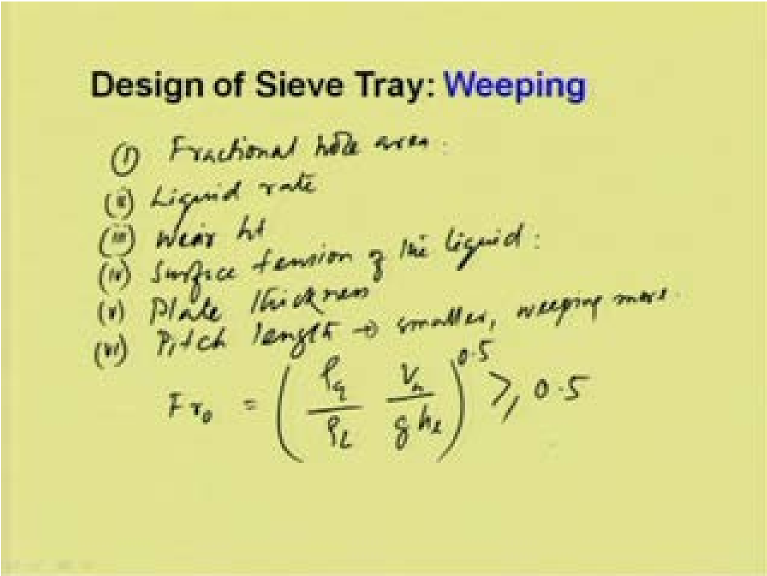
Now, the entrainment of the liquid can occur at high vapor or gas rate; so if the vapor rate or gas rate is high, entrainment is higher and hence decreases the efficiency of the plate or efficiency of tower. This can be defined the fractional entrainment. Fractional entrainment can be defined as the ratio of the mass transfer rate of entrainment liquid or mass flow rate of entrain liquid divided by the mass flow rate of upward gas. So, this is the fractional entrainment and this can be calculated using the following correlation: E t will 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; t s is the tray spacing and h beta is the height of two-phase region on the plate.

(Refer Slide Time: 14:55)



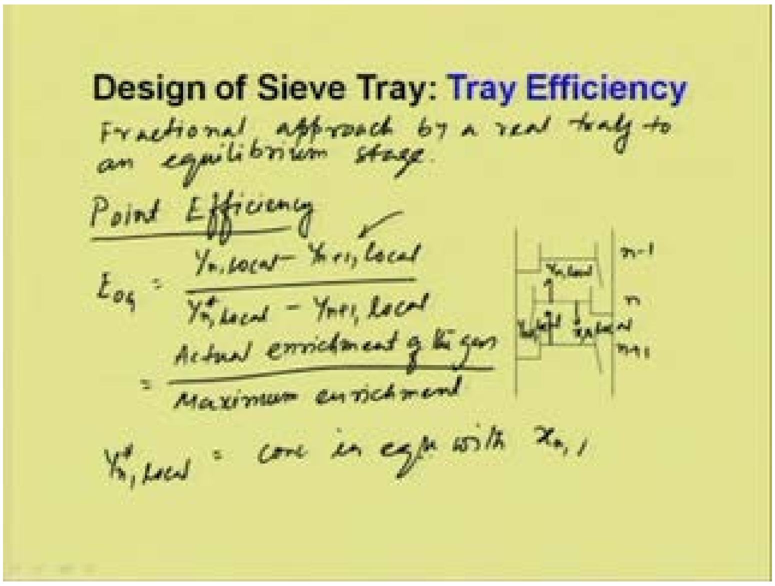
This h beta we can calculate is h l by beta plus 7.79 into 1 plus 6.9 d h by h l to the power 1.85 into C s square by divided beta G h by k a; and this k is a constant, we can calculate it is 0.5 into 1 minus tan hyperbolic 1.3 l n h l by d h minus 0.15. Using this equation we can obtain the fractional entrainment. And the fractional entrainment should not exceed 10 percent and below this 10 percent is desired. So, weeping is another factor for the plate column.

(Refer Slide Time: 16:43)



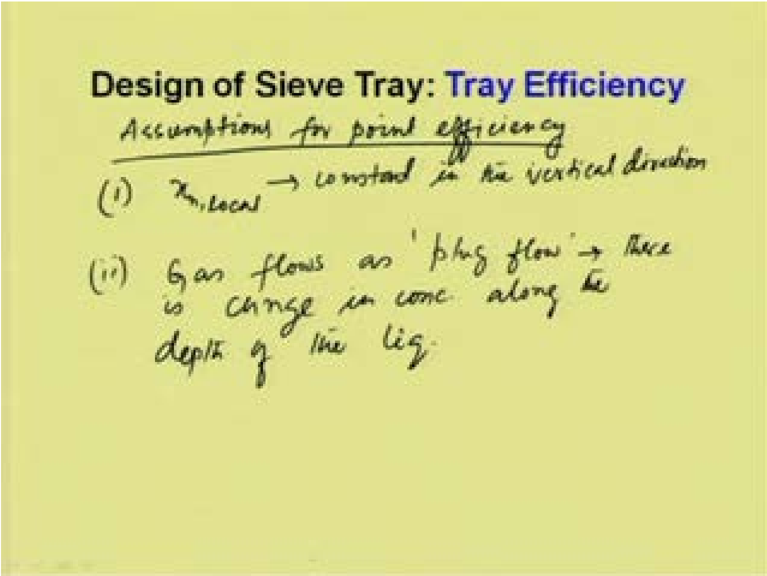
Weeping depends on the following factors: one is fractional hole area and then liquid rate, weir height, surface tension of the liquid, plate thickness and pitch length that we can see if the fractional hole area is more and weeping will be more; liquid rate is higher means weeping will also be higher; and higher weir height will lead to higher weeping and surface tension of the liquid if it is lower, then the weeping will be more; plate thickness if it is lesser then weeping also increases and if pitch length is smaller weeping will be more. It is proposed that if the fort number which is equal to rho G by rho L V h by G h l to the power 0.5 is greater than equal to 0.5 then weeping is not a major problem in this case. So, before designing if we calculate the fort number which is coming greater than 0.5 we can consider the weeping is not a severe problem.

(Refer Slide Time: 19:11)



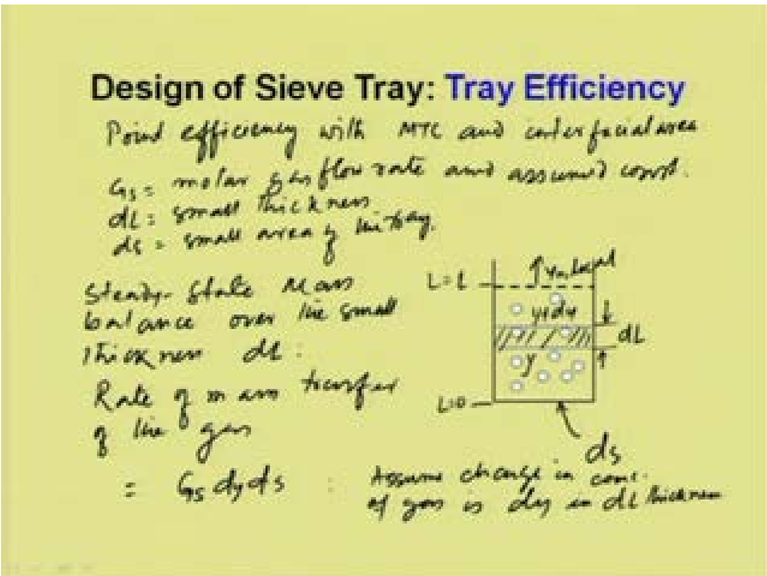
Now, we will discuss the tray efficiency. Let us consider this is n plus 1 tray, this is n tray and this is n minus 1 tray. The tray efficiency is the fractional approach by a real tray to an equilibrium stage. The contact among the gas and liquid in the plate is not uniform and the efficiency varies from point to point. So, first we will discuss the point efficiency. This is n plate and the vapor which is coming is y n local and the liquid which is coming out from this is x n local and the vapor coming from n minus 1 tray is y n plus 1 local. So, we can write point efficiency E o G is y n local minus y n plus1 local divided by y n local star minus y n plus 1 local; that is actual enrichment of the gas divided by maximum enrichment. So, y n plus 1 local is the local concentration of the gas leaving n plus 1 tray; and y n local is the local concentration of the gas leaving n tray; and y n star local is the concentration in equilibrium with x n local.

(Refer Slide Time: 22:43)



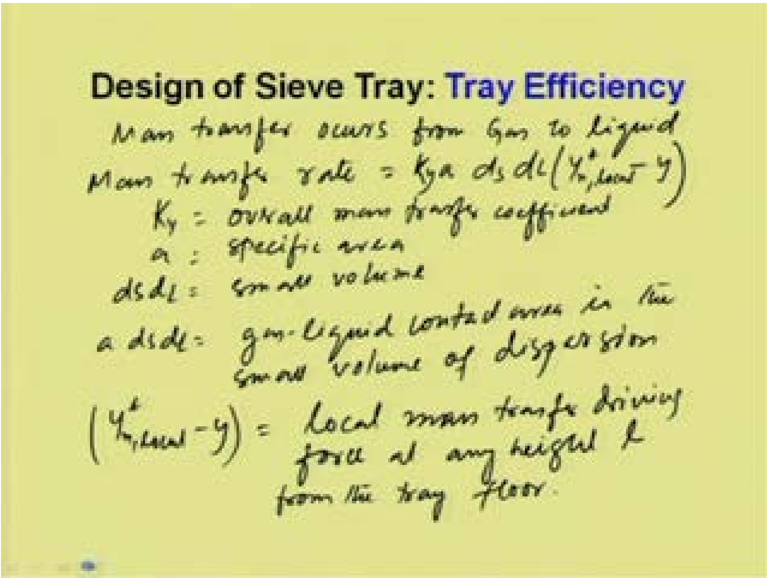
So, now, the following assumptions we have taken for point efficiency: one is the local concentration x n local is constant in the vertical direction; that means, vertically the liquid is well mixed so the concentration at each point is same which is x n local; and the second one the gas flows as plug flow that is there is change in concentration along the depth of the liquid. This tray efficiency depends on the mass transfer coefficient and the interfacial area.

(Refer Slide Time: 24:30)



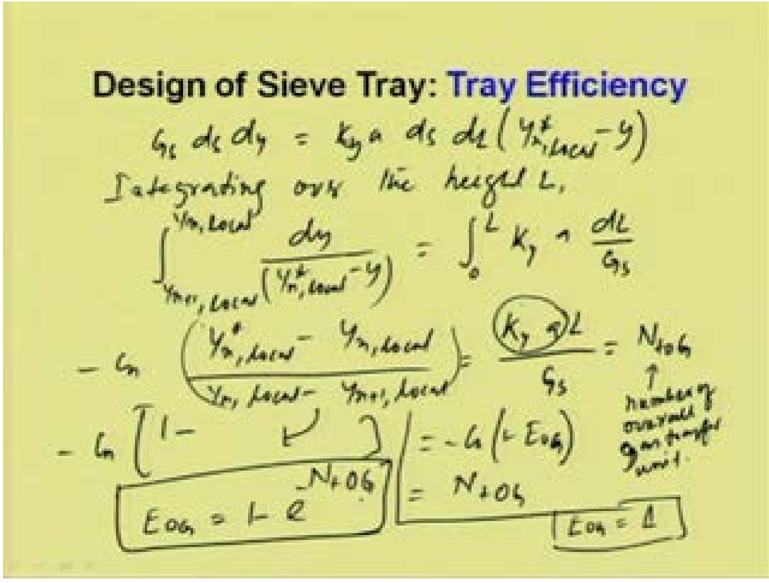
Now, we will try to correlate between the point efficiency with mass transfer coefficient and the interfacial area. Let us consider this is one plate whose liquid depth is here l is equal to 0; and here l is equal to l; and this is the point small thickness of the liquid on the plate we are considering which is d l and the small area you can consider which is d s and then in this side say the concentration change here is y and at this point y plus d y. And let G s is a molar gas flow rate and assumed constant and this is at the top surface this is y n local. So, d l is the small thickness, d s is the small area. If we do the steady state mass balance over the small thickness d l, the rate of mass transfer to the gas is equal to G s d y d s. So, the change in concentration is d y. So, this is the mass transfer rate. And assume the change in concentration of gas is d y in d l thickness.

(Refer Slide Time: 28:09)



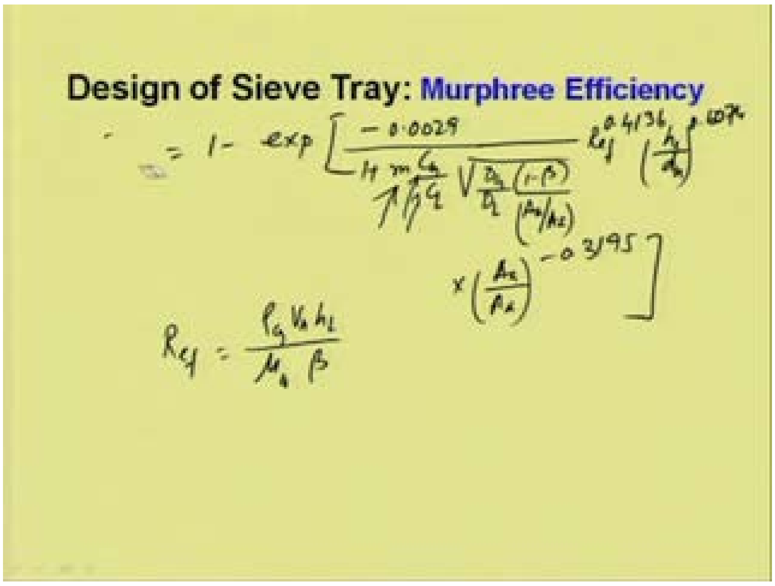
Here we have assumed the mass transfer occur from the gas phase to the liquid. So, the mass transfer rate, again we can write is equal to K y a capital K y a d s d l y n star local minus y; K y is overall mass transfer coefficient, a is the specific area, d s d l is small volume and a d s d l is the gas liquid contact area in the small volume of dispersion, and y n local star minus y this is the local mass trans for driving force at any height l from the tray floor.

(Refer Slide Time: 30:47)



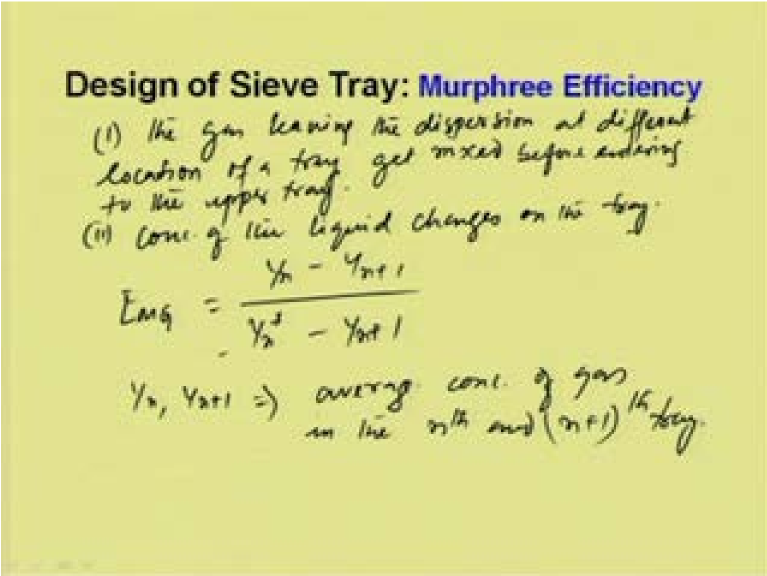
If we equate these two mass transfer rate, it will give you G s d s d y would be equal to K y a d s d L y L local star minus y. So, if we integrate over the height L this will be integral y n plus 1 local to y n local d y by y n local star minus y is equal to integral 0 to l K y a d l by G s. So, this will be minus L n y n star local minus y n local divided by y n local minus y n plus 1 local is equal to k y a L by G s which is known as N t o G, this is the number of overall gas transfer unit we can write minus L n 1 minus this part, this one would be equal to minus L n 1 minus E o G is equal to N t o G. So, we can write E o G is equal to 1 minus e to the power minus N t o G. This is the equations we have derived; if N t o G is very high then E o G will be equal to 1. This means the stage will approach to the equilibrium stage. So, for this we need to know the value of K y a, the point efficiency.

(Refer Slide Time: 34:16)



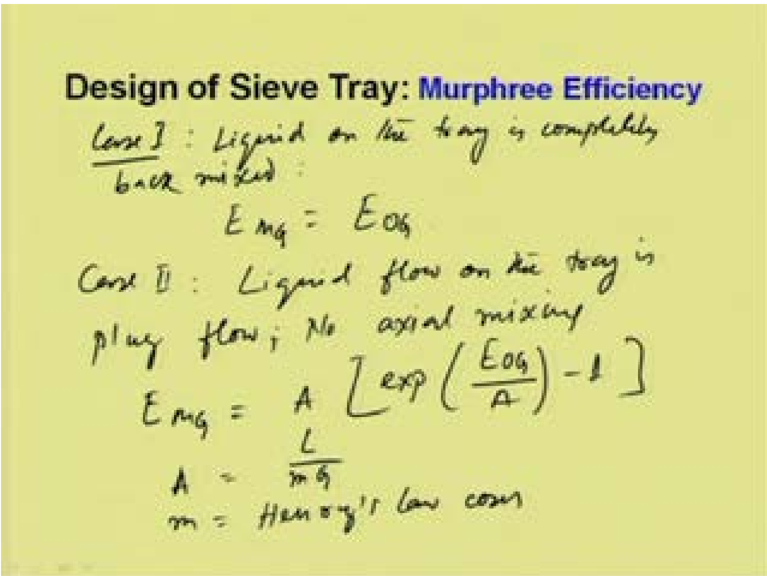
To calculate the point efficiency we need k y a. So, if we do not have then we can use the following correlations proposed for. So, this correlations we can use E o G will be equal to 1 minus exponential minus 00.29 divided by 1 plus m C G by C L root over D G by D L 1 minus beta divided by A h by A a R e f to the power 0.4136 h l by d h to the power 0.6074 into A h by A a to the power minus 0.3195; where R e f is equal to rho G V h h L by mu G beta; m is the slope of the equilibrium curve; and C G and C L these are the molar concentration of the gas and liquid respectively; and D G and D L are the diffusion coefficient of gas and liquid. This way we can calculate point efficiency. Now we will consider another type of efficiency which is known as Murphree efficiency.

(Refer Slide Time: 36:19)



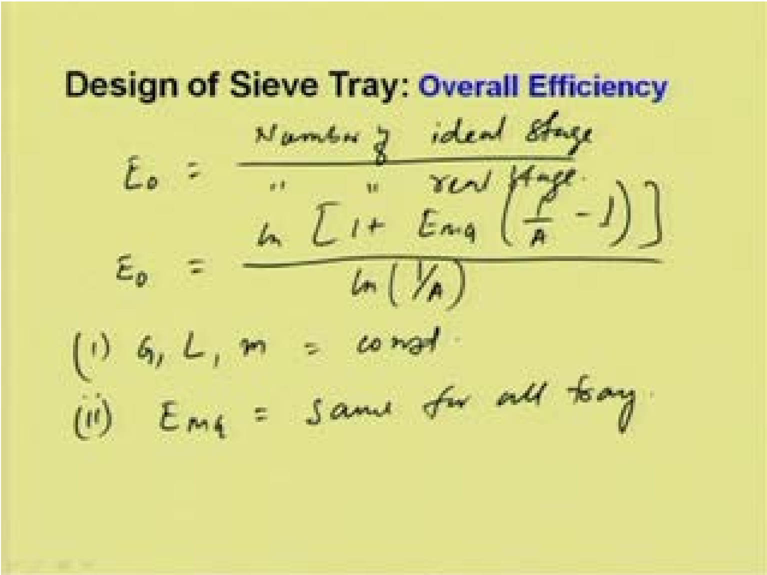
To derive the Murphree efficiency it is assumed that the gas leaving the dispersion at different location of a tray get mixed before entering to the upper tray; and the concentration of the liquid changes on the tray. So, this is defined E m G is equal to y n minus y n plus 1 divided by y n star minus y n plus 1; and this y n and y n plus 1 these are the average concentration of gas in the n and n plus 1 tray.

(Refer Slide Time: 38:21)



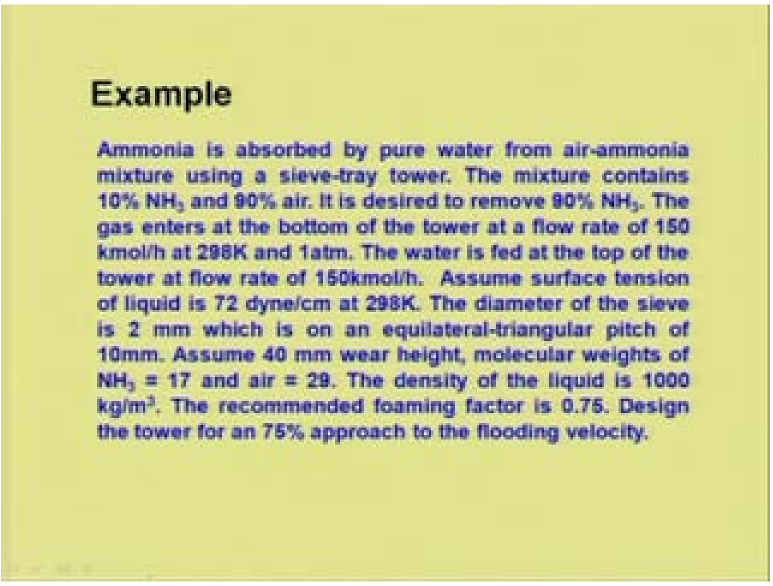
Now two cases may arise. In this case one when the liquid on the tray is completely back mixed then this E m G will be E o G; and if the liquid flows on the tray is plug flow then we can write that is no axial mixing, in that case we can write E m G will be A into exponential E m G by A minus 1. So, A is the L by m G and m is the Henry's law constant.

(Refer Slide Time: 39:55)



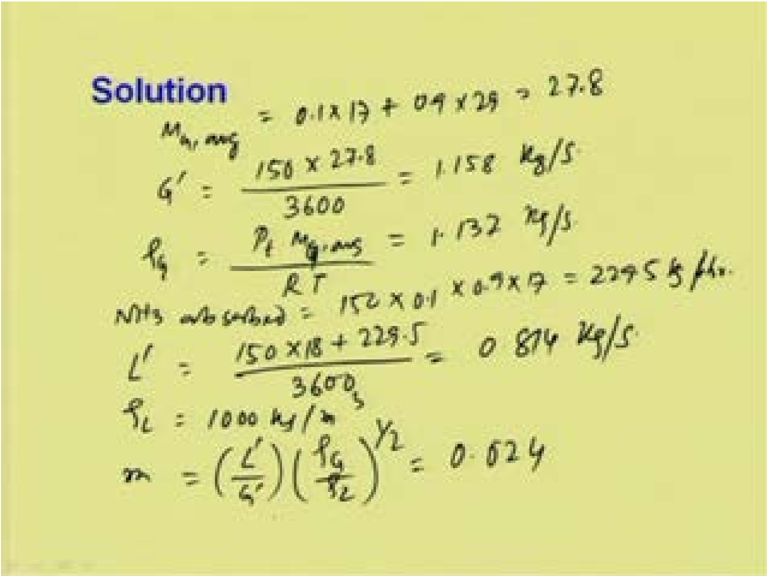
Now the overall efficiency E o is defined as the number of ideal stage divided by number of real stage. And the following relations between E m G and overall efficiency can be derived L n 1 plus E m G 1 by A minus 1 divided by L n 1 by A, only when the gas and liquid rate G and L and the slope of the equilibrium curve are constant; and the second is E m G is same for all tray. So, in this situation we can derive between these two.

(Refer Slide Time: 41:17)



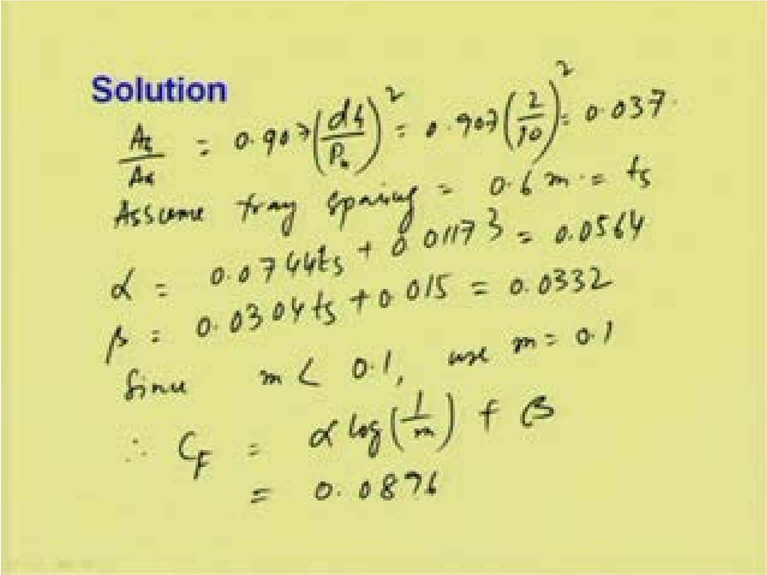
Now, let us consider a simple example. Ammonia is absorbed by pure water from air-ammonia mixture using a sieve-tray tower. The mixture contains 10 percent ammonia 90 percent air. It is desired to remove 90 percent ammonia. The gas enters at the bottom of the tower at the, that is the flow is counter current and the flow rate of gas and liquid are same that is 150 kilo mole per hour; the surface tension of liquid is given 72 dyne per centimeter at 298 Kelvin; the diameter of the sieve is 2 millimeter which is on an equilateral-triangular pitch of ten millimeter. Assume 40 millimeter weir height and molecular weight of ammonia is 17 and air is 29. The density of the liquid is given is1000 kg meter cube; and the recommended foaming factor is 0.75. Design the tower for an 75 percent approach to the flooding velocity.

(Refer Slide Time: 42:21)



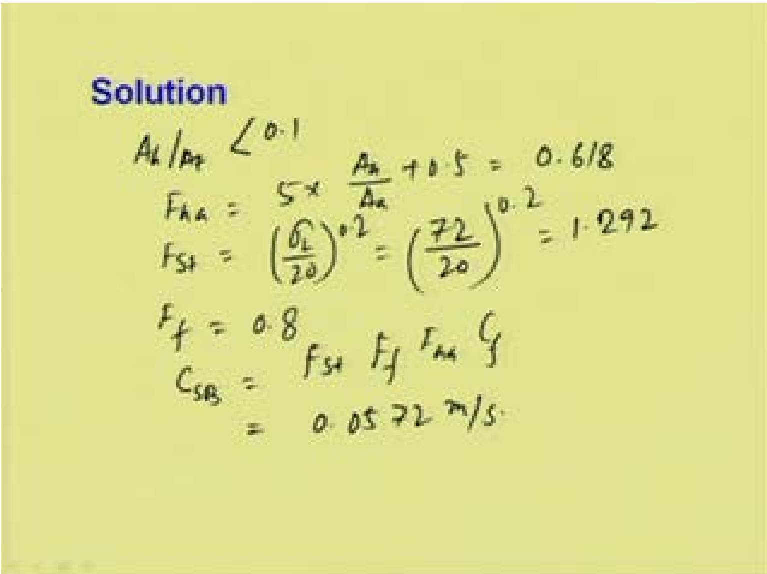
Now, let us consider how to calculate the diameter. We can calculate the average mass M of the gas m g average which is equal to 0.1 into 17 plus 0.9 into 29. So, it will be 27.8. And the gas flow rate which is given is 150 into 27.8 divided by 3600. So, it will be 1.158 kg per second. Now rho G we can calculate p t M G average by RT. So, putting these values it will be 1.137 kg per second. Now ammonia absorbed is equal to 150 into 0.1 into 0.9 into 17 is equal to 229.5 kg per hour. Now L dash is 150 into 18 plus 229.5 divided by 3600. So, it will be 0.841 kg per second. And rho l is given 1000 kg per meter cube. So, m we can calculate L dash by G dash into rho G by rho L to the power half which is equal to, if we substitute these value, 0. 024. So, slope is known.

(Refer Slide Time: 44:37)



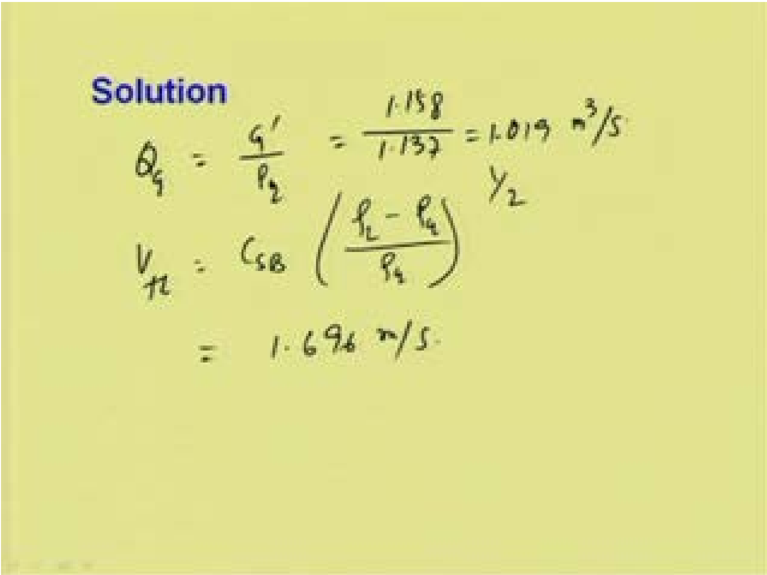
Now, we can calculate A h by A a is 0.907 d h by p h square 0.907 2 by 10, the pitch length is ten and the sieve dia is 2 square, so it will be 0.037. We can assume tray spacing is 0.6 meter, then we can calculate alpha which is 0.0744 t s plus 0.01173. So, this will be around, substituting this t s, 0.564; and beta we can calculate 0.0304 t s plus 0.015 which is equal to 0.332. Since m is less than 0.1 we have calculated, we can use m is equal to 0.1. So, CF we can calculate alpha log 1 by m plus beta. So, substituting these values this will be 0.0896.

(Refer Slide Time: 46:28)



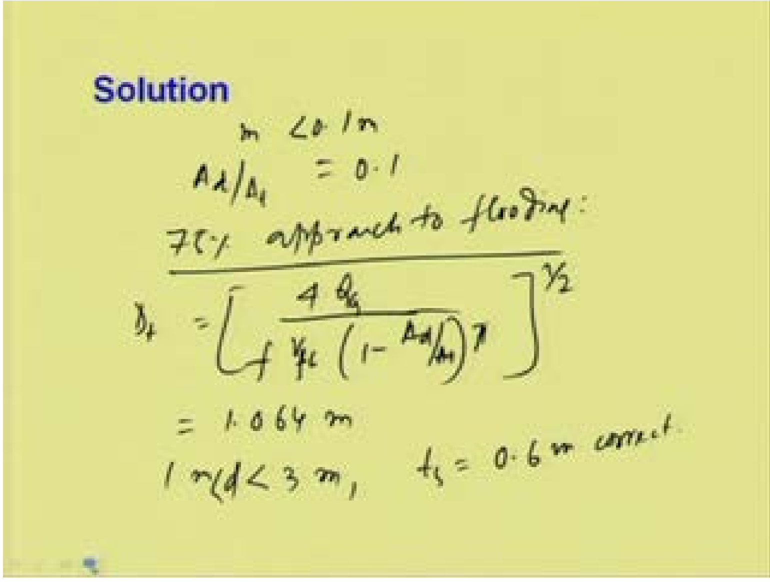
Now we know that A h by A t is less than 0.1. So, F h a we can calculate 5 into A h by A a plus 0.5 and this will give 0.618. F s t also we can calculate, which is sigma L by 20 to the power 0.2 and which is equal to 72 dyne by 20 to the power 0.2 which will be equal to 1.292. So, and we can calculate we have taken the factor 0.8, so now we can calculate C SB is equal to F s t F f F h a and C f; substituting these values this will be equal to 0.0572 meter per second.

(Refer Slide Time: 47:43)



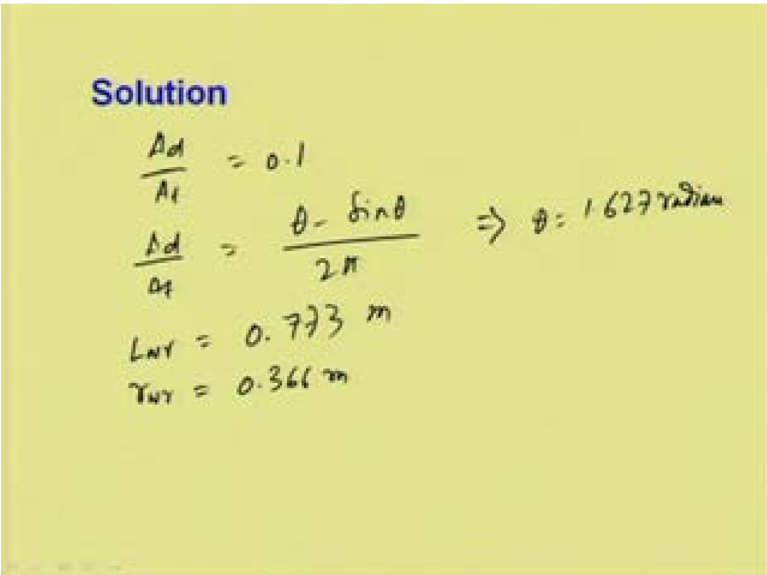
Now we can calculate gas flow rate, volumetric flow rate which is G dash by rho G and which is equal to 1.158 divide by 1.137 which is equal to 1.019 meter cube per second. Now, V f L is C s B rho L minus rho G by rho G to the power half; now substituting these values it will be 1.696 meter per second.

(Refer Slide Time: 48:39)



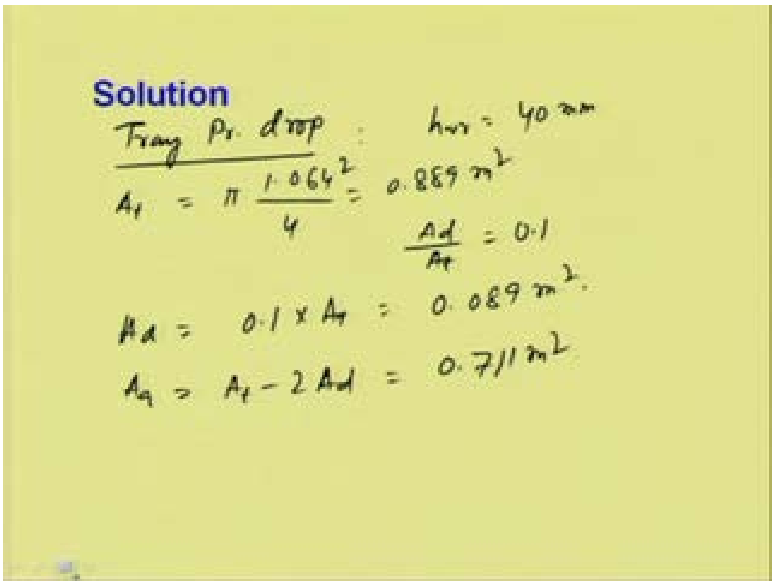
Since m is less than 0.1 meter we can use A d by A t is equal to 0.1; and 75 percent approach to flooding. So, we can obtain D t is equal to 4 Q G by f V f L 1 minus A d by A t into pi to the power half. So, substituting this, this will be 1.064 meter. Since the diameter is greater than 1 meter and below 3 meter, we can write the assumptions of t s is equal to 0.6 is correct. So, no more iterations is required to calculate the diameter with the assumed tray base spacing.

(Refer Slide Time: 50:05)



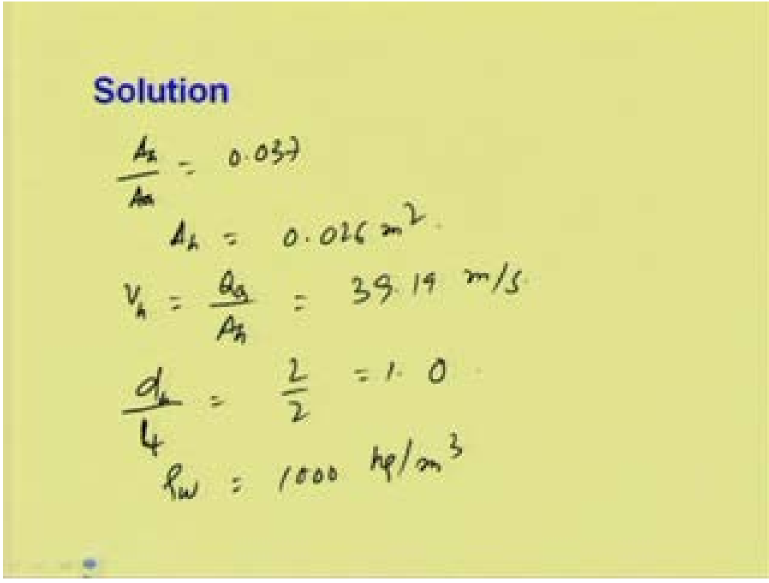
Now we can calculate A d by A t is known to us 0.1; and A d by A t we know that theta minus sin theta by twice pi. So, from this we can calculate theta is equal to 1.627 radian and d is known, so L w r which is length we can calculate which will be 0.773 and r w r will be around 0.366 meter.

(Refer Slide Time: 51:03)



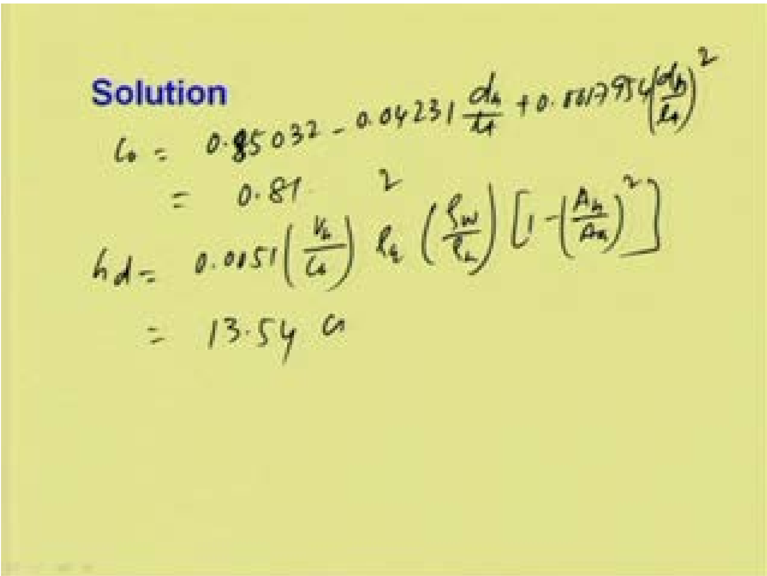
So, the tray pressure drop, the weir height is given h w r is 40 millimeter; and then we can calculate tower cross sectional area A t is pi into d square by 4 which is equal to 0.889 meter square and since A d by A t is equal to 0.1, down comer area A d we can calculate 0.1 into A t which is 0.089 meter square; then active area A a can be calculated A t minus twice A d. So, this will be around 0.711 meter square.

(Refer Slide Time: 52:10)



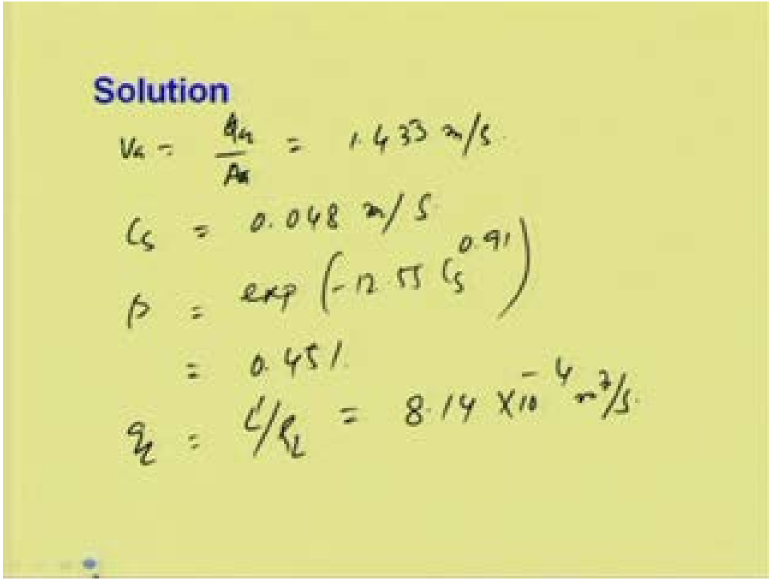
Now A h by A a is 0.037. So, A h will be 0.026 meter square V h Q G by Ah, if we substitute it is 39.19 meter per second. So, dh by L t is 2 by 2 is 1.0; and rho w is 1000 kg per meter cube.

(Refer Slide Time: 52:53)



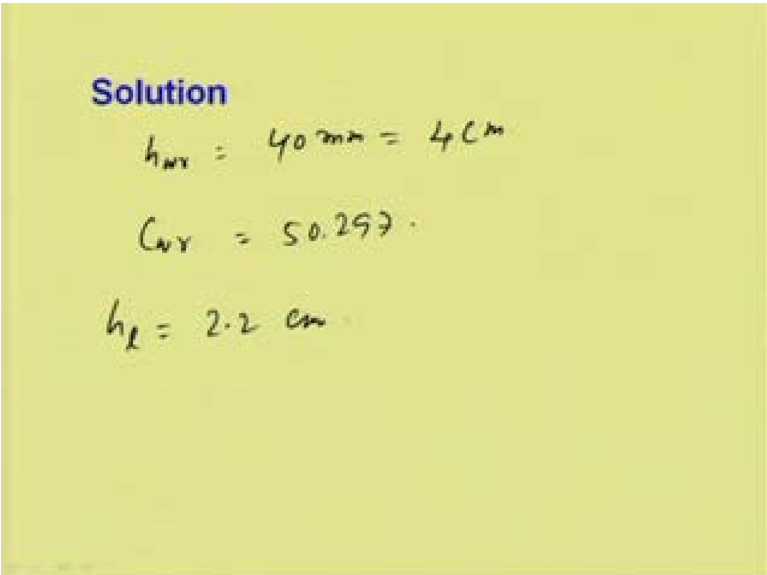
With this we can calculate C o which is 0.85032 minus 0.04231 d h by L t plus 0.0017954 d h by l t to the power square. So, if we substitute, this will be 0.81. Now, h d we can calculate which is 0.0051 V h by C o square rho G rho w by rho L 1 minus A h by A a square. So, this will be about 13.54 centimeter.

(Refer Slide Time: 54:00)



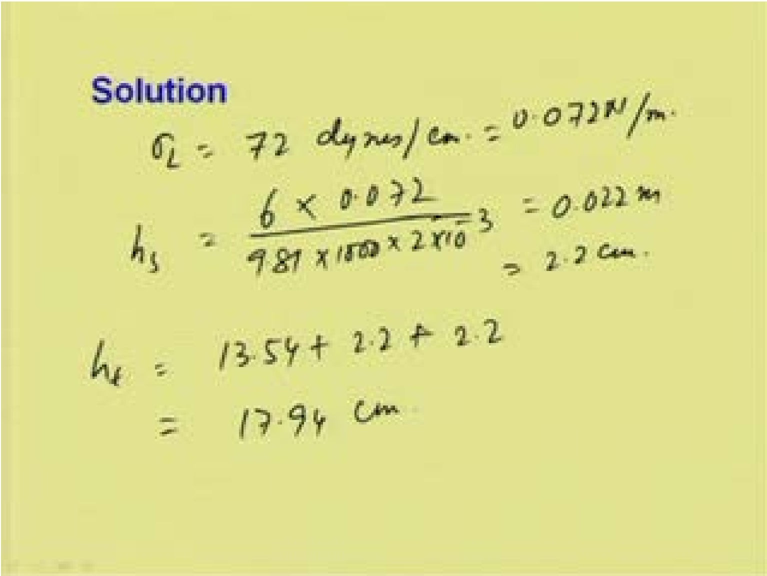
Now, we can calculate V a, Q G by A a which is 1.433 meter per second; and C s we can obtain substituting the data 0.048 meter per second; beta we can obtain then exponential minus 12.55 C s to the power 0.91. So, this will be 0.451. Now q L is L dash by rho L which is 8.14 into 10 to the power minus 4 meter cube per second.

(Refer Slide Time: 54:54)



And we have h w r is 40 millimetre, which is 4 centimetre. So, we can calculate C w r which is equal to 50.297. So, from this we can calculate h l which is 2.2 centimetre.

(Refer Slide Time: 55:20)



Similarly, if we know the sigma L which is 72 dynes per centimetre is equal to 0.072 Newton per meter. So, h s we can calculate 6 into 0.072 divided by 9.81 into 1000 into 2 into 10 to the power minus 3. So, which is 2 point point zero sorry, 0.022 meter which is 2.2 centimetre. So, the total head h t is equal to 13.54 plus 2.2 plus 2.2. So, total is 17.94 centimetre. So, the other part of the design like entrainment calculations if we substitute this data, we can see that there is not much entrainment for the liquid and the weeping also less, the froude number will be around 0.5. So, in the next class we will discuss the equipment for liquid disperse.

Thank you for your attention.