Physico-Chemical Processes for Wastewater Treatment

Professor V. C. Srivastava
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Lecture - 17
Aeration - VI

Good day everyone and welcome to this lecture, we will be continuing with the aeration section, where aeration is being used for removal of VOC's, dissolved gases and some amount of metals, some amount of other elements like iron and magnesium et cetera can be removed by aeration. So, in the previous class we studied how to determine the volume of a some treatment unit, where some amount of VOC has to be removed.

So, in the first case, we tried to understand that how to determine the volume in the case where the VOC has to be removed using the surface aeration condition, where a mechanical type of aerator may be used. In the second case, we try to learn regarding a treatment process in which diffused aeration is being used and how to determine the volume of the unit so, that the desired aeration can be performed. So, now, we are going to solve a problem related to this and then we will further study another type very common type of aeration which is like packed bed aeration, where stripping is being done for removal of any VOC from the water phase into the air phase. So, this is being done.

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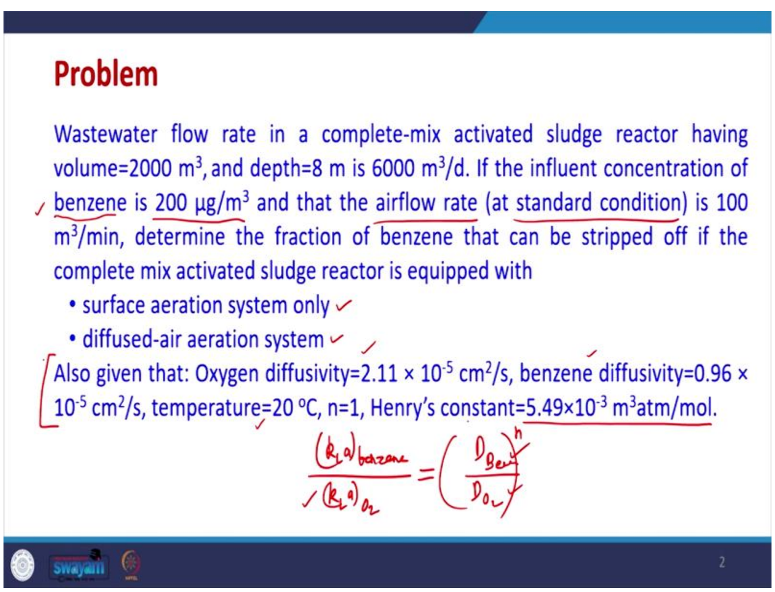

So, we will start with the trying to solve a question related to VOC removal designing a unit. So, in this problem, there are certain conditions. So, in any problem in actual condition, though, we always give a question which is very simpler, but in actual condition the questions are not simple, any question has two three sections, one of the sections is like the one which will be given by any industry in simple means.

Second section is the one where we the learned persons have to go and collect the data from that industry. So, all the parameters have to be determined by us in the third case, again we have to look into the literature and determine all other known parameters which are required for solving that problem.

And in the fourth step actually we solve the problem. So, as to tell okay, this is what is required for your problem and how to solve. So, in this particular problem, suppose a industry is there and it is telling us that they are having a and already a reactor is there which is having a 2000 metre cube volume and that depth of the whole activated sludge process is 8 metre or the aeration unit is only 8 metre and they are having a flow rate of 6000 metre cube per day of water. And in that particular water the concentration of one of the VOC is there and that VOC is benzene and its concentration is 200 microgram per litre.

Now, the industry wants that all of the VOC should be removed and they want to determine that how much friction will be removed under certain conditions. One condition is that they are using only surface aeration and in the second case they are only using diffused air system. Now, they are also telling that they have a airflow like a air flow rate some air is available at a certain flow rate and that flow rate is 100 metre cube per minute at a standard condition.

So, what we have to find out there is that determine the fraction of benzene that can be stripped off if the complete mix activated sludge reactor is considered. So, this is known. Now, we can always find this data from the literature because it is given for benzene. So, that means we will have to find out the KLa value as we know beforehand for solving such type of problem we have to find out that KLa values.

Now, KLa values are not easily available. So, we will have to look into the literature to look at the relationships which are available. So, relationship already we have determined that relationship with respect to like finding out for benzene will be like this. So, for benzene this is written, so, we will always look for KLa value with respect to oxygen and that will be in relationship with the diffusivity value of benzene and also with respect to diffusivity value of O_2 up to a certain index n.

So, if we can find out the diffusivity of benzene in water diffusivity of oxygen in water and overall mass transfer coefficient value of oxygen in water, then we can find out that diffusivity overall mass transfer coefficient of benzene which will be the essentially required thing for solving this problem.

Again for diffused aeration system, we require the Henry's constant also, if you remember, in the previous class, we derived the equation for that, so that means we will have to look for the Henry's constant. So, if you look for the Henry's constant for benzene its value is this as the one which is reported in the literature. So, we have the oxygen diffusivity value which is given, benzene diffusivity value which is given and the temperature of whole operation is 20 degrees centigrade, the index is already given 1 and Henry's constant is given. Now, we have to solve for each of the condition.

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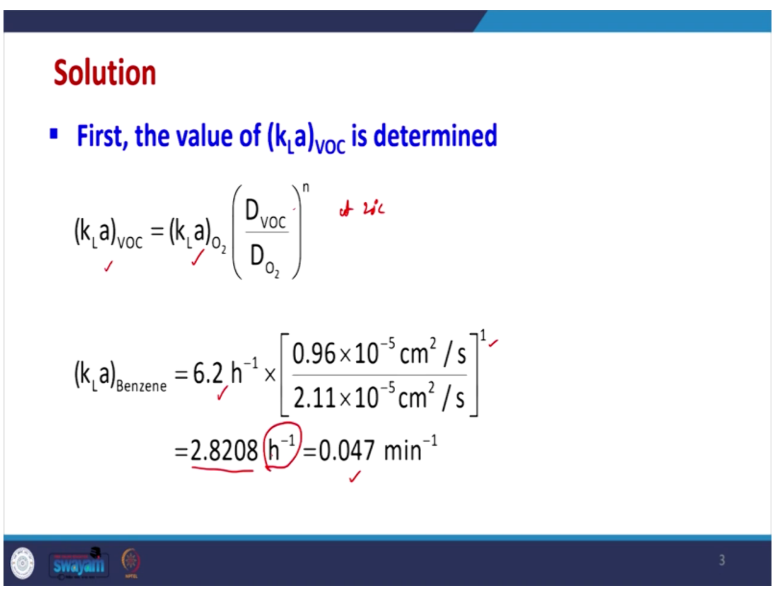

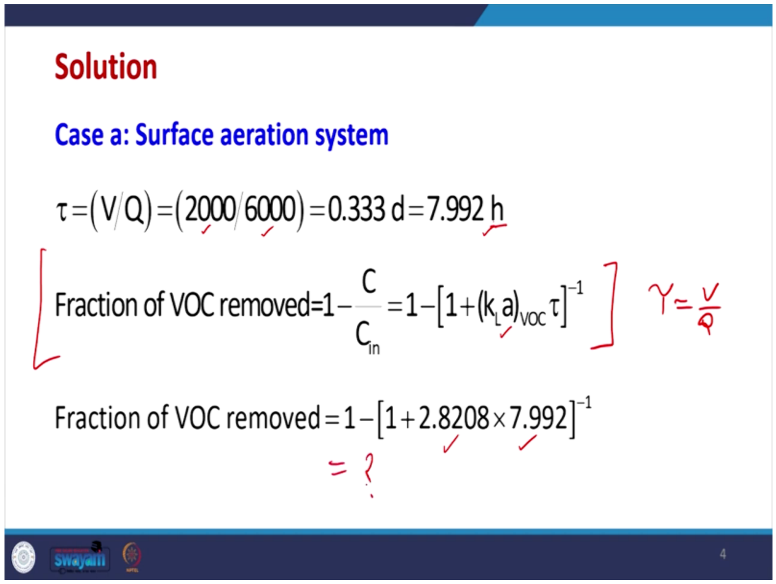

So, for surface aeration only if suppose we have only surface aeration and in the second case we have only diffused aeration. So, first step is to find out the KLa value if you remember, the equation for surface aeration was this and within this that tau value is given by V by Q. So, this this was the equation that we derived in the previous class.

Now, for finding out the KLa what we do is that, we use the equation that we did earlier and all this is all the values are known for diffusivity overall mass transfer coefficient of oxygen in water is given so this is 6.2 per hour and these diffusivity values are already given. So, using the index of 1 we can solve it easily and we can get 2.8208 per hour or it is like 0.047 per minute.

So, this is the first step and we can find out the KLa of the benzene. Similarly, for any other problem, we can find out the KLa for any other VOC if the generally these diffusivity values are given at 20 degrees centigrade. So, if we have to find out the KLa value of VOC at any other temperature, then we have to use the temperature relationship as well.

So, this is so again we will have to look for some data from the literature for finding out the overall mass transfer coefficient of VOC in that water at maybe elevated temperature of 35 degrees centigrade. So, some relationship we will have to look into the literature and get the values of those empirical constant in that particular equation.

Now, going further, we have to find out the V by Q value and V is already given 2000 and 6000 is the flow rate in metre cube per day. So, we have 0.33 per day and which is equivalent to 7.992 hour. So, this is now known to us. So, we put all the values in there and we can find out so, this is like 1 plus so value, we can write down the this value and remember both the values are in terms of hour. So, we are keeping this our value here 2.8208 because this value is in hour and if we solve we can get the fraction of VOC removed. Now, in the second case, I am missing this. So, we can easily find out this value.

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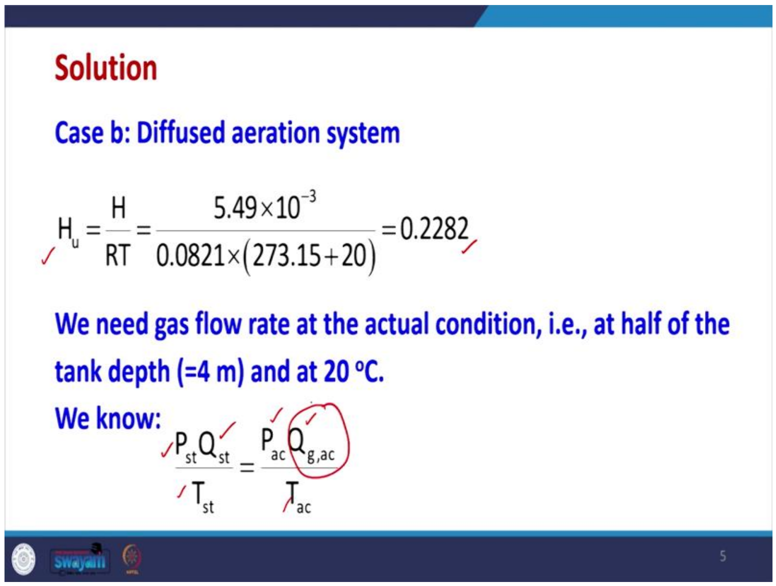

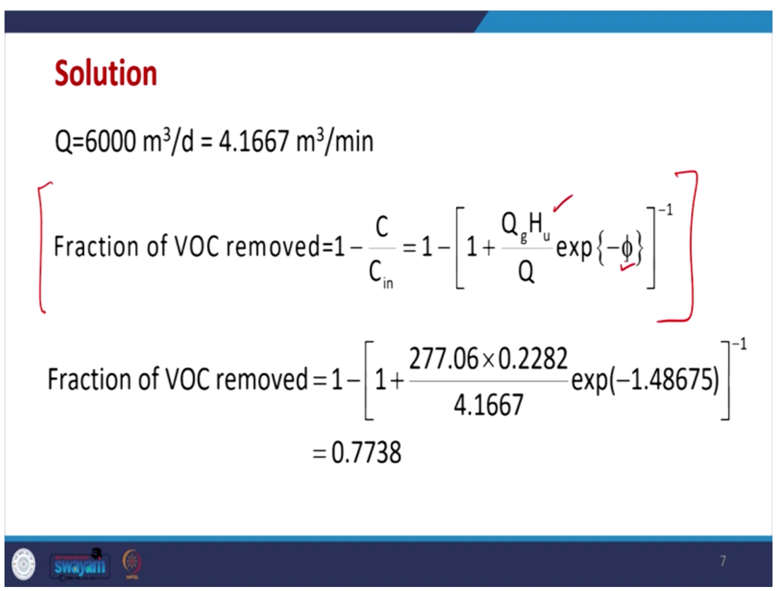

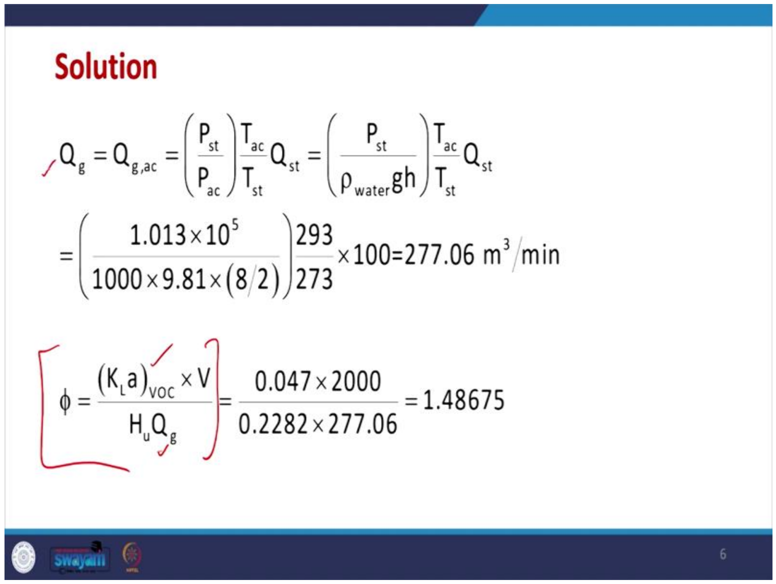

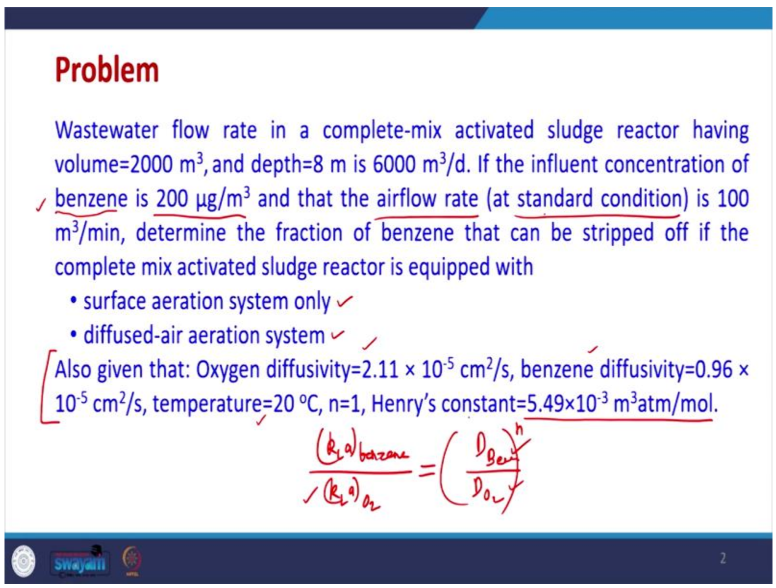

In the second case for the diffused aeration system, if you remember the equation was given like this that the final equation was like this, we derived and for solving this we require Hu, we require this psi and this psi itself is given by this particular equation and in this KLa is also required.

So, we have already solved the KLa there is no issue, we have to find out the actual flow rate of the gas at that temperature and pressure. So, this we have to solve separately. So, this is done here. So, we are solving like this first we have to find out the dimensionless Henry's constant. So, for this we are doing dividing by RT. So, we are using appropriate units so, that it is dimensionless. So, this is the first step, second step is that we have to find out the gas flow rate at the actual condition and actually in the problem it is given that we have the flow rate outside a system at 100 metre cube per minute at standard condition.

So, standard condition it is known, so, what we are doing is that, we are using the this equation P is equal an RT equation. So, P at the standard condition flow at the standard condition is divided by T at the standard condition is same as P at actual condition Q at actual condition and T at actual condition. Now, we had to find out this thing.

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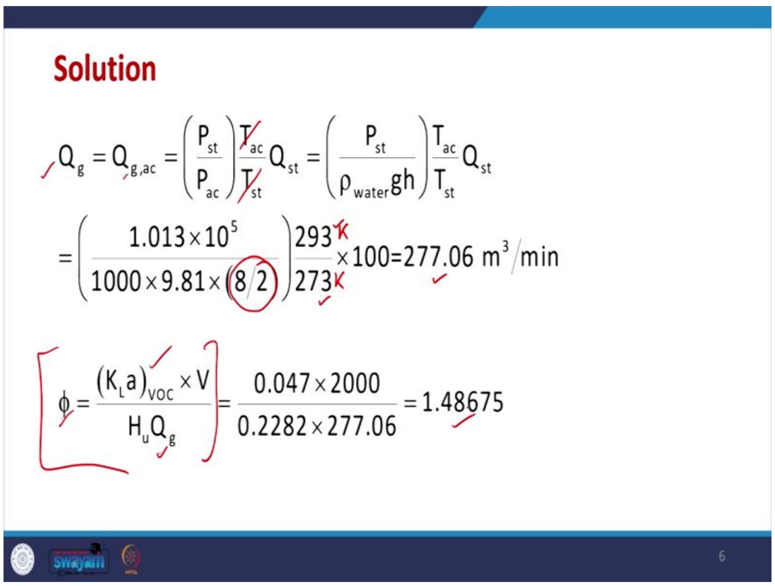

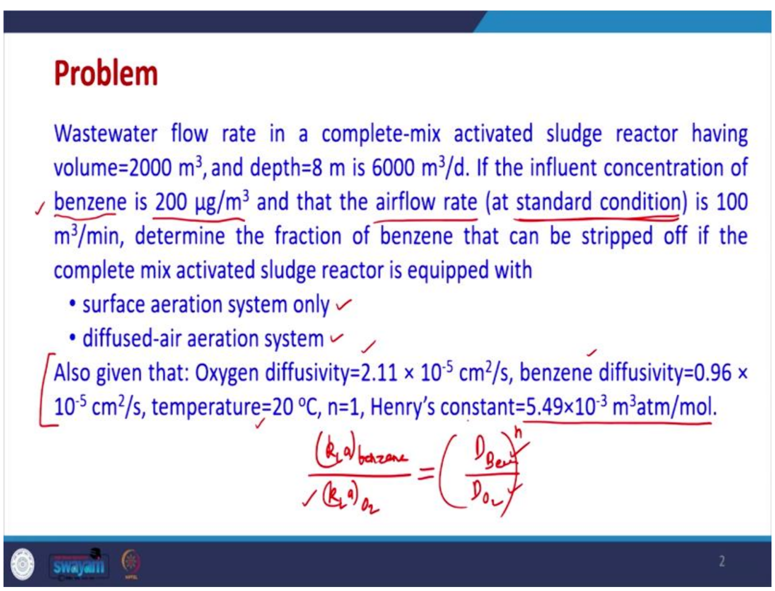

Now, this equation can be changed. So, Qg is actually equal to Qg ac and this is the equation. Now, we are what we are doing we are assuming this both the temperatures to be same. So, no, no, here at the standard condition it is given 200, 100 metre cube per minute. So, at a standard condition it is 273 degrees centigrade and here we have to calculate at 20 degrees centigrade it is 293 kelvin.

So, we are using both the temperatures here they are not getting strike out, so, both the temperatures are kept similarly, we have to know the rho gh condition, so, using this and we find out pressure at half the half the height. So, 8 metre is the height of the, this whole tank. So, what we are finding average height.

So, that is why 8 by 2 division has been done and if you solve it actually it will come out 277.06 metre cube per minute in terms of this as compared to the earlier value which is already given as 100 metre cube per minute at the standard condition. So, at this pressure condition this comes out to be like this. So, we can solve it and then we can find out the value of psi. So, this is given here.

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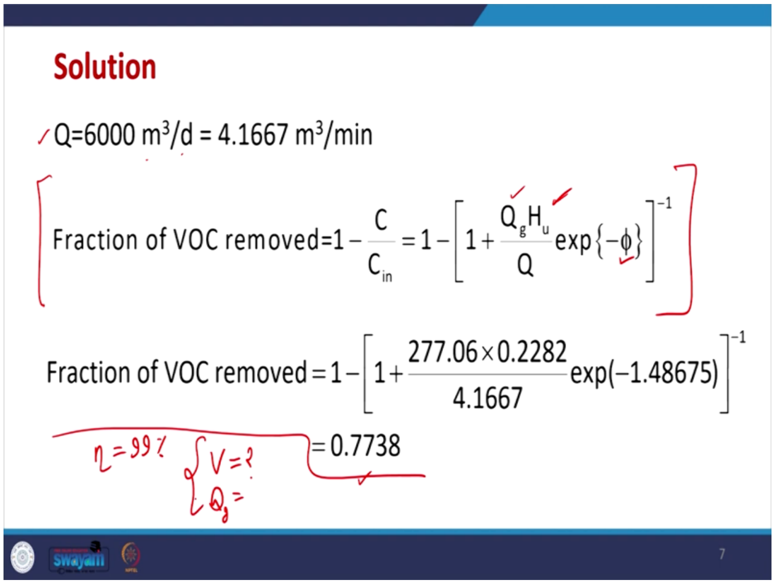

And thereafter, we put the flow rate is given in metre cube per day. So, we have to change in metre cube per minute. So, that appropriate units are taken and overall if you put all the values Qg Hu psi et cetera. So, we get to solve and we find that 77 percent or 0.77 fraction of the total VOC will get removed in that diffused aeration case. So, through these problems, we can solve vice versa also we can always fix it, there is a possibility that we want the fraction of VOC removed suppose it is desired the efficiency to be 99 percent so, this is possible.

So, efficiency is known. So, under that condition, we have only two manipulations which are possible one is the volume of the reactor. So, we can vary the volume of the reactor in actual then condition and second variation which is possible is the flow rate of the gas. So, we can increase the flow rate to remove the efficiency. So, both these two are the manipulating variables in this particular case for diffused aeration. So, we can always play with them, so, that so, as to reach a optimum condition under which that desired efficiencies can be the. So, this way we can perform the calculations.

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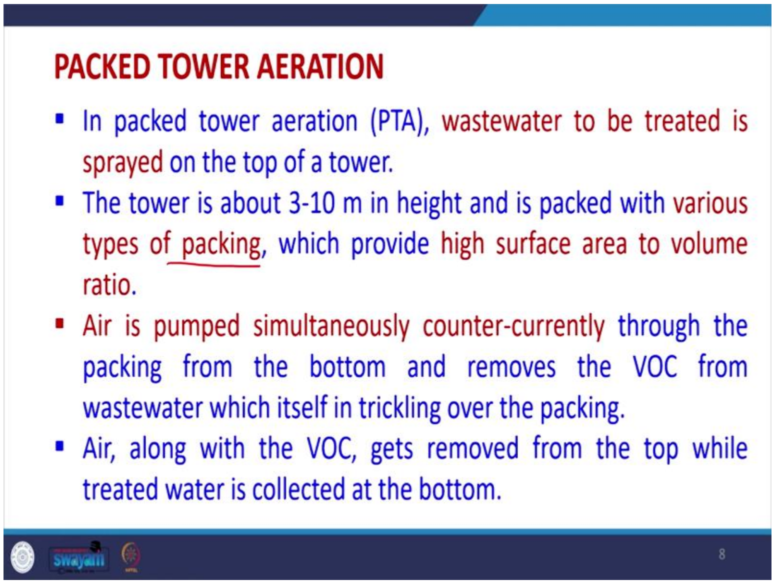

Now, going further there is another type of aeration which is very common it is called packed tower aeration. So, in the packed tower aeration wastewater which is to be treated is sprayed on the top of the tower and the tower height may be anything from 3 to 10 metre a little higher a little lower and is packed with various types of packing.

So, these packings are very important because we desire very high surface area to volume ratio and some other parameters which are actually used for calculation or for design depend upon this packing. So, what type of packing we are using? So, they may be structured packing, they may be random banking et cetera. So, this is very very important parameter in the packed bed or packed tower aviation after that water there is coming from that top and air is pumped counter currently have from the bottom through the packing from the bottom and actually while moving up, it removes a VOC from wastewater and which itself is actually being trickled over the packing. So, air along with the VOC gets removed from the top while treated water is collected at the bottom. So, this is the packed tower aeration.

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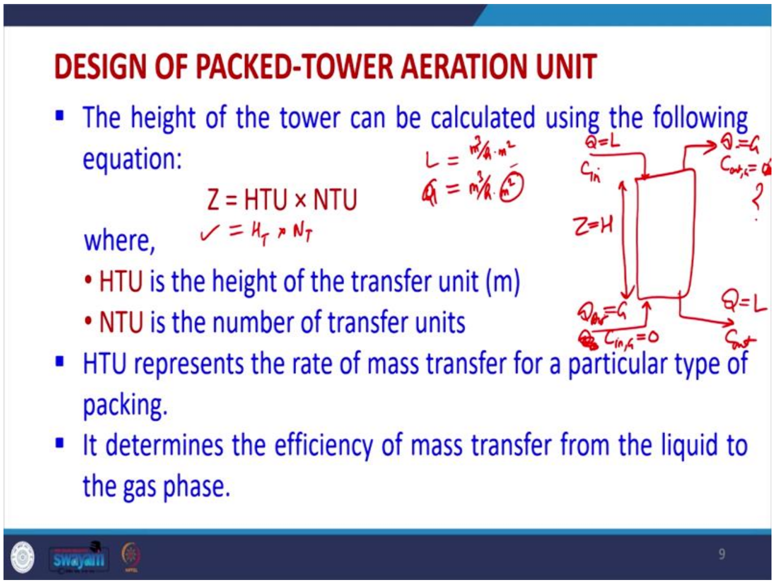

So, this is a simple packed tower aeration we may write like this. So, water is coming here, it will be having some concentration of pollutant and this water will go out from here and its concentration will be reduced a certain value will be having a air. So, we can write for air some flow rate, it will be certainly having no VOC concentration initially and then it will be going out at certain air flow rate.

So, like Q is generally for the packed bed it is represented because it is in a liquid phase we always write generally in L. So, this is in place of Q we write L and for air generally in the gas phase, so it will be write to G. So, L and G are common known things and for this the C out which will be there for the gas phase, this will be equal to some particular value not 0. It will be Qn sorry, the concentration which is in, in the gas phase of the VOC this will be 0.

But this will be certain value which we have to determine and for that we always want to know that what should be the height of this packing. So, this is desirable and this is actually given by Z. So, the height of the tower can be calculated using the equation which is given here. This is this how to calculate the height of any packed tower for different mass transfer operations which include aeration, absorption very various other operations mass transfer operations.

So, this is taught in detail in the chemical engineering subjects in particular in mass transfer or design of mass transfer units, what will be only studying in this particular lecture will be only a small section of that. So, if anybody is interested in going learning this in detail, they have to study in depth other books related to chemical engineering for better understanding.

But still we will get the some idea how to find out the height of the tower for aeration. So, HTU height of the tower is multiplication of HTU into NTU, HTU is called height of transfer unit and NTU is called number of transfer unit. So, sometimes they are written like this into NT. So, there are different ways in which they can be.

So, it and height is one of the essential parameters that we have to find out with aspect to design and also via using the flow rates, the superficial flow rates with respect to area actually we had to find out this L and G value. So, L and G value are generally represented as the flow rate per hour per metre square of the bed. So, this is called this is what is desired and similarly for gas phase also, we can write like this. So, and where this metre square gives the surface area, this cross sectional area and from that we can know the diameter. So, this is how we can find out that diameter of the bed as well as the height of the tower.

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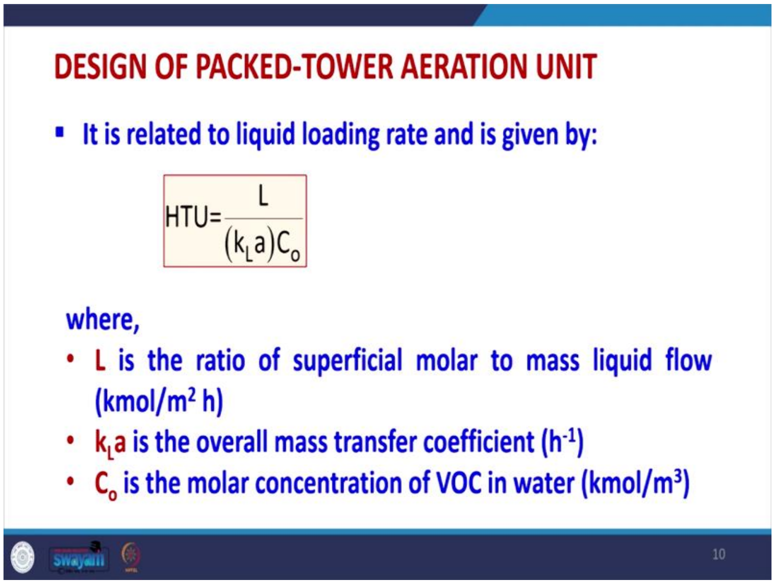

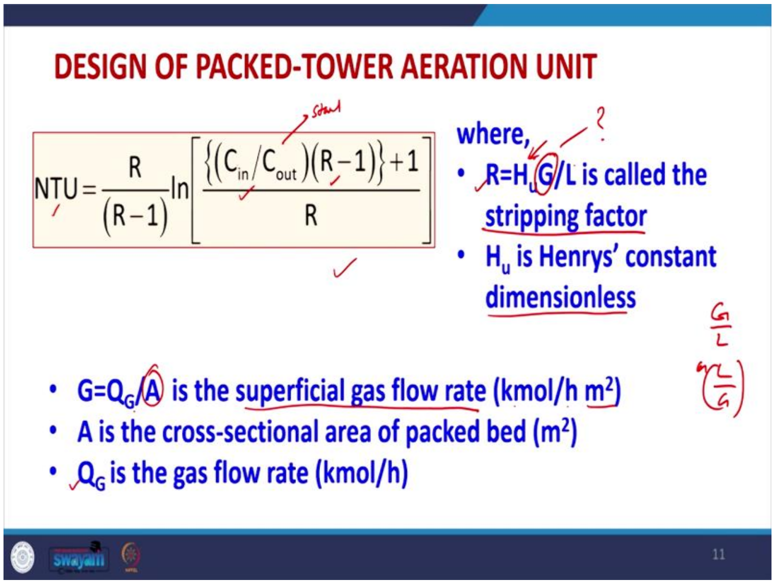

HTU is related to liquid loading rate and is given by:

$$HTU = \frac{L}{(k_L a) C_o}$$

where,

- L is the ratio of superficial molar to mass liquid flow (kmol/m^2 h)
- $k_L a$ is the overall mass transfer coefficient (h^{-1})
- C_o is the molar concentration of VOC in water (kmol/m^3)

Now, HTU can be found out using this equation for packed aeration unit or any other, where it is the ratio of L divided by overall mass transfer coefficient multiplied by the molar concentration of VOC in that water. So, it is like molar concentration of in the water what is the molar concentration that we have to determine. So this is there.

NTU can be calculated as:

$$NTU = \frac{R}{(R-1)} \ln\left[\frac{\{(C_{in}/C_{out})(R-1)\}+1}{R}\right]$$

where,

- $R = H_u G/L$ is called the stripping factor

- H_u is Henrys' constant dimensionless

And it is related to loading rate. Similarly, we can determine the NTU and the number of transfer unit using this formula. And within this formula, there is a term which is called as a stripping factor. So, a stripping factor R is called Hu by GL where Hu is the Henry's constant in dimensionless form.

So, again Hu we have to find out we have to find out G and L and from that we can calculate the R value. So, if R value is known, and we have the inlet concentration of the VOC and outlet concentration, whatever is desirable and this will be as per the standard. So, if this is known, we can find out the NTU.

So, if you had to find out NTU this is already fixed, only R has to be fixed now, if R has to be fixed Hu is already known, because Hu for any VOC is known to us. Now, the liquid flow rate is also fixed, because we know at what flow rate the wastewater is being generated. So, that means, the G is the only variable that we have to find out and this G by L G by L or we can call it L by G, this is what we have to determined and this is determined by material balance.

So, why material balance we can find out the minimum L by G and then we can take some L by G value of above that. So, we can always have some value idea regarding this G by L or L by G so, we will understand this when we will solve the problem, where G is the superficial gas flow rate.

So, remember, the general flow rate is like kilo mole per hour, but we are dividing by here metre square and A is the cross sectional area of the packed bed. So, here A is the cross sectional area. So, this is also one of the our manipulating variable, because, we have to find out the diameter of the packed bed also So, from here we can get the idea of what will be the diameter QG is the normal gas flow rate which is there.

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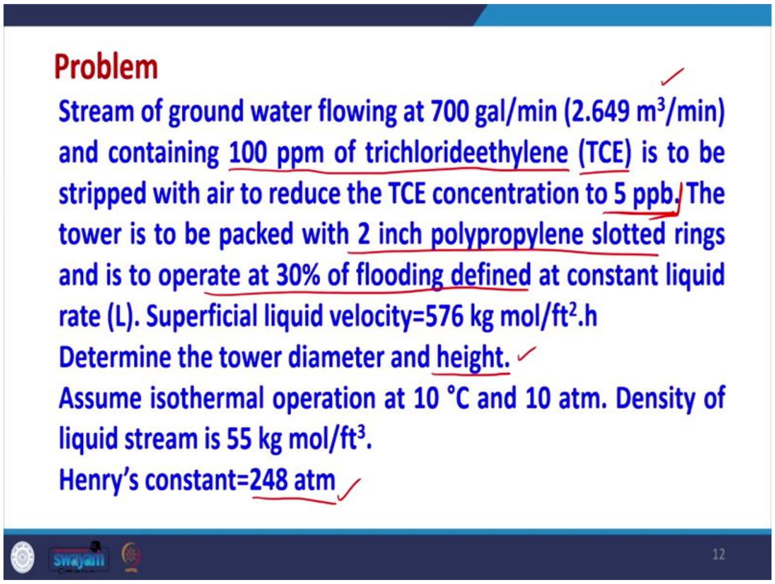

So, let us understand a little bit regarding how to solve problem. So, here a problem is given that a groundwater is having we desire a groundwater at this rate for our community, but that groundwater is having 100 ppm of trichlorideethylene. So, this TCE is there trichlorideethylene in is there and which is not desirable and it has to be removed from 100 ppm to 5 ppb which is the standard given by different organisations for drinking or for any uses purpose.

So, we have to reduce the TCE from 100 ppm to this particular value, now, the tower is packed with 2 inch of. So, this is the thing with the designer does. So, suppose this problem comes to us. So, we will choose that which type of packing we have to use at what operating conditions flooding conditions.

So, all these things you can learn more in mass transfer operations, which is taught more in detail in chemical engineering. So, you can go there we have to find out the tower diameter and height in particular we are will be only trying to find out the height for our case, so, that we can understand it a little bit better. And we are assuming isothermal operation density et cetera is given Henry's constant in non dimensionless form is 248 atmosphere for TCE so this is known to us.

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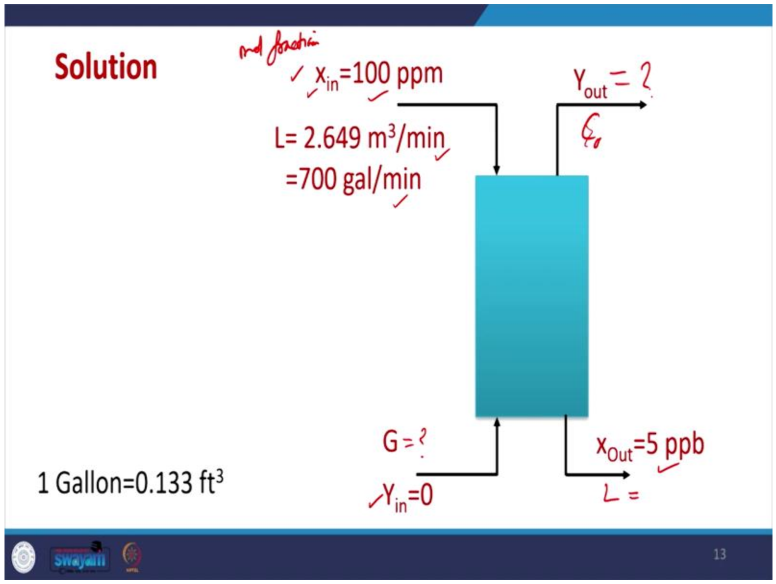

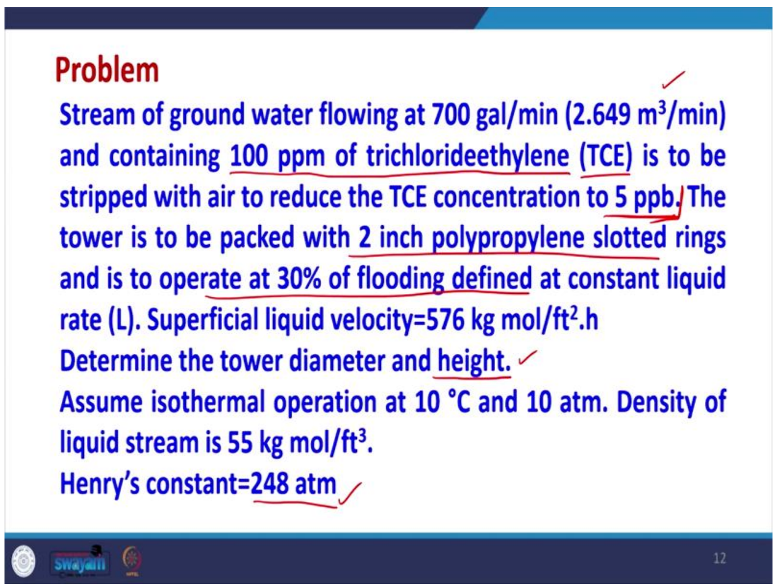

Now, let us put a balance of what is given here. So, in this equation in this problem it is given to 2.649 metre cube per minute is the flow rate okay in gallons also because gallons is the common terminology in many countries. So, we can calculate in gallons also, but we are writing like this only. So, this is the flow rate and this is the 100 ppm, but we want it to be reduced at 5 ppb. So, here L will be the same.

Now, we do not know the G value yet. And the out value is also known, but the concentration which is of TCE in certainly in the gas is not known, it is 0. So, this is there and we are to find out the concentration we are here remember, everything is written in the mole fraction form for better material balance. So, Xin is the mole fraction of that. So, it is it can be written in 100 ppm, which is the, we can always convert it and it will remain the same so 100 ppm, this is 5 ppb and here we do not know what will be coming out. So, this is there.

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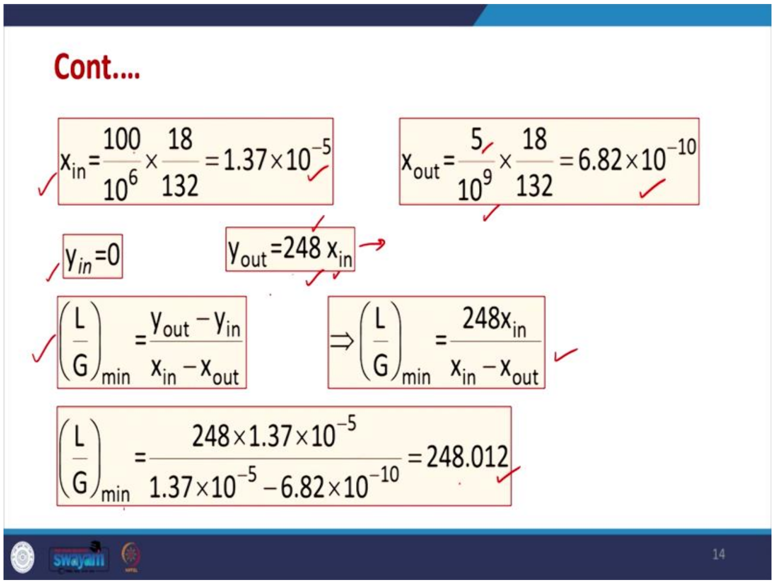

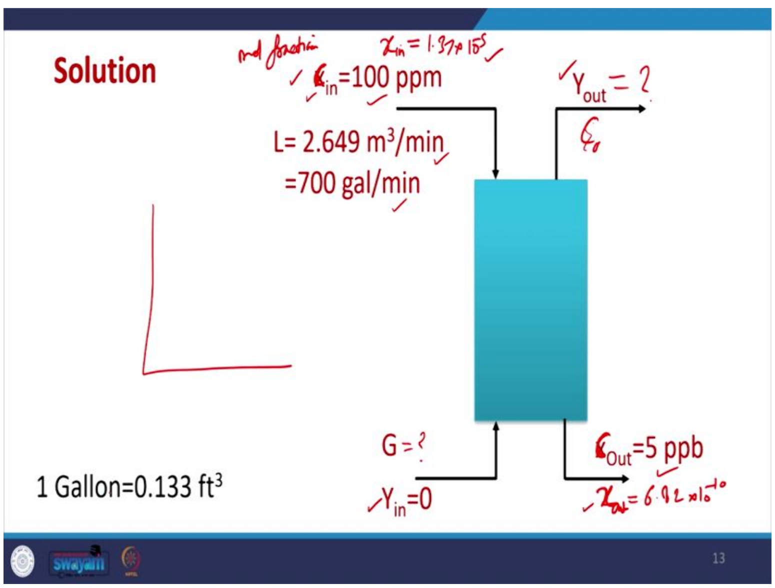

Now if we perform the, this is 100 ppm Cin. So, we have to find out the Xin. So, Xin is being found out here. So, 100 ppm is being converted into mole fraction. So, this is first step, similarly, 5 ppb, which was given here it is being converted into mole fraction. So, both the mole fraction at Xin is known and X actually this is C out. So, we have X out is known to us and this has been calculated in this slide.

So, this is 6.82 into 10 raise to minus 10 and this is 1.37 into 10 raise to minus 5. So, we can write like here is 1.37 into 10 raise to minus 5 and similarly, for X out 6.82 into 6.82 into 10 ways to minus 10. So, this is the mole fraction with respect to liquid phase we know so concentration was given now, we have changed into mole fraction. Now, Yin is 0 and if we perform the Henry's constant because for any such type of operations, so, we always look at the equilibrium line.

So, the equilibrium line is such that this V out will always be in equilibrium with this because we can have this V out only up to a maximum equilibrium value and this is given by mole fraction Henry's constant is already given. So, from the Henry's constant we know that the what will be the mole fraction of anything in the gas phase, if the mole fraction in the liquid phase is known.

Now, mole fraction in the liquid phase is known and G value is also known so V out this is the maximum V out possible, but it will never be the same it will be much lesser than that, it is at this condition that height of tower will become enormous. So, it is not possible. So, what we do is that we try to find out the V out using the this equilibrium values of V out is known. At this condition we can find out the minimum L by G. So, L by G we can put everything here and you can see here it has been found out 248.012. So, we can use this value for finding out the actual L by G.

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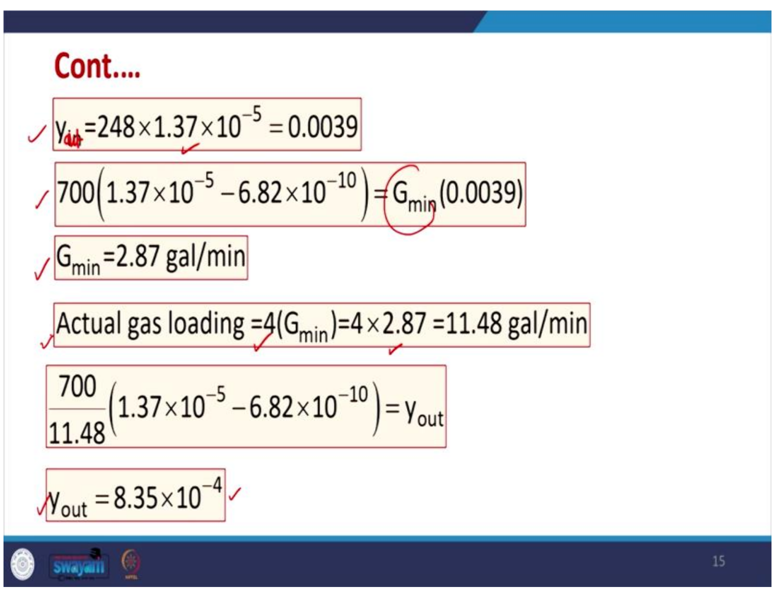

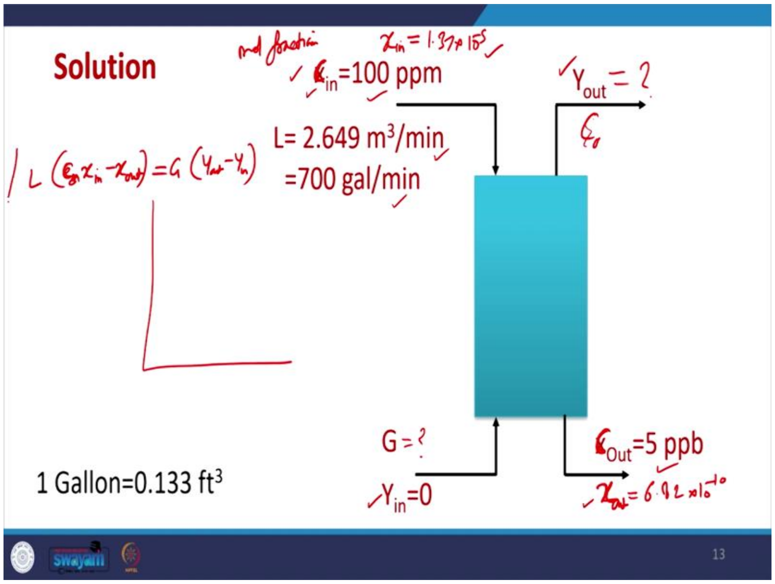

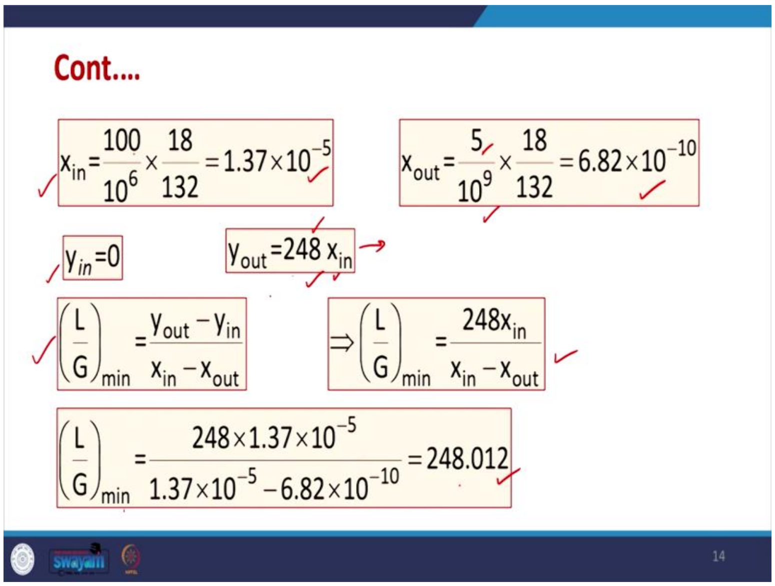

So, actual L by G can be assumed like for the gas it is assume like 4 into G by minimum. So, Y in has been calculated if L by Y, sorry this is Y out. So, we can find out Y out has been calculated from putting in the material balance we can find out the G minimum. Because material balance we can always write the material balance equation for this particular case and this will can be written like this L is equal to C in sorry L into Xin minus Xout and this will be equal to G into Vout minus Yin so mole fraction. So, this is the material balance and using this we can find out the G minimum.

So, this is the balance which has been done here and from this G minimum has been found out and from that, we are assuming that actual gas loading has to be around 4 times the minimum value. So, once we get this, we again do the material balance because the actual is now known here and from that we can calculate the what will be the Vout value we are going to take. So, this will be the Vout, so, we have Vout value and G actual is known to us. So, we can find out.

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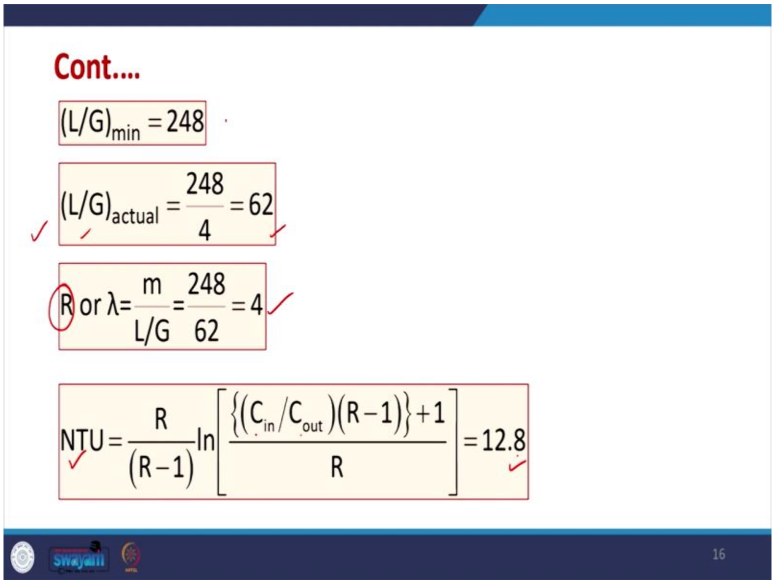

So, LG minimum was this LG actual is this 62 and if once this is known, we can find out the R value which is given by m divided by L by G so, this is known, so, this is comes out to be 4. And if this 4 value is known, we can find out the NTU because Cin upon Cout is known to us. So, this comes out to be 12.8.

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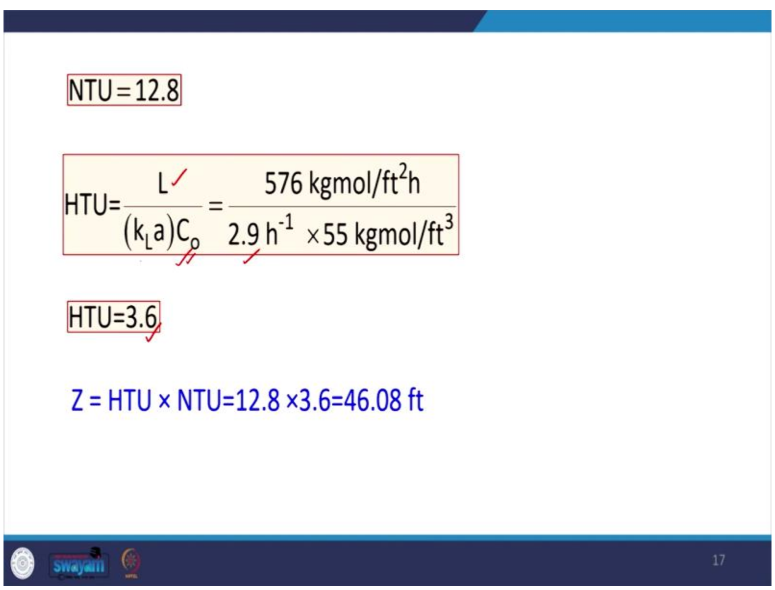

Now, we can find out the HTU also because HTU can be given by this. So, for this particular problem we can if you go and cross check, we can put all these values from the literature we are getting the kLa value. Similarly we can take different values. So, HTU will be coming out to be

3.6. This is a not that straightforward we are we assuming lots of conditions here. And for better reference, we have to go and look out for better books to understand how to determine all these parameters, there are other concepts related to overall height of transfer unit based upon gas side or based upon liquid side, all those concepts are there, but those are beyond the scope of this particular subject. So, we are only solving it to give an idea how to find out the height of the packed bed aeration unit.

So we can multiply this NTU and HTU together and we can get so tentatively we are getting this much height, so we can convert it into the meter also, so this will be so what we are getting. Certainly, this may look to be higher side because we are presuming a number of think for better understanding. So this is there.

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So, this is the preliminary design of any packed bed tower and we have taken a lot of ideas from different books and some data also has been taken. So, all our references are given. So, through this will end the aeration section. And in the aeration section, we have learned how to find out the solubility of any gas in the water. Then we try to learn the different mass transfer resistances, try to understand that kLa then from that, we try to determine how to find out the oxygen transfer rate. Thereafter we try to understand the different types of are aerators which are used commonly in the industry.

And also, we try to solve problems related to finding out the volume of any unit which will be used for aeration in the case of surface aeration as well as in the case of diffuse aeration and also try to find out the height of any packed bed tower. So, some ideas have been we have learned through this lecture. So, we will continue with other treatments units in the next class onwards. So, thank you very much.