Course Name: Industrial Wastewater Treatment

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Week - 03

Lecture 12: Gas Transfer and Air Stripping (Ammonia Removal)

So welcome you all. Today I am going to deliver my lecture 2 of module 3 which is on gas transfer and air stripping process. So if you remember in the previous lectures we have seen the concept behind this gas transfer and the air stripping process. Then we learnt about the mass balance analysis, Henry's laws. So today what we are going to cover in this lecture is dynamic approach for design of stripping column, design equations which are used, then stripping factor, mass transfer coefficients and then based on that we will have certain numericals to illustrate the design concept of stripping tower.

So if we see this again similar to our equilibrium analysis, here we will be learning about the dynamics analysis of stripping column. So this basically considers like counter current flow system. So in this system what happens this wastewater enters from the top and comes out from the bottom whereas the air is inserted from the bottom of the tower and it comes out from the top of the column. So it is like a counter current system. So in this system if we consider the flow rate of liquid like L which is the flow rate of the wastewater here and then G which is the flow rate of the air we insert for stripping of the dissolved gases, VOCs or ammonia nitrogen from the wastewater. So if this G is the flow rate of that air, and C is the concentration of solute in the water and P is basically the concentration of solute in the air and this R if you see that is the universal gas constant and if in this if we consider this is the column where this is the packing media and in this packing media let us consider this Z_t basically that is the height of the stripping column. So in this if we consider the cross-sectional area like this cross-sectional area of this column this is like A_x. So for this dynamic equilibrium of a column what are the various design equations we use for determination of the height of the column, for determination of the height of the packing media, cross-sectional area. So many more dynamic parameters we can analyze using this dynamic analysis.

Then if we see various design equations so first of all we need to find out the height of the stripping tower which is equal to Z, $Z = HTU \times NTU. HTU$, basically this is the height of the transfer unit, where NTU that is the number of the transfer units. So in a given column we can have number of stages so accordingly the number of transfer units will increase and accordingly then we have to design the appropriate height of the column and in this if we see that height of the transfer unit basically it depends upon the flow rate of the waste water, the mass transfer characteristics of the solute and also to the cross-sectional area of the packing medium. So this we can find out using this equation $HTU = \frac{L}{K_l a A}$, where HTU is equal to L which is the liquid flow rate or the waste water flow rate in this case and $K_l a$ is the mass transfer coefficient and A is basically representing the cross-sectional area of the stripping tower. So similarly in this equation if we see this $K_l a$ we have to find out which is basically the mass transfer coefficient which depends upon the characteristic of the solute and the characteristic of the waste water and the concentration gradient between the water and the air.

So how to determine this mass transfer coefficient for that we can use this equation $r_{VOC} = -K_L a_{VOC}(C - C_s)$, where C is basically the concentration of the VOC in the water or the wastewater and then C_s basically its saturation concentration, where r_{VOC} represents basically the mass transfer rate of VOC. So this is the equation which we can use to determine the $K_L a$ value which is used in the previous equation to determine the height of transfer unit. So this $K_L a$ basically determination of $K_L a_{VOC}$ that is little bit difficult so for this determination we use this equation $K_L a_{VOC} = K_L a_{O_2}\left(\frac{D_{VOC}}{D_{O_2}}\right)^n$, which is inter correlated with the diffusion coefficient of oxygen and VOC. So here this equation we use $K_L a_{O_2}$ we can determine and this by using this diffusion coefficient of VOC and oxygen. We can find out the mass transfer coefficient of VOC, which is to be used in the design equation to determine the height of the transfer unit. And then if we see in this equation this n value which is basically a coefficient which depends upon the type of the aeration, the method of the aeration and the characteristic of the solute, the packing media, the type of the towers we are using.

So this you can see the value of n which is equal to 0.5 for packed column and having mechanical aeration system with the power intensity of the equipment used which is <100 W/m^3. And in case of basically diffuse aeration system in a packed column the value of n that must be taken equal to 1 for the power intensity <100 W/m^3.

So then we have to find out the number of the transfer unit which is required $NTU = \left[\frac{C_0 - C_e}{C_0 - C_e - C_0'}\right] \ln\left[\frac{C_0 - C_0'}{C_E}\right]$ which is basically the equilibrium concentration whereas C_0 that is the initial concentration of solute in the water and C_e is the final concentration of the solute in the water or the wastewater. So using this equation we can find out number of the transfer unit required for this stripping column.

Then finally we can find out the total height of the column required and for this in the previous equation if we see this C_0' which is the equilibrium concentration this can be find out by using this equation $C_0' = \frac{L}{G} \times \frac{P_T}{H}(C_0 - C_e)$, where this L is the flow rate of the water, G is basically the flow rate of the air, P_T is the partial pressure of the solute and then H is basically the Henry's law constant and C_0 and C_e basically they are the initial and final concentration of solute in the water. So by using this equation we can find out the value of this equilibrium concentration if we see this $\frac{L}{G} \times \frac{P_T}{H}$ inverse of this entire term that if we take equal to S which is equal to $S = \frac{G}{L} \times \frac{H}{P_T}$ so if we take inverse of this equal to the stripping factor then this equation can be converted in the in this form $C_0' = \frac{(C_0 - C_e)}{S}$ and this is the simple equation which we can use for determination of equilibrium concentration in terms of stripping efficiency.

So now if we substitute this value of equilibrium concentration that is C_0' in the previous equation, equation for NTU so this will be the final equation which is equal to $NTU = \left[\frac{S}{S-1}\right] \ln\left[\frac{C_0/C_e(S-1)+1}{S}\right]$. This is basically the final equation we can use for determination of the number of transfer unit required for an ammonia strippers or an air stripping column. In this equation if we see if S = 1, it means that this represents the minimum amount of the air required for stripping process and that becomes very economical. But if we take S > 1 to ensure complete stripping of the solute from the wastewater in case S < 1 it means there is insufficient air is used and this will result into lower stripping efficiency of the column. So normally this is stripping factor the value of S varies from 1.5 to 5. So depending upon the economy of the process we can use a factor of 2 to 3 as per the design.

So this if we see this is a table which contains the design values for different design parameters if we see that is the liquid loading rate so for VOC removal and for ammonia removal separately in these two columns these design parameters which are used for design of stripping tower so like if we see the first parameter like liquid loading rate so for VOC removal the value is 600 to 1800 whereas for this ammonia removal the value is very less that is 40 to 80 L/m^2-min. So this is basically the for VOC removal and this column will give the values for the ammonia removal. similarly G/L ratio that should be 2260 in case of VOC removal while in case of this ammonia removal a huge amount of air is required so this basically affects the economy of the process and similarly this is the stripping factor which is this is the symbol S and because this is a unit less and so here for VOC this may be taken from 1.5 to 5 and similar values we can take for ammonia removal. So this table gives all different parameters like the type of the packing media we use like pall rings or maybe saddles or etching rings whatever we use this the packing depth factor of safety wastewater pH like if we see pH for VOC removal this is 5.5 to 8.5 whereas in case of ammonia removal this is very high it should be 10.5 to 11 more than 11. So it has more efficient stripping at this pH. So basically this table describes the typical design parameters which are used for design of stripping column for removal of VOCs as well as for removal of ammonia which is normally used in the industry this towers for removal of ammoniacal nitrogen similarly there are aviation systems which are used for removal of VOC$_s$.

So now let us see about the advantages and disadvantages of back tower strippers we can see it's very effective for volatile and even semi-volatile organic compounds so far VOCs removal it is very effective but if we see like in terms of ammoniacal nitrogen removal the stripping efficiency is comparatively less than this VOC, because in case of VOC removal it can remove more than 99% of the VOCs but ammonia strippers normally they results in through 70-80 % of maximum stripping efficiency. So this is also an economical way of removal of VOCs and ammoniacal nitrogen compared to the other treatment systems and if we see for VOC removal it implies very low G/L ratio whereas in case of this ammoniacal nitrogen this is very high. so and it ensures complete removal of VOC. Okay so also it can be used for wide range of applications having extended air flow rates so these are basically the advantages of the packed bed tower air strippers but if we see the disadvantages. So that is not good for the contaminants which are not readily separable like having the Henry constant less than 0.1, so this type of compounds they cannot be stripped off and it might be costlier since it requires a high towers and number of pumps number of blowers along with number of piping works so it becomes a little bit costlier and then there is one more practical problem associated with this that is the fouling of the packing media and the another disadvantage like we are transferring the pollutant from water to air. So air gets contaminated this which is one of the major disadvantage of this process and requires high maintenance cost so these are the advantages and disadvantages of the air stripping towers used.

So now let us we see certain numerical which are based on these concepts. So let us see first numerical determine the theoretical amount of air required at a temperature of 20ºC to reduce the ammonia concentration. So here the solute concentration that is ammonia which is 40 mg/L to 1 mg/ L. So we have to reduce out the ammonia concentration from 40 mg to 1 mg in a treated wastewater having a flow rate so flow rate is this much 4000 m^3/d and the pH of the wastewater has been increased to a value of 11, that is basically required for in case of ammonia stripping process. The Henry's law constant for ammonia at 20ºC that is given like value of H is given 0.75 atm and also if we see that the air entering at the bottom of tower does not contain any ammonia so initial concentration of solute in the stripping media like air what we use in this case so that is 0. So here first of all what to determine that is to determine the amount of air required so basically that is G/L ratio we have to find out and for this first of all we have to find out the molar fraction of the solute present in the water and the air phase so here if we see that the molar fraction of the solute that is present ammonia in wastewater that is will be equal to $x_g = \frac{No.\,of\ moles\ of\ Gas}{No.\,of\ moles\ of\ gas\ (N_g)+No.of\ mole\ of\ water(N_w)}$. So here if we see that the concentration of ammonia that is given as 40 mg/L, $\frac{[(40\times10^{-3})/17]}{[55.5+\frac{40\times10^{-3}}{17}]}$ that is equal to 4.24×10^{-5} mole NH_3/mole H_2O. similarly if we see that is C_e which is the molar fraction of ammonia that is present in the effluent so similar way that is 1 mg/L, So 1 milligram into convert it into gram divided by 17 which is the molar weight of the ammonia. So divided by this so you will get number of moles and this 55.5 is the number of moles of water which is present in 1 liter so that is basically that is 55.5 plus this is the number of moles of ammonia. So total number of moles of water plus ammonia so now if we calculate the value of C_e comes equal to 1.06×10^{-6} mole NH_3/mole H_2O.

Then similarly we can find out the molar fraction of ammonia in the treated effluent which is equal to y_e and can be given by this equation $y_e = \frac{H}{P_t}\times C_0$, where H is the Henry's law constant which is given equal to 0.75 atm, whereas this P_t is the one atmospheric pressure. So this here we can put one atmospheric pressure and then this C_0, which is molar concentration of ammonia gas in the wastewater initially present which is equal to 4.24 as we have worked out earlier. By putting this value in this equation we get the value of the effluent molar concentration of ammonia which is equal to 3.18×10^{-5} mole of NH_3/mole air. So now if we see because we need to determine $\frac{G}{L} = \frac{P_T}{H}\times\frac{(C_0-C_e)}{C_e} = \frac{(C_0-C_e)}{y_e}$, because this if we replace as per this equation so we will get the final equation equal to this $\frac{(C_0-C_e)}{y_e}$ and in this again if we see this C_e is very very less than C_0 so here we can use this $C_0 - C_e = C_0$ and then this G/L ratio that will be equal to C_0/y_e. so C_0 value already we have got here that is 4.24×10^{-5} whereas this value of y_e which is equal to 3.18×10^{-5} we can substitute here and then we can find out the ratio of G/L which is equal to 1.3 $mole\ air/mole\ H_2O$. So this is in terms of moles but now we have to determine how much meter cube per meter cube of water, it will be required or per unit volume of flow it is required so we have to convert this moles into their weight and volumetrical unit.

So here if we see at 20ºC like per mole of air has a volume of 24.1 L. So if we have 1.3 moles so this much liter of this air will be required and for water if we see one mole of water will have 18g of weight so if we multiply with 18, its molecular weight and divide by 1000 which is to convert into liter which is the density of the wastewater, 1000 g/L ($\frac{(1.0\ mole\ H_2O)(18\frac{g}{mole}\ H_2O)}{10^3\ g/L}$). So this is basically coming equal to 0.018 and thus G/L ratio in terms of this if we put this value 31.33 year and this the volume of the water equal to 0.018, so this will be 1741 L/L or we can say it's the ratio of the same unit so we can say like 1741 m^3/m^3 of wastewater. From this G/L ratio we can find out how much air is required for a given rate of flow so the rate of flow we have 4000 m^3/day so if we multiply with this G/L ratio which is 1741 m^3/m^3 and convert this day into minutes so one day having 1400 minutes. so if we convert so it will come 4835 m^3/min. So this is basically the amount of air which will be required per unit time which is per minute.

So now let us have some example on the determination of height of the stripping column, G/L ratio, we have already seen in the previous examples so now let us learn how to find out this the height of the stripping tower which is required to treat the wastewater so we can assume this data like flow is given like 4000 m^3/d as per the previous example and the diameter of the tower we can assume 4.13 meter and there is packing media which is made of 25 mm pall brings and then ammonia concentration again if we see that is same 40 to 1 mg/L this must be reduced Henry's law constant already we have seen this is 0.758 atm at 20°C and here also we have assumed this air does not contain any amount of initial ammonia and K_La value is given that is 0.0125 per second. So using this values how we can find out the height of the shipping column.

So let's discuss how to do this so if we see first of all we have to assume the packing factor, so for packing factor we have to see the size of the pall rings which is 25 mm, so from that table which I have earlier shown to you so that is this table if we see so pall rings for 25 mm size the packing factor which is 30 to 60 for this VOC removal and this for ammonia removal this is 30-60. So here in between 30 to 60 we can assume any value so here we have assumed that is 50. So similarly, the shipping factor this is 1.525 so that is given in the table, so here we have assumed that is 3 and similarly we can assume a pressure drop of 200 (N/m^2)/m. So accordingly we have to see the equation which is used for determination of the height of the transfer unit so this is basically $HTU = \frac{L}{K_LaA}$. So here this liquid flow rate which is given as 4000 m^3/d if we substitute the value and this day if we convert in terms of seconds which is 86400 seconds in a day and then here this K_La value that is given as 0.0125 per second, so this is the value we have substituted similarly this is cross-sectional area so which is the diameter is given 4.13 meter, so $\pi/4 \times d^2$, this diameter is 4.13, so square of this will give you the value of this HTU. So by calculating this the HTU value which is the height of transfer unit that comes equal to 0.028 and then similarly we can find out the number of transfer unit which we can use this equation $NTU = \left[\frac{S}{S-1}\right] \ln\left[\frac{C_0/C_e(S-1)+1}{S}\right]$ and here if we see this value of stripping factor we have assumed equal to 3. So if we put the value 3 divided by 3 minus 1 and similarly this C_0 which is in mg/L, so 40 mg/L and then this is 3 minus 1 this is S minus 1 and this again s that is equal to 3. So substituting this value what we will get that is number of the transfer unit which is required that is 4.94.

So then we can find out this HTU × NTU that will equal to the total height of the column required for the packing media and which if we see HTU value we have got 0.28 and similarly NTU from the equations we have got 4.94 if we multiply we get a value of 1.38 meter. So which is the required height of the packing media in the column so this we can take approximately equal to 1.4 meter. So this is how we can also work out the height of the column as per the dynamic analysis of the stripping column.

And then similarly one more example we can take which is on the determination of mass transfer coefficients and Henry's constant. So here if we see the example so determine the mass transfer coefficient and unitless Henry's constant of the benzene that can be stripped in a completely mixed activated sludge reactor, equipped with diffused aeration system so here the aeration system is defined, the completely mixed activated sludge reactors are defined and we have given this following data to find out the mass transfer coefficient and Henry's law constant. So this air flow rate which is given 50 m^3/min at the standard temperature conditions oxygen mass transfer rate is given 6.2 per hour, then the influent concentration of the benzene which is given 100 μg/m^3, similarly this Henry's constant that is given as 5.49×10^{-3} the unit if we see that is m^3.atm/mol and here if we see that n value which is the coefficient of the equation which is equal to 1, temperature we is given that is 20 ºC and this diffusion coefficient is also given for oxygen and for benzene also which is 2.11×10^{-5} cm^2/s, similarly for benzene it is very less which is 0.96×10^{-5} cm^2/s.

So for this data let us see the equations to find out the mass transfer coefficient of benzene so here we take $K_L a_{VOC} = K_L a_{O_2} \left(\frac{D_{VOC}}{D_{O_2}}\right)^n$. So the all these values are given so we can put these values here we can find out that is the mass transfer coefficient of benzene, which is 2.82. So this is the answer. And similarly we have to calculate is unit less henry's constant which is equal $H_u = \frac{H}{RT}$ so h value is already given and this R value we is basically this at a standard temperature and pressure so we can assume this R value and then temperature is like 20 ºC so this is 273.15+20, so that will get converted into kelvin so by putting this value we can find out the unit less henry's constant equal to 0.228.

So, for this you can use this Metcalf Eddy where this stripping process is nicely described so with this, I conclude my lecture.

Thank you.