Course Name: Industrial Wastewater Treatment

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Lecture 33: Treatment of wastewater produced from Distillery and Dairy Industries

So, welcome you all. Today I am going to deliver lecture 3 of module 7 which is on treatment of wastewater produced from distillery and dairy industry. So, under this what we are going to cover a new reactor configuration that is called as anaerobic hybrid reactor system. A basic introduction on this type of system and then we will also study the various reactor configurations which were used in treatment and disposal of distillery spent was. Followed to this we will also discuss about the concept which have been used in designing of hybrid reactor configuration and then we will be also looking upon the various process parameters which affects the performance efficiency of this reactor. And finally, we will have a comparative study of the existing system that is UASB and the hybrid reactor system in order to compare and evaluate the performance efficiency of these two reactor systems. And then based on this there will be certain numerical which will illustrate the performance of the reactor, the efficiency of the reactor, the different design parameters.

So let us start with this basic introduction which is the anaerobic hybrid reactor. So, this reactor system which combines basically the two different reactor configurations, like attached growth system, suspended growth system, a mixed kind of system which are built in a single system we say that is anaerobic hybrid reactor. Basically when we combine the attached growth system and suspended growth system, we try to combine the dual advantages of the two different attached growth system and suspended growth system bioreactors which ultimately enhances its overall efficiency and the biomass retention capacity of the reactor which affects the process performance.

And in the existing UASB system there has been a lot of problem that has been perceived during its operation and maintenance that it has lot of sludge washout from the effluent end that causes reducing in the overall biomass retention capacity of the reactor leading to the higher F/M ratio and due to this the reactor ultimately goes frequent upsets and failure. So, to reduce this anaerobic hybrid configuration that inbuilt the attached growth system along with the suspended growth system along with the existing UASB system. So as to create a new configuration and is referred to as anaerobic hybrid reactor which has lot of potential to reduce the sludge washout rate and can also enhance the performance efficiency of the system in terms of BOD and COD removal. And then also will assess the shock loading capacity of the two reactor system that is hybrid system and then the existing UASB reactor to see how much shock loading can be applied, how the reactor behaves during shock loading conditions and apart from this if we see that because of the two systems inbuilt together in a single reactor so this basically can handle high organic loading rates than the conventional UASB reactor these are the few added advantage of this type of reactor configuration.

And let us see what are the different configuration if we talk about different configuration which are used in anaerobic treatment of spent wash. So initially this conventional anaerobic digesters were used but the basic problem associated with this type of digesters that is required higher HRT which in turn requires high volume of the reactor which enhances the capital cost. And also if we see the another reactor system which is basically the anaerobic filter system so this has been also tried for the treatment of the spent wash but this system have frequent choking and clogging problem there is a lot of short circuiting that takes place which overall reduces the performance efficiency of this system and the most widely used system which is the upflow anaerobic sludge blanket reactor this system basically that is presently used in the industries which offers very low HRT and very high removal efficiency. So, this system is mostly and most widely used in the industries for treatment of the spent wash but during this operation also there were a lot of problem associated with this UASB reactor that is lot of sludge wash out rate that happens from the UASB reactor during the high organic loading rate conditions so that causes loss of biomass from the system which reduces the biomass retention capacity and which lead to the increase in the F/M ratio and that causes frequent upset and failures in the system. So, to avoid this a new reactor system that has been perceived that is anaerobic hybrid reactor which can significantly reduce the sludge wash out and can enhance the overall removal efficiency of the system compared to the UASB reactor. So, this configuration of the system has been reported as the most efficient system for the treatment and disposal of distillery spent wash.

So let us talk about these two systems, so here if we see this is the schematic diagram of the UASB reactor and then this is anaerobic hybrid reactor. So, here if we see they are looking similar to each other one litre difference is biomass retention in the two reactors so here if we see this is up flow reactor so wastewater is fed into the reactor from bottom and it flows to the top upward direction and here if we see as in the bottom there is the sludge bed which basically having high concentration of biomass that is inoculated in the system. So this wastewater when it comes with this sludge microbial sludge so this comes in contact and undergoes anaerobic decomposition and during this decomposition the biogas will be produced, so lot of CO_2 (lot of carbon dioxide) that will be generated when this biogas is produced this gets entrapped within this biomass and makes this sludge particles buoyant so they will float upwards because of the off flow velocity and also because of getting buoyant because of entrapment of this biogas which are formed during the anaerobic digestion process so they will float towards the top and if we see this is basically that is the deflector beam which is provided to basically separate the biomass from rest of the solid particles from rest of the water liquid containing biomass that strikes on this deflector beam so this will separate out the biomass from rest of the liquid and whatever the biogas that will be directed towards this collection chamber which is like the floating dome provided at the top of the reactor where the biogas which is produced is collected and taken out from the top of the reactor through the vent pipe, so from this end the biogas is removed and this basically this part if we see that is called as the liquid solid separator system this is designed in order to separate the sludge and biogas from rest of the liquid and the treated liquid after separating from the biomass and biogas, the treated effluent that comes out from the top of the reactor. So, this is basically the conventional UASB reactor so what the problem happens with this kind of system that when this biogas is generated so lot of biomass that gets entrapped with the biogas CO_2 and methane. So, this will make the sludge particle buoyant and they will come out along with this treated effluent so there is a continuous loss of the biomass that takes place from the system and especially during the high organic loading condition there is an excessive wash out of the sludge that takes place and that results into reducing its biomass retention capacity and increasing the F/M ratio in the reactor which causes failure of the system. So, this kind of failure because of the reduction because of the excessive sludge burst out from the system that is the major bottlenecks of this conventional UASB reactor. So, to remove this there has been a modification that is done in the anaerobic hybrid system which can be seen here so here in addition to this in the middle just below the top of this deflector beam. So we have provided an attached growth system so this is a filter media which is provided here which further helps to retain whatever this floated biomass that goes out of the system so when biogas along with the sludge particles passes through this filter media so they get attached they get and surface they get attached on to the surface of the filter media so from here the sludge was out that can be reduced by incorporating the filter media in the anaerobic hybrid system and not only this sludge was out but also it can enhance the overall performance efficiency of the system because here the first is a treatment that is taking place here the microorganism they are suspended growth system so here first of all the initial biodegradation that will be taking place in the suspended growth system and this filtered media acts like a attached growth system where when the wastewater comes in contact so additional degradation that takes place so here if we see the performance efficiency we compare with the UASB reactor so what we will get there is the additional 5 to 10 % more of COD reduction that can be achieved in this hybrid reactor. So, this is like the modification that has been made in the existing UASB reactor in order to reduce the sludge was out from the system and then to enhance the performance efficiency removal efficiency of the reactor.

And then to assess this performance of the anaerobic hybrid reactor there has been many parameters. So these are the essential parameter that we have to monitor and we have to look into so as to get the optimum removal efficiency from the system so if we see there are a number of process parameters like pH, alkalinity, volatile fatty acids, organic loading rate, hydraulic loading rate, then there is a shock loading rate, then there is a sludge was out rate. So, these are the process parameter basically in this anaerobic hybrid reactor process when the anaerobic degradation of the organic matter takes place so this can be like divided into two major phases like acidogenesis and methanogenesis process. So, in the acidogenesis process the optimum pH requirement that has to be maintained 5.5 to 6.5, whereas in second stage of system what we have read like diphasic system in our previous lecture. So, in that the optimum pH requirement that is 6.8 to 7.2. So, measurement of pH is very important in order to improve the overall efficiency of the system and then because the reactor sometimes if the methanogenesis fails so and acidogenesis is taking place so this causes the built up in the acidity into the reactor so the reactor should have sufficient buffering capacity in order to neutralize the acidity formed during acidogenesis process so a minimum of 1500 to 5000 mg/L of alkalinity must be present in the system in order to neutralize the acidity formed during acidogenesis process and that too in the form of bicarbonate alkalinity which is the most easily available form of alkalinity used by the microorganisms to neutralize the pH in the system. And then this is the volatile fatty acids as in the first phase whatever the carbohydrates proteins and other organic matters present into the wastewater that undergoes acidification and various volatile fatty acids like, acetic acid, propionic acids, butyric acids, valeric acids these are formed and their accumulation may cause the upset and failure in the system, so care has to be taken that their concentration should not be going beyond 500 mg/L so as to not affects the efficiency of the system. Then there is organic loading rate so this is the amount of total BOD that can be applied per unit volume of the reactor so this is a very important parameter so we have to obtain the optimum organic loading rate which is required and is basically depends upon the BOD concentration and the flow rate which is being applied to the reactor and normally the UASB reactor that can handle organic loading rate around 5 to 15 kg COD/m^3-d. And similarly we see that is hydraulic retention time that is basically the time till which the wastewater retains in the reactor so this time basically if we see if we maintain very high HRT so this will cause larger capacity of the reactor in case if HRT is reduced then it will cause further increase in the organic loading rate, so a optimum HRT we need to find out that normally for spent wash treatment that is found four to five days and then similarly we see the shock loading capacity as we know in the plant. So, this incoming wastewater their characteristic their flow varies time to time so it's our reactor system must be also assessed for shock loading capacity and should be able to absorb the peak loads during the excessive organic loading rate conditions and basically this shock loading frequent shock loading in the system that can cause a decrease in the removal efficiency of the system. And then the next parameter what we have to also look is that is basically connected with the biomass retention capacity of the system that is sludge wash out rate. So, this basically gives us the amount of biomass that is gain that is wastage out of the reactor per unit time. So, this basically increases this the F/M ratio in the reactor because the microorganism that is reduced and the food is constant so this sludge was out rate from the system will enhance the F/M ratio which will adversely affect the process efficiency. So, these are the basically the process parameter that we have to look into while assessing the performance of the anaerobic hybrid reactor the anaerobic reactors.

And then basically this is the definition and the formula that we can use to get the different process parameter that is hydraulic retention time. So, this is the formula for this that is $HRT = \frac{Volume}{Flow\ rate} = \frac{V}{Q}$. So if we say V is the volume rate and Q is the flow rate so this if we divide so we will get the HRT which basically represent the average time for which the waste water is kept inside the reactor. Similarly if we see the formula for sludge wash out rate, so that is basically the amount of the suspended solids which are going out of the reactor along with the treated effluent so this can be worked out using this formula that is $SWR = Flow * SS\ conc.\ in\ treated\ effluent$ = Q × SS.

Similarly, if we see that organic loading rate that is basically the amount of total BOD that can be applied per unit volume of the reactor per unit time and this the formula $OLR = \frac{FLow \times BOD}{Volume} = \frac{Q \times BOD}{V}$. The unit for this organic loading rate that is basically normally we use that is kg/m^3.d.

And then this is another process parameter which basically is the sludge retention time. So similar to the hydraulic retention time so like hydraulic retention time indicates the time period for which the liquid retains in the reactor whereas in the sludge retention time it is the time for which the biomass remains there in the reactor so biomass which is held within the reactor that total time for which the biomass is retained in the system that is called as the sludge retention time this is also referred as solid retention time sometimes in some of the books this is also given as the sludge age and to get this we have we have to use this formula that is the solid retention time $SRT = \frac{Quantity\ of\ sludge}{Rate\ of\ washout\ of\ sludge}$=$\frac{W \times 10^6}{Q \times MLSS}$, where Q is the flow rate of the wastewater effluent that is going out of the reactor and this MLSS that is the mixed liquid suspended solid concentration in the treated effluent so they are here explained the W, Q and MLSS. So accordingly using this formula if we are not recycling anyways so this formula can be used for determining the sludge retention time in a reactor.

Now let us see a case study where we have studied the performance of the hybrid reactor system and UASB reactor system for the treatment of this spent was which is having this characteristic so effluent pH that was 7± 0.2, this was coming from the equalization tank after the neutralization so this is the effluent pH of the spent wash to be treated and if we see the initial alkalinity that is around 3950 mg/L and this the effluent BOD concentration that basically varied because this concentration varies from time to time and depending upon the concentration of the molasses and the process that has been used. So, let us assume the COD concentration or BOD concentration that is 36,280 to 44,520 mg/L and the OLR that is given as 4.53 to 11.13 kg COD/m^3.d. So, this is the prescribed organic loading rate range that can be applied for the treatment of the spent was and we have varied the HRT in the two system like we have studied the system for hybrid and UASB reactor both so here these are mostly the HRT range which are used in the treatment of spent was in hybrid and UASB reactors.

So, one by one we will see how this process parameters they affects the performance efficiency. So, this if we see the effect of HRT. So, what we can see this is basically the COD removal efficiency curve and this was the methane yield curve for different HRT if we plot so here what we can see that this as we increase the HRT, the COD removal efficiency keeps on increasing and after a further increase in the HRT the removal efficiency in both the reactor that got decreased so this says a particular organic loading rate need to be selected which we say that is the organic loading rate or the optimum HRT for which the reactor will have maximum efficiency. So, in this we see at five days HRT the performance efficiency in this hybrid reactor that is comparatively higher than the UASB reactor and similar is the case in terms of methane yield. So, methane yield also increases with increase in HRT and then finally increase in the HRT reduces this methane yield.

And if we see further the VFA and the sulfide profile in the two reactors at different HRT. So, what we can see the as we keep on increasing the HRT the VFA level keeps on increasing. And similarly, the sulfide levels that will keep on increasing. So, we have to look into this that sulfide concentration that must not be more than 200 to 300 mg/L and if VFA concentration also goes beyond like 1000 to 1500 mg/L more than that has to be restricted in order to avoid the offset in the performance of the reactor.

So this is the rate of sludge washout, so again if we see as we increase the HRT so there is so again if we see the effect of HRT on the percentage suspended solid reduction and the sludge washout rate so these curves that gives us the percentage suspended solid reduction whereas this two curves shows the sludge washout rate, so what we can see this percentage suspended solid removal system in the hybrid reactor that is much higher compared to this UASB reactor whereas similarly the sludge washout rate that is more in the UASB reactor compared to the hybrid reactor. So, here basically the added advantage that we are getting in case of this hybrid reactor because of hybrid configuration the rate of sludge washout that is reduced and that causes enhanced suspended solid removal efficiency in the hybrid reactor compared to the UASB reactor.

And then this is basically the effect of shock loading in the performance of UASB and hybrid reactor. So, here to analyze the effect of shock loading what we have done we have increased the concentration of the BOD to the tune of 1.25 times 1.5 times, then 1.75 times and then further two times. So in case of UASB reactor when we increase the concentration of this BOD, COD level so here this is COD concentration was increased so what we can see this is the performance parameter like this gives the effluent COD and this basically bar gives the effluent VFA concentration. So, here this is the shock loads profile of the system so here if we see effluent concentration keep on fluctuating whenever there is a change in the organic loading rate conditions like here also here also there is a slight change in the performance so here what we can see the performance efficiency of the system up to 1.5 times was okay but when we have increased the shock loading to 1.75 times the effluent VFA concentration keeps on increasing this says that the system is not able to withstand with the 1.75 times of the shock loading of the concentration or the organic loading rate this can sustain up to 1.5 times of the shock loading.

But if the same performance we see in the hybrid reactor so what we can see this is like the increase in the concentration 1.25 times, 1.5 times, this is 1.75 times and this is 1.2 times so what we can see this is the effluent COD level so what we see the fluctuation is like within plus minus 5 to 10 percent of the removal efficiency so it shows that up this hybrid reactor can absorb two times of shock loading beyond this there has been a little bit more fluctuation in the performance of the system but as soon as we have switched to the normal concentration again this concentration of BOD level got reduced and this basically similar profile we can see for the VFA during this two times of organic loading it is started going towards the peak but as soon as we have switched down so this got again reduced to its normal level. So this study shows that the hybrid reactor configuration they are more robust in order to absorb the shock loading compared to the UASB reactor.

So here in this numerical the BOD concentration that is given as 40,000 mg/L and it is also given that is spent was is fed at a rate of 50 m^3/d that is the flow rate of the reactor system and it is also given that the total biomass in the reactor that is inoculated with is 4,000 kg and the volume of both the reactor that is given as 200 m^3 and it is also given that the effluent BOD and biomass concentration in the two reactor that were 8,500 mg/L 10,500 mg/L and then 400 mg/L, 500 mg/L respectively. So, these are the BOD and biomass concentration in the AHR and UASB reactors so for this we have to determine this process parameters so we have learned the equations to determine these parameters.

So one by one we have to see how this OLR, HRT, sludge washout rate and SRT finally this BOD removal efficiency how we can obtain. So let us see how we can calculate this process parameter first of all let us see how we can use to determine organic loading rate so this is the formula $OLR = (FLow \times BOD)/Volume = (Q \times BOD)/V$ that is the flow rate equal to

$50\ m^3/day \times 1000\ L/m^3 \times 40000\ mg/L \times \frac{10^{-6}\ kg}{mg} \times \frac{1}{200}$. So this will give you the value equal to 10 $kg\ BOD/m^3.day$. So the organic loading rate in the two reactor system that is equal to in both anaerobic and hybrid reactor that is 10 $kg\ BOD/m^3.day$ and then how to determine the HRT. So, for determination of HRT again we have to see into this formula $HRT = Volume/(Flow\ rate) = V/Q$. So this is the volume is equal $\frac{200}{50}$, so if we divide we get the HRT equal to 4 days.

And similar to this we have to get this sludge wash out rate, so sludge wash out rate again if we see the formula that is $SWR = Q \times SS$. So we can determine for both UASB and hybrid reactors so here $50\ m^3/day \times 1000\ L/m^3 \times 500\ mg/L \times 10^{-6}$ kg/mg, so if we do this calculation the total sludge wash out rate from the UASB reactor that comes to 25 kg/day. Similarly, if we do for the anaerobic hybrid reactor so this is the flow rate again multiply with the effluent concentration and do its unit conversion the value will come 20 kg/day.

Similarly for SRT we have to see $SRT = \frac{Quantity\ of\ sludge}{Rate\ of\ washout\ of\ sludge}$, so this is the formula so here again if we know $\frac{4000\ kg \times 10^6 mg/kg}{\frac{50m^3}{d} \times 103\frac{L}{d} \times 400\frac{mg}{L}}$, so if we put the SRT in AHR we get 200 days similarly if we go for UASB reactor system $\frac{4000\ kg \times 10^6 mg/kg}{\frac{50m3}{d} \times 103\frac{L}{d} \times 500\frac{mg}{L}}$, so we get that is 160 days in UASB reactors. So, this we can see SRT value in AHR that is around 40 days more in AHR compared to the USB reactor.

And similarly then finally we can calculate the BOD removal efficiency that is $BOD\ removal\ efficiency = \frac{(BOD_{in} - BOD_{out}) \times 100}{BOD_{in}}$, So that is $\frac{(40000\frac{mg}{L} - 10500\frac{mg}{L}) \times 100}{40000 mg/L}$ so this is percentage BOD removal efficiency in USB reactor. Whereas in case of AHR the value of effluent BOD that comes to 8,500 mg/L, so this is around 78.75 percent so this if we assess the overall removal performance efficiency of the hybrid reactor compared to USB reactor so this is around 5 % more efficient than the UASB reactor.

And then these are the references that we can use for our practice.

Thank you