Course Name: Industrial Wastewater Treatment

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Week - 03

Lecture 11: Gas Transfer and Air Stripping (Ammonia Removal)

Welcome you all. So today we are going to study a new lecture, lecture 1 on module 3. which is on gas transfer and air stripping process which is basically used for removal of ammoniacal nitrogen from industrial wastewater. If we see there are number of industries like fertilizer industries like coke oven plants iron and steel industries. So there are many industries where this ammoniacal nitrogen is present in their wastewater. For removal of this ammoniacal nitrogen we use a process called air stripping process.

So this we will be discussing under this lecture. So under this what we have covered is the basic introduction the concept the mechanism of air stripping process. Then we will be discussing about the Henry's law which is basic concept behind the air stripping process. Then we will be learning about the various factors which affects the stripping efficiency and then we will be finally looking into the various design approaches for design of air stripping tower. So here we will be learning about the equilibrium approach then we will be also learning about the dynamic approach and then we will be also looking about the mass balance analysis which is basically used to evaluate various design parameters which are used in design of air stripping towers like the gas to liquid ratio, the height of the tower, type of the packing materials we use and the type of flow patterns. So all these aspects we will be looking at the mass balance analysis how this mass balance analysis are used and this will be followed by taking some design examples which will illustrate about the procedures to design a ammonia stripping tower.

So this air stripping the process of transfer or stripping out of dissolved gases various types of volatile organic compounds which are present into the wastewater. So this is the transfer of these dissolved gases and the VOC from liquid phase to gaseous phase and this is essentially carried out by blowing the air in the form of bubbles through the wastewater which basically trickles from top of a stripping tower through a packing media which convert them in a liquid droplets. So this liquid droplets basically increases the surface area of the contact between the liquid and gaseous interface and resulting into increased contact surface area. So when this wastewater comes in contact with this blowing air so these dissolved gases and substances they are stripped out and get transferred from liquid to gaseous phase. So in this process air is basically used as a gas media to strip out of the dissolved gases and volatile organic compounds present into the wastewater. So stripping tower which is mostly used in the industries for stripping out ammonia from industrial wastewater is a very good example for this process. So in this process what happened basically the ammonia if we see this is present in the wastewater in the form of ammoniacal nitrogen so if we increase the pH of the wastewater this ammonia nitrogen can be directly converted into the ammonia nitrogen and this ammonia nitrogen can be stripped out along with the air. So for this process to occur the required pH that is the maximum stripping occurs basically at a pH of 11. So in this process whatever the ammoniacal nitrogen is present in the wastewater in the liquid phase using the air as a stripping media and we can convert this ammoniacal nitrogen from dissolved to vapor phase and that is in the form of ammoniacal nitrogen and can be removed from the liquid phase. So thus the wastewater which was earlier containing the ammoniacal nitrogen after this air stripping process that is get removed from the ammoniacal nitrogen.

So now we will be learning about the Henry's law which is the basic concept behind air stripping process and which is used for removal of these dissolved gases. So as per the law if we see the equilibrium concentration of gas dissolved in a liquid is a function of type of gas and the partial pressure of that gas which is in contact with that liquid. So if we mathematically write this law so this is the equation which describes the Henry's law according to this $P_g = \frac{H}{P_t} \times x_g$, where this P_g basically indicates the mole fraction of the gas in the air which is in the form of number of moles of that gas per mole of air and x_g which is the mole fraction of the gas in the liquid the unit if we see that is in the moles of gas which is present in per mole of water then is the Henry's law constant H unit if we see this is the in the form of atm moles of H_2O per moles of air. So this is the unit for this Henry's law constant and then this P_t is the total atmospheric pressure so which is equal to one atmospheric pressure so that is one atm for air if we use as a stripping media. So now x_g basically that is the mole fraction of the dissolved gases in the liquid phase so how we can find out this is the formula to calculate this mole fraction of dissolved gases which are present in the liquid phase which is equal to $x_g = \frac{No.\ of\ moles\ of\ Gas\ (N_g)}{No.\ of\ moles\ of\ gas\ (N_g) + No.\ of\ mole\ of\ water (N_w)}$. So this is how this equation is used to determine the equilibrium concentration of a dissolved gases in water and gaseous phase. So this equation can be also reduced in the following form if we put this P_t equal to one atmospheric pressure so this $P_g = H \times x_g$. So, this Henry's law basically states the equilibrium concentration of the dissolved gases or VOCs in water and vapor phases so accordingly we can find out when the equilibrium is achieved in the stripping tower how this dissolved gases, they are transferred from the liquid phase means wastewater to the air which is the stripping media used for stripping out of the dissolved gases.

So from Henry's law we conclude that the liquid phase concentration and the gaseous phase concentration of the dissolved pollutants that depends upon this H value so let us discuss about the H values how it depends upon the various factors so this constant basically this depends upon the many factors like this type of the gases, temperature and the nature of the liquid if we see like the gases which are readily strippable like toluene, benzene, vinyl chloride but there are some gases which are less strippable like ammoniacal nitrogen, so some of the gases which are hardly strippable so this H value depends very much on the type of the gases if we see this table so for different gases you can see the carbon dioxide, carbon monoxide, chlorine so number of gases and these are the values of the Henry's law constant so you can see the values differs significantly for different types of gases depending upon the nature of the gases which are strippable so this depends upon the basically the nature of the gases so this H values for different types of gases we can adopt from this table and then temperature if we see temperature is another important aspects because this H value greatly depends upon the temperature and the relationship of this H value with the temperature we can see this is $\log_{10} H = \frac{-A}{T} + B$, where A and B they are basically the empirical constant where this T is the temperature expressed in Kelvin. So here if we see the equation this H value basically is inversely proportional to the temperature so if we increase the temperature so what will happen this factor will be reduced and if this factor is reduced this is negative it means with increase in the temperature there will be increase in the value of H so this H value basically indicates the degree of stripping that may take place for a particular gas. So here if we see with the increase in temperature the H value increases and stripping efficiency of different gases will also increase with increase in the temperature. So for this coefficient if we can see A and B these are the coefficient which can be taken from this table and after substituting the values for temperature and these coefficients we can find out this H value for different temperature so this is how we can use this Henry's law constant for different temperature.

So, then let us see what are the limitations which are associated with the Henry's law so the basic limitations that when the gas present in the solution reacts with the gases so there is a chemical reaction happens so in that case this Henry's law is not applicable. Second the major aspects that is under the extremely high pressure, we cannot use this Henry's law so these are the basic limitations.

And then let us learn about the air stripping process this is basically the schematic view of the stripping tower if we see this is the polluted water which is presented in storage tanks so from this storage tanks we have a pump which will pump out this waste water through this pipeline so here it will be spread over the packing materials so this polluted water contains number of dissolved gases volatile organic compounds so when this is spread over the packing media the water basically is made to trickle down through this packing media, so when it trickles down it converts into the liquid droplets and its surface area increases and from the bottom if we see this is the air blower through which the air is blown from in a counter current direction to the flow of the water, so they meet each other when they come in contact with the liquid so what happens there is a transfer of dissolved substances, dissolved VOC_s from water to gaseous phase and along with the gases they rise to the top of the tower and from the top of the tower there is again outlet and vent pipe through which the gas is collected and clean and then is discharged into the atmosphere so this is the gas and air collectors and then this is a complete air stripping tower here if we see this is water is spread over the packing media through different mechanism and these are the packing media which may be made of the plastic pipes and synthetic materials if you see the water after trickling down through this packing media that will come out of the tower through this outlet pipe and it will be basically get removed from those compounds which are dissolved into the water and thus here we will get a clean water so this basically is a different component of the air stripping tower how the process takes place how the dissolved substances are the VOCs which are present into the polluted wastewater when it comes in contact with this moving air how they are removed how this gas transfer phenomena takes place so this is an example of the different components which are used in design of the shipping tower.

So then let us look into the applications of this air stripping process so as we have discussed there are various dissolved gases like NH_3, H_2S and VOCs which are present into the municipal and industrial wastewater so for removal of these dissolved gases from liquid phase to air phase stripping process is used and then also it is used for removal of VOC_s which are basically found in the groundwater into the refineries area where this groundwater gets contaminated through the leaking of underground storage tanks, through the spillage improper disposal practices which are adopted in various refineries so these are the two major applications one is for removal of VOCs and another is for removal of dissolved gases as presented to the wastewater.

So then look into the various factors which basically affects the process of stripping so one among the important factor is the characteristics of the compounds which need to be stripped out so there are compounds which are having the Henry's law constant more than 500. So if the Henry's law constant of these substances are more than 500 so it means they are readily strippable and they can be easily removed from liquid to gaseous phase using the this air stripping process so this type of compounds like benzene, toluene, vinyl chloride they are very readily strippable so this air stripping towers are very effective for removal of these compounds from the wastewater. Similarly the compounds which are having the Henry's law constant in between 0.1 to 500, they are less strippable and these compounds basically comes like ammoniacal nitrogen you can see here in this table there are H values like for ammonia then we have similarly less than 500 for hydrogen sulfide similarly for sulfur dioxide so t hese are the compounds which are basically having very less Henry's law constant less than 500 but they can also be removed to a greater extent by using this air stripping process. Then there are also compounds which are having the Henry's law constant less than 0.1 atm so these compounds they are basically not strippable these are the compounds like acetones, methyl ethyl ketones. So these types of compounds are hardly strippable hence this air stripping process that is not suitable for stripping out of these types of compounds. So this is basically the effects of the nature of the compounds nature of the gases which need to be stripped off, then similarly the air stripping efficiency also depends upon the type of the contractor and the number of stages which are required for this air stripping process so if we see there are packed bed towers there are tray towers. So number of towers different types of tower different configuration the back to bed towers mostly they are having more efficient than that tray towers and then similarly if we see the number of stages if we increase in a contractor then the air stripping efficiency can be increased and similarly the air stripping efficiency also depends upon the type of the packing in a stripping tower. So that is also two types like random packing and then the structured packing so these different types of packing also affects the process of stripping and if we see the structured packing having the honeycomb structures they are most efficient compared to the randomly packed or dumped packing that is adopted during installation of these towers. Then we can also see this physical features and dimensions of the stripping tower which are basically we have to work out using the mass balance analysis of the air stripping process. Then we can see finally the nature of the liquid the nature of the wastewater like its pH its solubility also greatly affects the air stripping process like for example if we see the pH like ammonia if we design a ammonia strippers so this is being process the maximum efficiency of ammonia removal that occurs at a very alkaline pH which is equal to around 10.5 to 11. So this is how the nature of the liquid also affects the air stripping process.

And then you see here these are different types of towers, air strippers we have like if we see this is packed column strippers and this is the tray towers basically if we say there are number of trays provided here we can see there is packing media they are packed into the columns then there are liquid sprays arrangements are made mist eliminators are there and these are the gas outlets and this is outlet for the liquid and this is the inlet for the air.

So these are like different packing arrangement and different types of towers we used in the air stripping process these are the different types of rings or saddles we use as a packing materials. Then you see this is the packing materials here we see that they are basically of size 1 to 2 inches of nominal size referred to as rings or saddles and if we see the type of packing this is basically two types that is dumped packing where this media they are randomly packed and this type of packing does not have more efficient stripping process whereas there are the structured packing like honeycomb shape see this is honeycomb shape these are the like random packing materials used so a structured packing and this dumped packing media if we see the difference in their characteristic is basically to convert the liquid into the droplets. So that the contact surface area between the liquid and the gas plates gets increased so depending upon the packing material and its type of packing the process and efficiency of the air stripping is affected.

And then similarly this is another important aspect that is the flow pattern in the air stripping towers if we see that in this flow pattern which is three types the one if we say that is counter current flow, this is concurrent flow and then this is cross current flow so in counter current flow what happens water moves from top to down whereas air moves from down to upward so movement of liquid and water is in opposite direction, whereas in the case of concurrent flow both the air and water they are moving in the same directions while in this cross current flow the air is moving in this way and perpendicular to this water is flowing so this type of arrangement we say that is cross current flow and where the both the direction of liquid and air flow is in the same direction so that type of flow we say concurrent flow and similarly in case of counter current flow the flow of water and air that takes place in the opposite directions. So in terms of efficiency we see this counter current flow arrangement gives maximum efficiency compared to this concurrent flow and the cross flow this may be due to the increased contact surface area of dissolved substances with the air that happens more efficient in case of this counter current flow compared to this concurrent and cross flow.

Then let us we discuss about the design approaches so there are various design approaches we adopt one is equilibrium approach and another is dynamic approach. Equilibrium approach if we see that is mostly used to define the performance efficiency of stripping tower, whereas the dynamic approach that is also used to estimate the required packing volume, the height of the towers and the type of packing so all these aspects that is covered under this dynamic approach where equilibrium approach that is used mostly for finding out the amount of air required for a stripping process so these two approaches. We will be studying one by one. So this both basically are based on the mass balance concept.

So let us discuss about the equilibrium approach that is used for design of air stripping tower so in this if we see this is a stripping tower here this is the packing materials so here this is the liquid is flowing this red color shows the flow of liquid whereas the green color that shows the flow of gases so here if we see the liquid is flowing from top to bottom so this is flowing at a rate of say L, that is the rate of flow of liquid whereas this air if we see that is flowing from bottom to top so let us assume this is the flow of liquid and G is the flow of any gases used in the stripping process and let's see this is the liquid phase concentration of that dissolved gases so this is represented by C_L whereas the gaseous phase concentration of that is also substances represented by C_g and what is one and two suffix they represent top and bottom. So this is the concentration of dissolved substances in the liquid at the top whereas C_{L2} that is the concentration of that is also substances or VOCs in the liquid coming out from the bottom of the tower and similarly G is the gas flow rate and Cg_2 is the concentration of dissolved gases in the air phase or the stripping media used in the design towers at the bottom where this Cg_1 that represent basically the amount of that is all substances present into the stripping gases that is the air we use. So these are the different representation that is G is basically the gas flow rate, L is the water flow rate and then C_{g1and2} C_{L1and2} they basically represent the respective flow of water and stripping gases which are used in the design of air stripping tower so if we have this equilibrium approach then how this mass balance analysis can be used to find out the G/L ratio like the amount of air required per unit volume of the wastewater if we have to find out.

So let us see the mass balance analysis in the column so whatever the mass of the VOC_s that will be removed from the water that should be accumulated into the gaseous phase. So if we calculate the mass of the VOC_s removed from the water and if this L is the flow rate of liquid C_{L1} and C_{L2} is the respective concentration of the dissolved gases in the liquid phase at top and bottom. C_{L1} minus C_{L2} ($L\left(C_{L_1} - C_{L_2}\right)$ that basically will give you the amount of VOC_s that are removed from the water and if we multiply with the flow rate it will be giving the total mass of VOC that is removed from the water and similarly the mass of the VOC_s that are added into the gaseous phase that we can find out by multiplying the gas flow rate from the difference of the concentration from top and bottom of VOC_s in the gaseous phase ($G\,(C_{g_1} - C_{g_2})$). So this if we do the balancing we can get the amount of air that is required per unit volume of the wastewater ($L\left(C_{L_1} - C_{L_2}\right) = G\,(C_{g_1} - C_{g_2})$). So here if we see normally the Cg_2 which is the concentration of gas at the inlet or at the bottom of the stripping tower normally the air what we select that has a generally having zero concentration of the dissolved VOC_s which is normally taken as a stripping media so if we assume this C_{g2}=0, in this equation and similarly if the equilibrium is achieved at every point of the tower then we can say there is a Henry's law is applicable and accordingly and gaseous phase concentration of the VOC_s in the liquid and the gases can be related using this equation number two. So here from this equation $C_g = H_c C_L$, where H_c is the Henry's law constant and C_L is the liquid phase concentration of VOC_s, so in this equation if we find out the C_{g1} which is the amount of VOC_s that will be accumulated in the gaseous phase that will be equal to $C_{g1} = H_c C_{L1}$ where L_1 is the liquid phase concentration of the pollutant at the top of the column so by substituting this value of C_{g1} into this basic equation number one and the value of C_{g2}=0 what we will be getting this equation $L\left(C_{L_1} - C_{L_2}\right) = G\,(H_c C_{L_1})$. So here if we see this is the replacement of C_{g1} so from this again if we solve this equation 4 for $\frac{G}{L} = \left\{\frac{C_{L_1} - C_{L_2}}{C_{L_1}}\right\} \times \frac{1}{H_c}$ and now again if we presume that the C_{L2} which is the liquid phase concentration at the bottom of the tower so if there is a complete removal of VOC so this C_{L2} value that will be also we can assume equal to 0 and for that condition if we again put this C_{L2} in this equation what we will get this $\frac{G}{L} = \frac{1}{H_c}$ so this is basically a equation that can be used to find out the amount of stripping media that is required per unit volume of the wastewater and which will be equal to inverse of the

Henry's log constant. So using this equation we can assess the performance efficiency of the column also we have C_{L1} value we have C_{L2} value and then this percentage stripping also we can calculate then what we call that the stripping efficiency that $\frac{C_{L_1}-C_{L_2}}{C_{L_1}} \times 100$. So using this we can also get the stripping efficiency of the stripping column.

So let us take an example to illustrate how this Henry's law is applicable to determine the saturation concentration of oxygen in water to see how this equation is used to find out the concentration in the liquid phase and the gaseous phase. How this equilibrium exists between the gases and the liquid medium so here if we see that as per Henry's law we can say this is the basic equation which is $P_g = \frac{H}{P_t} \times x_g$ and using this equation what we have to find out the saturation concentration of oxygen at 20°C at air pressure of 1 atm. So here if we find from this equation the value of $C_g = \frac{P_g \times P_t}{H}$, so we will get this equation. So now we know this H value for oxygen at 20°C that we take it from the table which is equal to 4.11×10^4 atm into number of moles of H_2O/mole of air and then we also know this oxygen which is present in the atmosphere that is equal to 21% by volume so we know basically this $P_g = 0.21$ which is equal to number of mole of O_2 /mole of air, so this is 21% so P_g value we know and this H value also we know and then P_t value we can take equal to 1 atm.

So we can directly find out what will be the C_g value so after substituting this value in this equation we get this C_g is equal to this is the P_g 0.21 this is the P_t 1 atm and then this is the value of Henry's law constant if we put we get equal to 5.11×10^{-6} mole of O_2/ mole of H_2O. so now we need to express the concentration of oxygen in the liquid in terms of milligram per liter so we have to convert this molar fraction of oxygen and molar fraction of H_2O in their appropriate units. So if we see that is 1 L of water if we take having equal to 1000 gram so molecular weight of H_2O which is equal to if we take this H_2O so this will be (1×2)+16, so it will be 18, so it will have a 10 gram so in 1 L how much number of moles will be there so we can divide this molecular weight to the total weight of water having 1 liter volume so this will be number of moles of H_2O in 1 liter of water. So now 1 mole will have how much of volume so if we find out 1 mole of H_2O it have a volume equal to 1/ 55.6 moles of H_2On so we get the volume of 1 mole of s2o so in this equation if we write this is the volume of 1 mole of H_2O in terms of liter and then this is the mole of oxygen so here in if we put into this equation we will get the value of C_g which is equal to this 5.11×10^{-6} and then this number of moles we have converted in terms of its weight units means per mole equal to having 32 grams and then this is volume of 1 mole of H_2O, so from here we get saturation concentration of dissolved oxygen into the water which is equal to 9.09 mg/L. So this is how we can use this concept the Henry's law for determining the situation concentration equilibrium concentration of any dissolved gases into the water and the gaseous phase.

And then these are the references we have to use which is basically the Metcalf Eddy where this process is described in details. So here we have to refer this wastewater engineering by Metcalf Eddy. So today what we have learned in this lecture is like the air stripping process, the various factors which affects the air stripping process, then the Henry's law how to find out Henry's law constant what are the different factors where on which this H value depends and then we have also learned the design approach for a stripping tower basically the equilibrium approach and then the dynamic approach. So in the next lecture we will be going through details of the dynamic process, dynamic approach which are used for designing of ammonia stripping tower, air stripping process.

So thank you.