Physico-Chemical Processes for Wastewater Treatment
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Lecture - 16
Aeration - V

Good day everyone and welcome again to this lectures on the treatment of water and wastewater by physico chemical methods. So, we will be continuing with the aeration types of what are how the aeration works as a unit for the oxidising water from, oxidising pollutants from the water and wastewater. So, this we are going to study further and in the previous class we studied regarding different aerator types.

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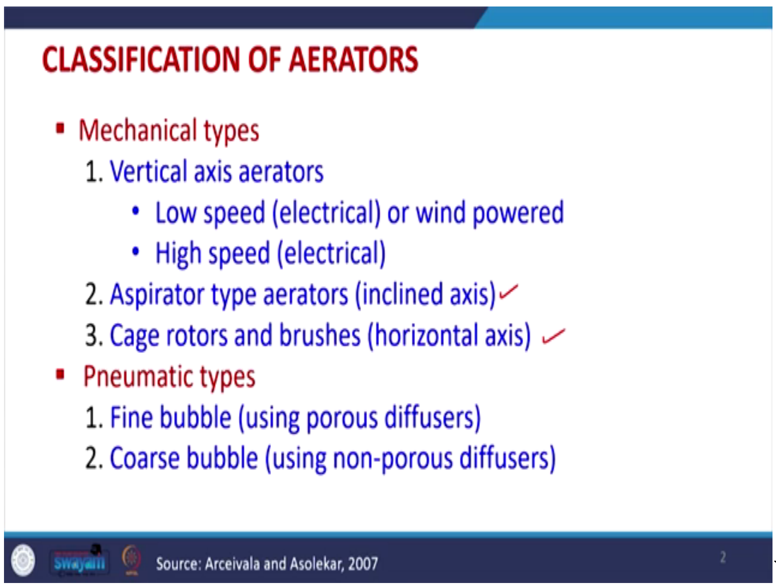

So, we will be continuing with another classification of aerator types which is like classifying the different aerator into either as a mechanical type of aerator or pneumatic type of aerator. So, pneumatic type of aerators are more like diffused aerators and mechanical type of aerators are more surface aerators but they have a certain characteristics based upon which they can be classified into different categories.

So, one of the common classification of mechanical type of aerator is based upon the axis. So, we may have vertical axis we may have inclined axis and we may have a horizontal axis. So, depending upon that vertical axis aerators have further classification as like low speed, high speed. So, this is possible.

So, we can have a vertical axis aerators, then we have a inclined axis aerators also. So, these are also commonly called as aspirator type of aerators. So, this is there, then third we have horizontal axis aerators. So, these are like cage rotors or brushes are there and they have a horizontal axis.

So, this classification of mechanical type of aerators is very common and another diffused aerators may also be considered as pneumatic types also and within pneumatic types that what is the type of bubbles they are generating. So, if they have a very fine bubble. So, that means they have a porous diffusers which are there and in the coarse bubbles with they have non porous diffusers and the air is coming out through more of the bigger pores or through various other mechanisms and we have coarse bubbles which are possible. So, pneumatic types we can classify based upon the bubble type. So, this is there.

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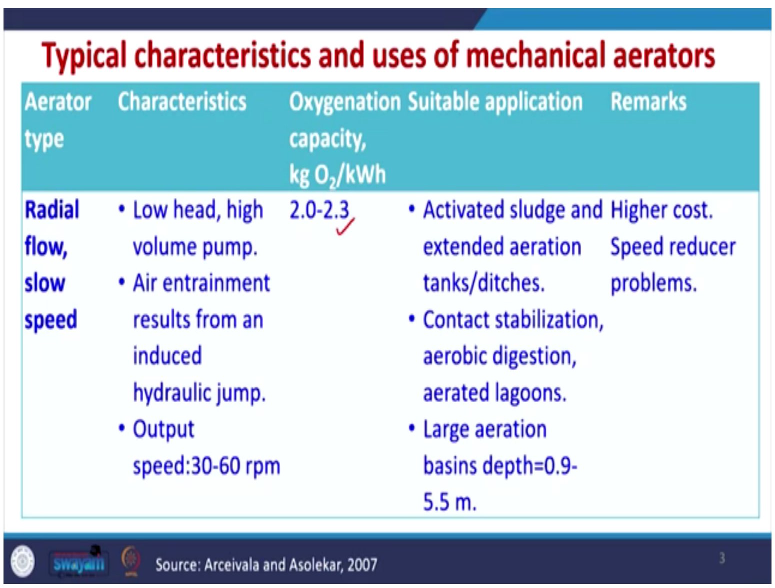

Typical characteristics and uses of mechanical aerators

Aerator type	Characteristics	Oxygenation capacity, kg O_2/kWh	Suitable application	Remarks
Radial flow, slow speed	• Low head, high volume pump. • Air entrainment results from an induced hydraulic jump. • Output speed:30-60 rpm	2.0-2.3	• Activated sludge and extended aeration tanks/ditches. • Contact stabilization, aerobic digestion, aerated lagoons. • Large aeration basins depth=0.9-5.5 m.	Higher cost. Speed reducer problems.

Now, some typical characteristics and use out we can collaborators is given here and which type has to be used at under which condition. So, this is then, a one of the major thing that we should look forward is that, what is the oxygen capacity of that particular aerator? So, like radial flow, slow speed, they have very good oxygenation capacity around 2 to 2.3 kilogram oxygen per kilowatt hour.

So, generally they have very low pressure, high volume pump and air entrainment results from an induced hydraulic jump, so this is there, and the speed is around 30 to 60 rpm and they are very suitable for activated sludge systems which are used where the secondary treatment is done and also extended aeration tanks and ditches.

And they can be used for contact stabilisation aerobic digestion, aerobic lagoons also so this is there. And they have very good depth with respect to aeration around 0.9 to 5.5 metre. Because of all these advantages, they have disadvantage that they have very high cost and sometimes speed reduction is a problem. So, this is one of the things with respect to radial.

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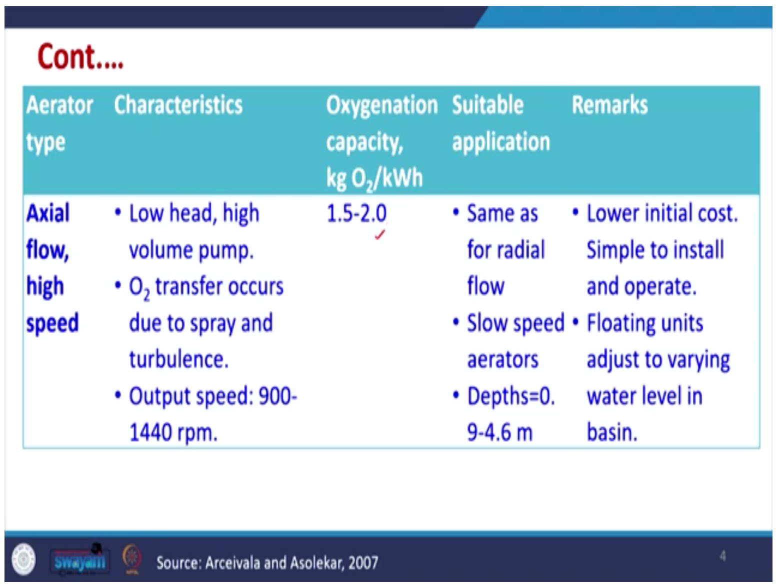

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Aerator type	Characteristics	Oxygenation capacity, kg O_2/kWh	Suitable application	Remarks
Axial flow, high speed	• Low head, high volume pump. • O_2 transfer occurs due to spray and turbulence. • Output speed: 900-1440 rpm.	1.5-2.0	• Same as for radial flow • Slow speed aerators • Depths=0.9-4.6 m	• Lower initial cost. Simple to install and operate. • Floating units adjust to varying water level in basin.

Source: Arceivala and Asolekar, 2007

Then axial flow highest speed aerator. So, they have again low head and high volume pump oxygen transfer occurs due to spray and turbulence action and speed is much higher around 900 to 1400 rpm so this is very high. The oxygenation capacities is lower as compared to the low speed pump, but they have very suitable applications depending upon the requirement.

And this is similar to like for activated slush processor et cetera and their depth is also good and up to 4.6 metre by approximately 15 feet, so, this is there. A lower initial cost as compared to earlier pump and simple to install and operate. So, these are the common.

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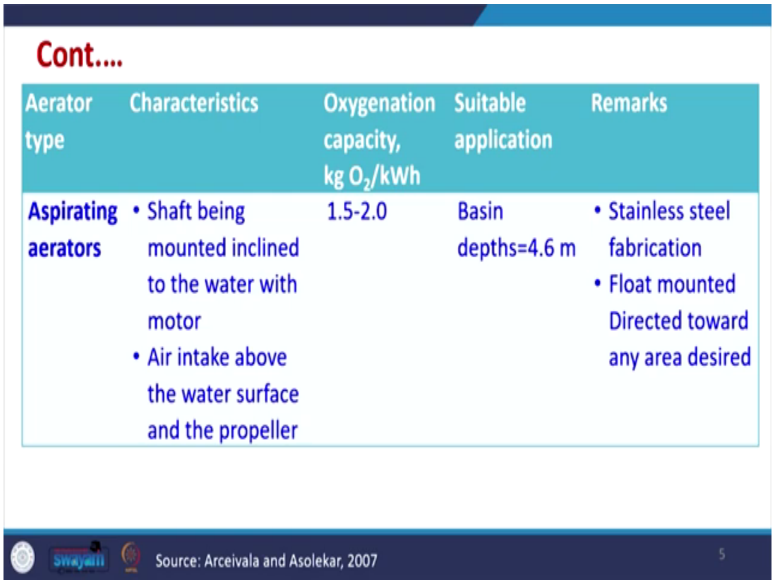

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Aerator type	Characteristics	Oxygenation capacity, kg O_2/kWh	Suitable application	Remarks
Aspirating aerators	• Shaft being mounted inclined to the water with motor • Air intake above the water surface and the propeller	1.5-2.0	Basin depths=4.6 m	• Stainless steel fabrication • Float mounted Directed toward any area desired

Source: Arceivala and Asolekar, 2007

Then we have aspirating aerators so shaft being mounted inclined, because this is the inclined axis aerator to so, this is there. An air intake above the water surface is there and there is a propeller also, the oxygenation capacities in the mid range and basic depth is similar to the earlier ones and they are generally made of stainless steel and float mounted directly towards any area where it may be desired. So, there is a lot of scope of this, but the first one is most common.

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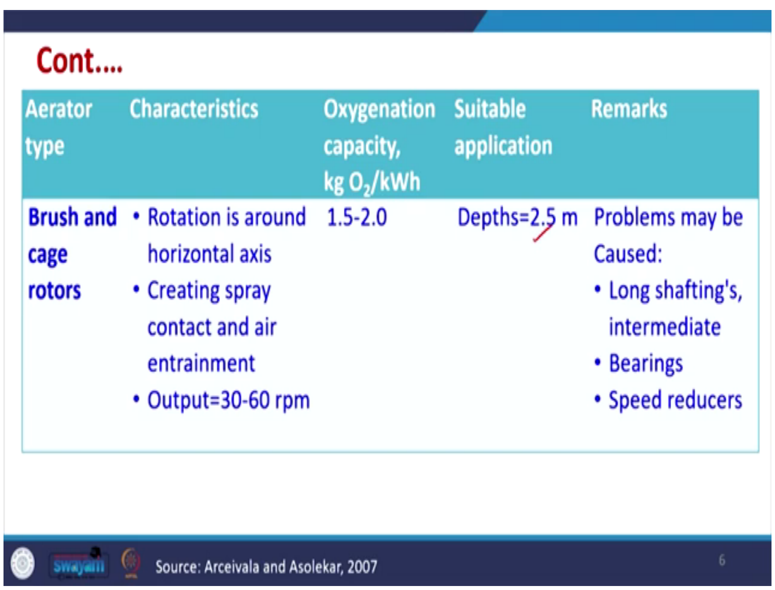

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Aerator type	Characteristics	Oxygenation capacity, kg O_2/kWh	Suitable application	Remarks
Brush and cage rotors	• Rotation is around horizontal axis • Creating spray contact and air entrainment • Output=30-60 rpm	1.5-2.0	Depths=2.5 m	Problems may be Caused: • Long shafting's, intermediate • Bearings • Speed reducers

Source: Arceivala and Asolekar, 2007

Then we have brush and cage rotor type of aerators which have horizontal axis and rotation is around the horizontal axis again the oxygenation capacity is similar to earlier once and this aerator creates spray contact and air entrapment type of mechanism works. The RPM is lower as compared to high speed aerator and depth is also lower as compared to high speed aerator. So, certainly this is only the suitable application is only up to 2.5 metre, but earlier were up to 4.5 and beyond.

So, problems may be there because of long soft things et cetera. Then intermediate conditions may prevail and they have lot of issues that is why they are not very common as compared to vertical axis aerator, bearing issues, speed reduction is another problem with this type of aerator as well. So, these are the common mechanical aerator.

Now, there is one very very important aspect in whenever we are using aerators in any effluent treatment plant in particular in industries. So, small scale industries never want to give money or incur money on the energy which is required the cost of electricity which is required for running these aerators. So, they have lot of issues.

So, now, there are challenges, these challenges are being met by providing energy from in place of electricity by other sources. So, if we can do this, so, these aerators and which is not only essential for simple aeration unit also for activated sludge treatment plant which is like a secondary or biological treatment plant and without that, generally that plant is common in all the ETP’s in the usual industries.

And if that aerator or the diffused aeration unit or the mechanical aeration unit is not running itself that means the oxygen is not being provided. And that means overall system will work only at much lower efficiency. And this means that the water they are discharging is not fully treated, and this they are doing for electricity saving the cost they have to save on electricity.

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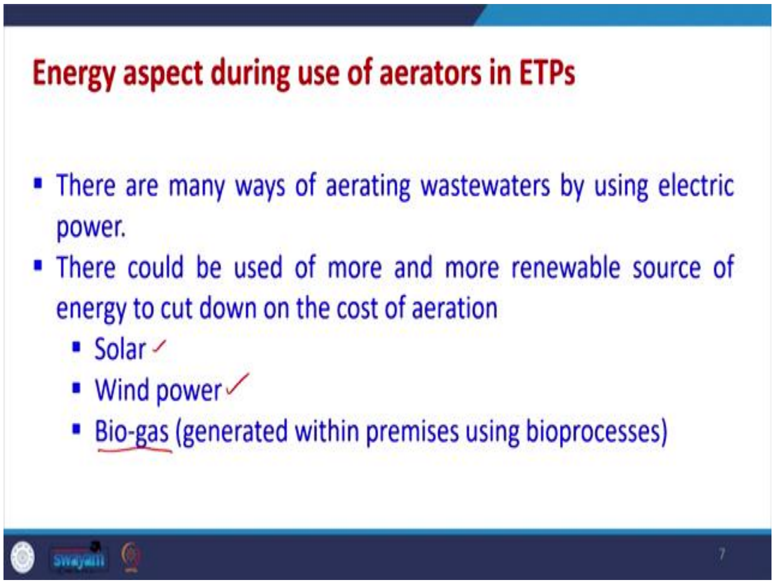

So, the good idea is that can we connect these aerators with the solar or wind power or the best option is to generate the biogas within that treatment plant and use the biogas by some ways, so that we can get the energy out of that and from that, we can get some of the supplies, maybe we can supply to the grid or something like that and we get money out of that.

So, the main thing is that how to replace the use the renewable sources of energy to cut down on the cost of aeration. And this is a very practical problem with all the major industries which are their major as well as small scale industries. So, if we can meet this aspect, this problem can be solved.

Now, we are going further for solving some of the problems or how to design a unit for some VOC removal or other things using different types of aeration mechanism. One is the surface aeration which is the most common then we have a diffused aeration possible. So, during how to use diffused aeration and what are the basic design things we can understand from them. So, this is this is what we are going to study.

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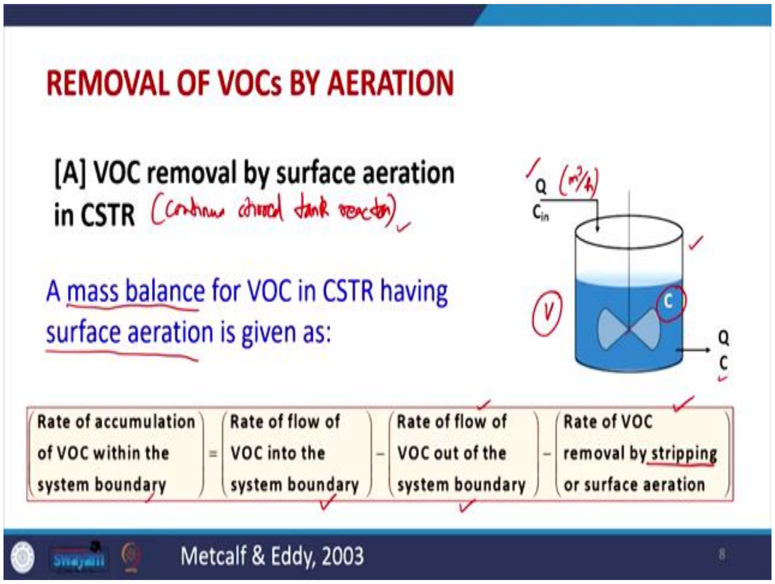

So, like if suppose we have to remove VOCs by aeration. So, we have some VOCs which are present in the water and that water has to be treated and now, if that water has to be treated what we are assuming that we will be making a batch type, a CSTR type of unit. CSTR type of unit means that we have a continuous steering which is going on and just steering is going on and through that the aeration is happening.

A mass balance for VOC in CSTR having surface aeration is given as:

$$V\frac{dC}{dt} = QC_{in} - QC + r_{VOC}V = QC_{in} - QC + \left[-(k_L a)_{VOC}(C - C_S)\right]V$$

where,

- V is the volume of the CSTR (m^3)
- dC/dt is the rate of change of VOC in the CSTR
- Q is the liquid flow rate in and out of the reactor (m^3/s)
- C_{in} is the VOC concentration in influent to the CSTR ($\mu g/m^3$)
- C is the VOC concentration in effluent from the CSTR ($\mu g/m^3$)

So, surface areas and is happening and we are presuming that this mixer is working in such a manner that whole of the water is getting properly mixed, there is no stagnant condition as such and it may be considered as continuously stirred tank reactor, so this is are the called continuously stirred tank reactor.

These are the, there are two three ways in which the mixing is presumed in any type of reactor and this is will taught in the chemical engineering discipline. So, one of them is like called as CSTR and other is called plug flow reactor, there are other type of mixing resins possible. So, we will we are presuming that everything is getting mixed well inside this reactor.

Now, the water which we have to treat is getting generated at the flow rate of Q. So, it will be some metre cube per hour or something like this so volume per unit time. So, this is the unit and it is having certain concentration of pollutants and these pollutants we have to remove or VOCs we have to remove out of the water. So, this is desirable.

And as soon as the water mixes into this liquid steam as soon as this gets so, its concentration will get changed to the concentration which is there inside this reactor and from here the same flow rate is coming out, but it will be having this concentration C and we want actually we should design in such a manner that this C should be up to the standard which have been prescribed by CPCB. And at that condition, we have to find out that what should be the volume of this reactor. The main aim is to have the volume known by designing this. So, this is what is the major objective.

So, for doing this, we what we have to initiate the process by performing a mass balance for VOC in the CSTR having this surface aeration via a mechanical agitator type of system. So, what is the rate of accumulation of VOC within the system binary? So, for this we apply the mass balance.

So, any rate of accumulation will be equal to rate a flow of VOC into the system boundary which is given here and then rate of flow of VOC out of the system boundary and also there is a, some VOCs certainly will because aeration is being done surface aeration so VOC will be stripped out of the water during this process. So, whatever is the VOC coming out, it will be maximum of that will be going off via this process and remainder will go into the system into the outflow and if there is some difference between in and out, so, that will get accumulated. So, this is any general mass balance equation.

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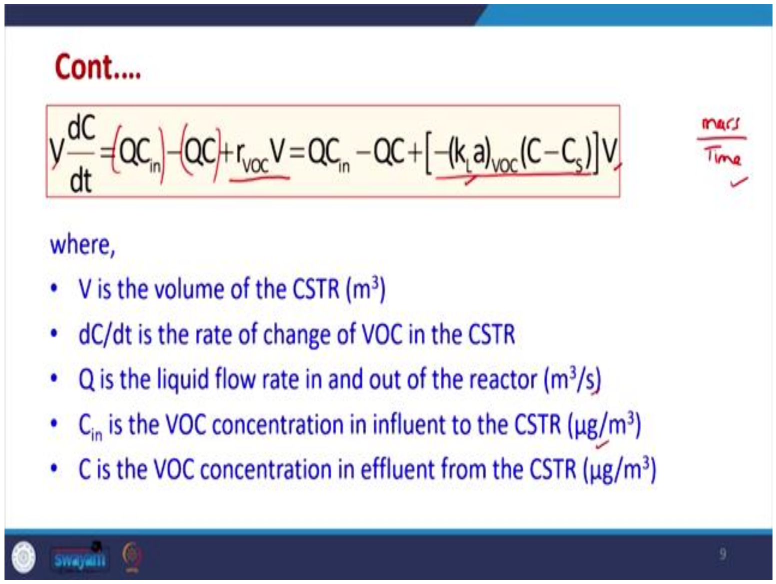

Now, going further for writing the mass balance equation. Now, we want to write each of the, there are different units in here. So, each of the units actually have a common, each of the unit each section of this has a common unit which is like mass per unit time. So, this is the overall unit.

So, first step the accumulation is given by V multiplied by dC by dt and this means the C is the concentration and concentration is in micrograms per metre cube if you are assuming and we are multiplying by volume, so, it becomes microgram per unit time. So, that unit time will be if we are taking in seconds so it will be second. So, microgram per unit second is the unit for this whole equation for each of the term.

Now, going further the since Q is the flow rate, which is like metre cubed per second and Cin is the concentration of the pollutant which is coming along with the water. Now, we want to reduce this concentration to a certain value, which is up to a standard and also this VOC will get removed because of the stripping action.

So, we are assuming this rate of stripping to be rate of VOC removal by rVOC and it is multiplied by volume to get the unit of mass per unit time. Further expanding this rate of VOC we can always write like this and already we have studied. So, rate of stripping will be like this, since the concentration of VOC is much higher than the saturation limit.

So, we are taking C minus Cs and this will depend upon the overall mass transfer coefficient of the VOC out of the system. So, this is taken together all other things are known here. So, these are the, this is a simple mass balance equation for this particular system at this condition, and for with respect to VOC.

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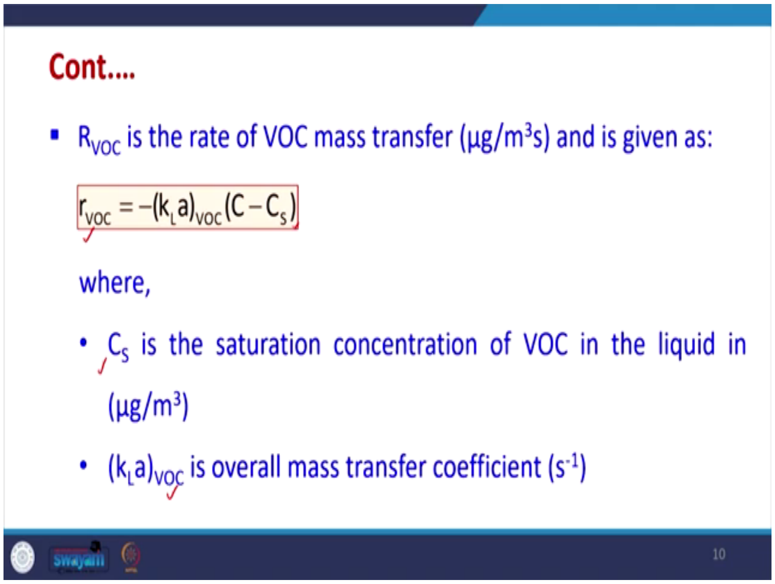

Now, there is a problem the rate of VOC rate of removal of VOC from the aeration is given by this where Cs is the saturation concentration of VOC in the liquid. So, for that we have we will have to understand use the Henry’s constant and other parameters to find out the VOC. What is the maximum solubility limit of VOC in the liquid? So, that we have to see. So, it will contain it will only be reduced up to this limit. Similarly, we have to find out the overall mass transfer coefficient of the VOC and that is a problem thing. Because it is not very easy to find the values of the overall mass transfer coefficient for each and every VOC. So, how to solve it, this is a challenge.

R_{VOC} is the rate of VOC mass transfer (µg/m^{3}s) and is given as:

$$r_{VOC} = -(k_L a)_{VOC}(C - C_S)$$

where,

- C_S is the saturation concentration of VOC in the liquid in (µg/m^3)
- $(k_L a)_{VOC}$ is overall mass transfer coefficient (s^{-1})

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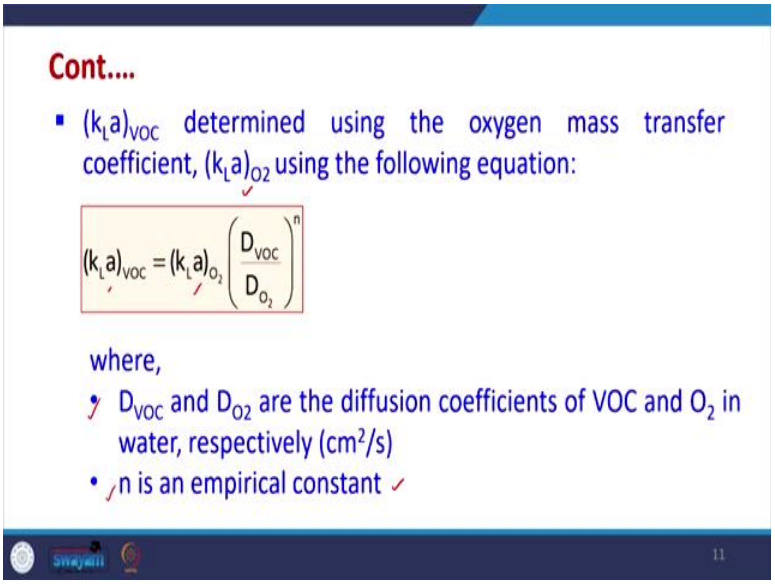

So, this is actually addressed, earlier also we had discussed so, we always try to look for a overall mass transfer coefficient value with respect to some gas in the same water system. So, like for oxygen, the KLa values are well known at 20 degree centigrade or any other. So, we can find if we can find out the KLa value of oxygen at 20 degree centigrade, we can find the KLa value of VOC also at 20 degree centigrade using this particular equation, which is given here.

$(k_L a)_{VOC}$ determined using the oxygen mass transfer coefficient, $(k_L a)_{O2}$ using the following equation:

$$(k_L a)_{VOC} = (k_L a)_{O_2} \left(\frac{D_{VOC}}{D_{O_2}} \right)^n$$

where,

- D_{VOC} and D_{O2} are the diffusion coefficients of VOC and O_2 in water, respectively (cm^2/s)
- n is an empirical constant

Assuming steady state condition, $V/Q=\tau$ and $C_S=0$, then:

$$\frac{C_{in} - C}{V/Q} = \frac{C_{in} - C}{\tau} = (k_L a)_{VOC} C$$

$$\textit{Fraction} \text{ of VOC removed} = 1 - \frac{C}{C_{in}} = 1 - \left[1 + (k_L a)_{VOC}\,\tau\right]^{-1}$$

But for finding this what we need to know is the diffusivity value of VOC and in this water and similarly, diffusivity value of oxygen. So, this can be determined a diffusion coefficients of VOC or oxygen in water can be determined from the literature and also there are experiments possible for doing so.

So, there are many empirical equations also which are available through which we can find out the diffusivity value, n is an empirical constant that that depends upon the VOC. Generally, it can be taken 1 it can be 0.5 so it varies. So, but generally, it can also be obtained for different type of VOC system or the treatment system. So, that is possible. So, we can through that, we can find out the value of oral mass transfer coefficient of the VOC. So, this is there.

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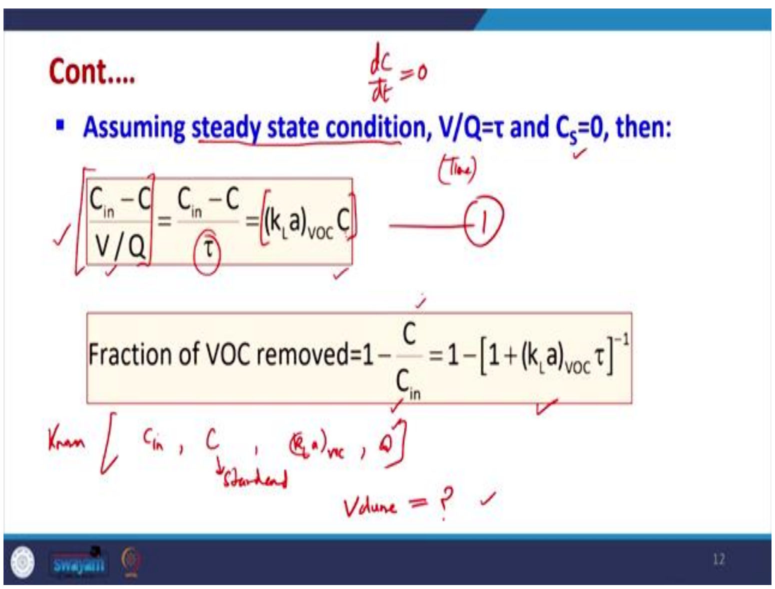

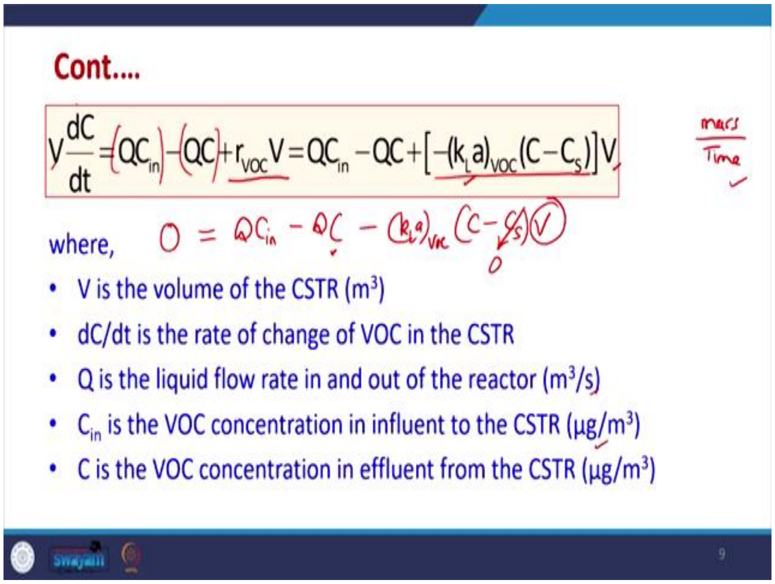

If this is known, so, we go further ahead and we assumed that a steady state condition when the steady state condition will reach the concentration will drop to a certain value and so, this is possible, also we can presume that the saturation concentration of the VOC in the water is approximately 0, it will be around some ppm.

So, we can may take that to be 0. If okay so, this is possible and V by Q, V by Q is like its unit is time. So, we are taking as this as a parameter and with respect to that we can determine the we can solve the equation to get the amount of VOC removed per unit time. So, at steady state condition what will happen? The value of dc by dt will become equal to 0 and now we are presuming Cs also to be 0.

So, if we apply everything on this equation that we are presuming this whole thing to be 0, so, this will become 0 then we have QCin in minus QC and this is minus KLa of VOC into C minus Cs and this Cs is also presumed to be 0 multiplied by V. So, we now, what we want is that we want to determine either the volume so, this is one of the key thing that we can find out or we can we can go on finding out the value of how much efficiency of removal is there. So, this way we can manipulate the equation a little bit and we can easily manipulate the equation in this form.

So, actually we will be having this on one side and this on another side, but we are replacing V by Q by this tau value. So, this is possible. Now, fraction of VOC remove can we written like 1 minus C by Cin so, whatever is the concentration of the pollutant at the inlet. So, and that is there and if we go for this so we can actually find out the C by Cin value also and after a little bit manipulation, because C is here also.

So, we can divide by whole of the equation by C. So, we can get easily this equation and this actually tells us that, what is the fraction of VOC which will be removed if we presume a certain volume. Otherwise, we can go on further we can opposite way also we can find out using the equation 1 that if we know that okay, how much should be that final concentration.

If this is known, so, under that condition Cin is already known, the known parameters will be like Cin, then concentration because it will be obtained from the standards, so because we have to always limit up to the standards and the KLa value already we have determined for VOC. So, only and Q is already fixed because the flow rate is already known. So, depending upon that the volume can be determined of the CSTR and if this volume comes out to be very high suppose.

So, under that condition, we can put 2, 3 CSTR in parallel. So, we can always divide the Q into smaller units. So, this is possible and still we can solve the, this condition so this is how we can design a system for removal of VOC in a mechanical aerated system with surface aeration. So, this is possible so, we can find out the volume. Sometimes if volume is already known to us we can find out the fraction of VOC removed et cetera.

Now, there is a second condition which is there which is like VOC removal by diffused aeration in a CSTR. So, here at what we are directly going for mass balance of VOC in the diffused aeration system in a CSTR type of system there is no mechanical aerator as such, but we are assuming that for diffused aerator which has been installed it is good enough that it is able to mix all the water.

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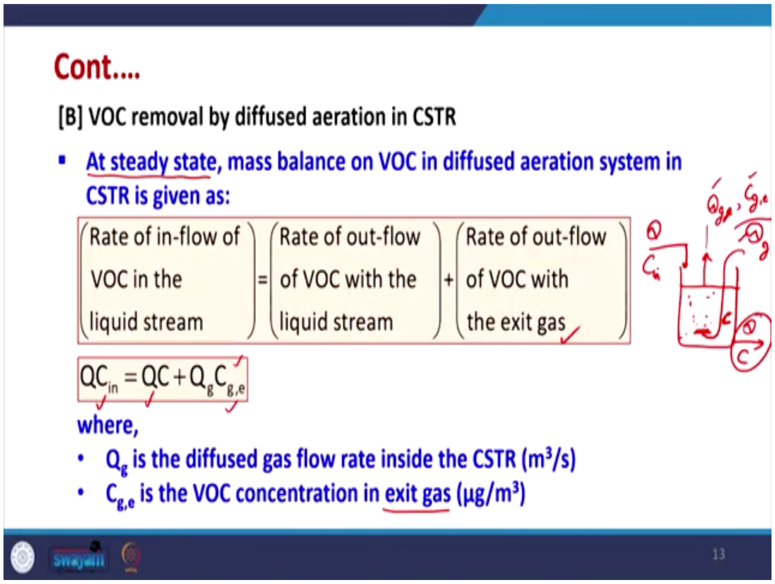

So, we can assume the CSTR condition. Now, under steady state condition when that means the amount of water which is coming into the system and amount of pollutant in terms of mass per unit time coming into the system and that is what is going out or it is going out with the exit gas. So, this is there.

So, under that condition, the same thing is there only is that the air is being actually diffused at certain level and this air is going further out and we are so, this is the Q this is the Cin and this is happening. So, air is there. So, we have a flow rate of air and from here along with this which when it is going out actually the VOC is also going out.

So, we have a flow rate of exit gas and this is having certain concentration of this VOC. So, this is possible. So, we are assuming two things one is the Qg is the flow rate. So, we have at steady state whatever is the gas in that gas will be out and in the exit, what is the concentration of VOC. So, this is there.

So, this we have to find out and certainly the water will also be going out from here and we are assuming that this is the C. So, concentration here inside this reactor is C. So, we are still assuming this to be a CSTR because of the mixing which is happening because of the diffused air.

So, under steady state condition, we can find out the QCin that will be equal to rate of outflow of VOC with the liquid stream. So, we are assuming this term is there, so this is Q multiplied by the concentration and because the we are also having the gas air which is actually being diffused. So, along with the gas, some amount of VOC will be going out. So, we are assuming the concentration in the outlet streams to be Cge. So, this is there so VOC concentration in the exit gas in microgram per metre. So, this is a very simple balance, which is there.

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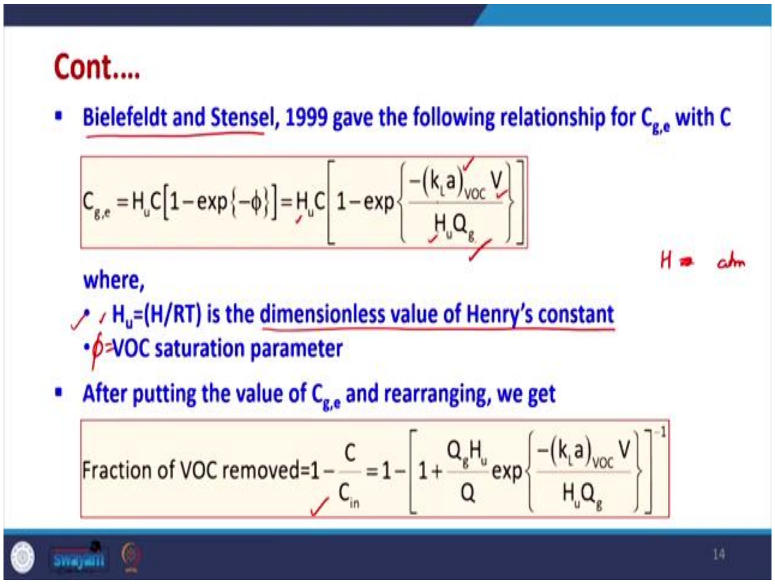

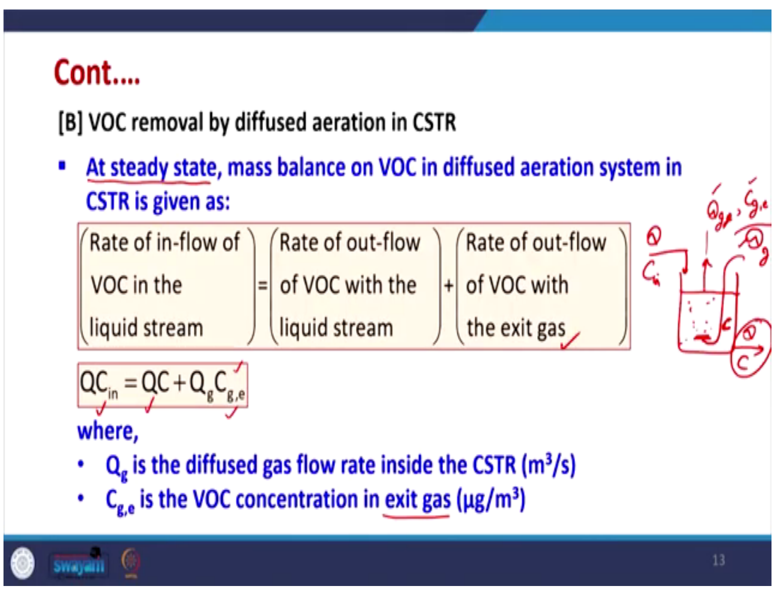

Bielefeldt and Stensel, 1999 gave the following relationship for $C_{g,e}$ with C

$$C_{g,e} = H_u C\left[1-\exp\{-\phi\}\right] = H_u C\left[1-\exp\left\{\frac{-(k_L a)_{VOC} V}{H_u Q_g}\right\}\right]$$

where,

- H_u=(H/RT) is the dimensionless value of Henry's constant
- VOC saturation parameter

And from this simple balance, there are a lot of issues. How to if we neglect this thing, so, the fraction of VOC removed is very simple, but in this particular equation, how to find out the concentration in the exit guess this is a major challenge. So, for that two of the scientists in 1999 gave equation for finding out the value of concentration of VOC in exit gas with respect to concentration which is there inside the reactor itself.

So, this is there and the equation is given like this. So, Hu into C 1 minus exponential minus phi and this phi is actually equal to this overall mass transfer coefficient of VOC into volume of the CSTR divided by the Hu, Hu is the H by RT that means dimensionless value of Henry's constant. Remember in the around two lectures back we studied the H has a unit of atmosphere, the Henry's constant and we used that unit in solving the problems. But any Henry's constant can be made into dimensionless form also.

So, this is we are using the dimensionless form of the Henry's constant here Hu here and here also and Qg is the flow rate of the gas which is being diffused and psi is overall called the VOC saturation parameter which is missing here. So, what we need is the KLa again volume we have to determine the Hu will be known for VOC from literature or we had to separately find it out and Qg is the flow rate.

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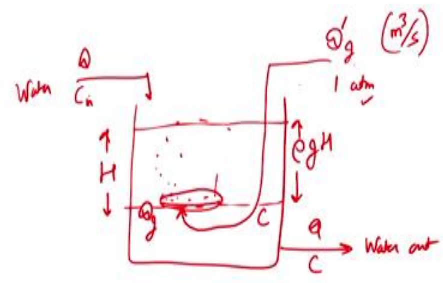

$$\frac{Q_g P_H}{\cancel{T_H}} = \frac{Q_g' \times 1\ \text{atm}}{\cancel{T_{atm}}}$$

$$\boxed{Q_g = Q_g' \times \frac{1\ \text{atm}}{P_H\ \text{atm}}}$$

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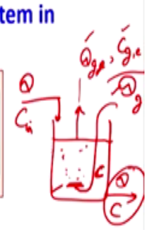
[B] VOC removal by diffused aeration in CSTR

- At steady state, mass balance on VOC in diffused aeration system in CSTR is given as:

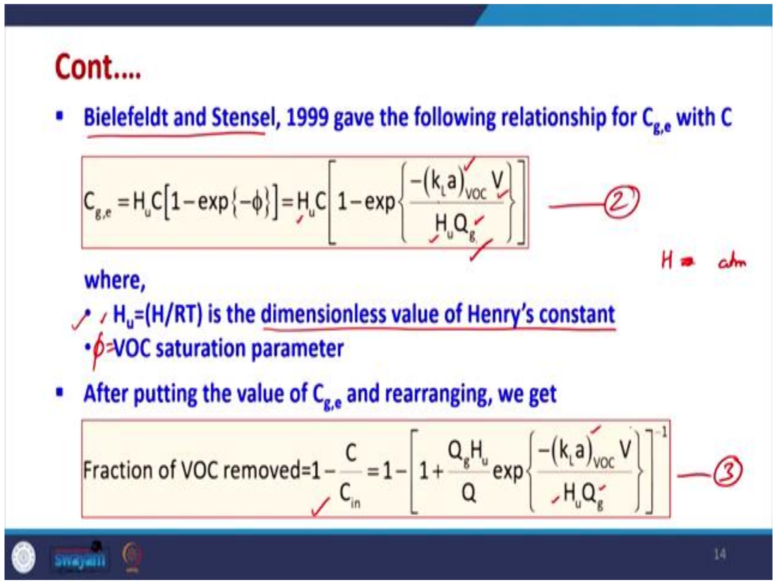
$$\begin{pmatrix}\text{Rate of in-flow of} \\ \text{VOC in the} \\ \text{liquid stream}\end{pmatrix} = \begin{pmatrix}\text{Rate of out-flow} \\ \text{of VOC with the} \\ \text{liquid stream}\end{pmatrix} + \begin{pmatrix}\text{Rate of out-flow} \\ \text{of VOC with} \\ \text{the exit gas}\end{pmatrix}$$



$$QC_{in} = QC + Q_g C_{g,e} \quad \text{——— (1)}$$

where,

- Q_g is the diffused gas flow rate inside the CSTR (m^3/s)
- $C_{g,e}$ is the VOC concentration in exit gas ($\mu g/m^3$)



Also is another thing in this particular equation, the flow rate has to be adjusted, this flow rate will be outside the water. So, that means, when we are assuming the CSTR and in the CSTR the flow rate of the gas is like suppose it is being diffused here, this is the diffuser which is there and from here the gases are coming out. So, these bubbles will be coming out.

Now, here the Qg is there, this is the flow rate and this unit we are just assuming suppose, the unit is assumed to be some metre cube per second or anything like this, but the actually we know that this metre cube for gas and this is the inlet with respect to for water this is like Q and here we have Cin and here we have Q and C.

So, this is the water out of the system and C is the concentration here. So, depending upon the depth, this depth at which this diffuser has been installed. So, we have to change the Qg value. What I am saying is that since we know that volume of gas is not a fixed parameter, it is dependent upon temperature and pressure.

Now, we can presume the temperature to be constant outside ambient condition and inside the water also. So, we can presume that but this gas is being pumped at a certain depth. So, that means the pressure is changing outside it is 1 atmosphere, but inside it is not 1 atmosphere because this particular it is being released at this particular depth, so the flow rate when it is being released it will change and this will be so, because we have to take account of rho g H this particular and the pressure is not 1 atmosphere it is 1 plus rho gH which is the where the H is the height of the liquid or depth of the liquid at which this diffuser is being install.

So, actually, if the this is Qg dash and actual value of Qg is we are assuming here. So, this Qg we can write equations like this Qg into P at this condition P at depth H and then T temperature. So, we can assume the temperature to be same and for this at this condition Qg this is Qg dash here starting from Qg dash multiplied by 1 atmosphere. Because at this condition it is only 1 atmosphere and we can assume this temperature to be T ambient and we can assume that T at that H to be same as T at ambient condition.

So, if this is there, this will go off and we have to calculate the actual flow rate of the gas at this condition and this will be equal to Qg dash into 1 atmosphere divided by the pressure at that height and it should be determined in 1 at atmospheric unit also. So, this way we have to determine the Qg value for use in this particular equation here and also in this balance equation.

So, this equation 1, equation 2 are combined together to get this particular equation 3 and for solving 3 we require Qg we require KLa and we require Hu and if these are known, we can find out the volume of that particular system. So, this is how we can solve the problem with respect to diffused aeration type of system and we will try to solve one numeric problem in the next lecture and try to understand that how the we can find out the volume of the system under this condition so this is one of the like a design problem so we can solve it very easily. So, please join in the next lecture. Thank you very much we will continue in the next lecture thank you.