Course Name: Industrial Wastewater Treatment

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Week – 06

Lecture 28: Treatment and disposal of sludge

Welcome you all. Today I am going to deliver my lecture 3 of module 6, which is on treatment and disposal of sludge. So, under this if we see we are going to cover the sludge digestion process and then what are the factors which affects this digestion process, what are the different types of digesters we use like aerobic digesters, anaerobic digesters and then finally we will be going in more details of the design of aerobic digesters and then also we will be taking one numerical example to illustrate how anaerobic digesters can be designed.

So, if we see the sludge digestion this is basically the process of stabilization of sludge biomass or sludge solids present into the sludge. So, if we see the sludge which is generated out of different physical, chemical and biological units they are not stabilized. So, the process of stabilization of sludge that is termed as sludge digestion and this is achieved by decomposition of organic solids through controlled aerobic or anaerobic conditions. So here the process basically results into conversion of whatever the organic solids that are present into the sludge in the form of final end products like carbon dioxide or methane gases and then there will be supernatant which will be relatively free from the suspended solids and then finally at the bottom we will be getting the digested sludge. So the process yields the digested sludge which can be used as a manure and if we see the overall digestion process which takes place, which are used for digestion of sludge results into the final end product in the form of gases and the stabilized sludge biomass and in this process if we see the overall volume of the sludge that is basically reduced about 70-75% percent. So this is why this sludge digestion process that is essential because the process of sludge digestion is like one of the treatment system wherein we try to stabilize the sludge so that it may not get further into the putrification process may free from the odour and odour nuisance, smell problems.

So this is like to make the sludge for final disposal we have to go for sludge digestion process and then we see what are the factors which affects the digestion process. So here if we see the very important factor that is temperature, which is basically accelerates the process of digestion and can also be used as one of the important design tool for reducing the overall digestion period which ultimately demands for higher capacity of digesters and then if we see there are the pH is one of the another important parameters which affects the digestion process. So if we see the digestion mechanism aerobic mechanisms here we see a lot of a city is produced which need to be neutralized so this pH also in plays a very important role that if the water goes towards acidic phase the this will adversely affect the digestion process and then also the seeding of digested sludge that is another important tool which we can use for enhancing the process of digestion. So this is one of the another important parameters which can enhance the overall digestion efficiency and then type of mixes we are which are used in digestion process for mixing of the sludge in within the digestion tank so that is also very important factor whether it is like diffused air mixing type of mechanical diffusers they are used.

So depending upon different types of mixing source the effects of temperature on the desert digestion period if we increase the temperature of the digestion tank then what we can see that digestion period that is significantly reduced. So with increase in the temperature in fact what happens the temperature the rate of digestion is directly proportional to the temperature. So this enhances the rate of metabolism and ultimately results into higher digestion efficiency and in temperature also there is a mesophilic zone there are thermophilic zone so depending upon the temperature set for digestion so there may be like mesophilic bacteria which are active in mesophilic temperature in zone and there are thermophilic bacteria which are active in thermophilic zone so if we see up to this temperature like up to 40°C like in mesophilic range this this basically shows the variation of digestion period required for a particular temperature so we can see around this 35°C that is the optimum temperature required for a minimum digestion period and similarly for in thermophilic zone if we see so in this if we see that is around temperature zone around 50-52°C that is the optimum temperature when there is a minimum digestion period required. So depending upon the temperature range the kind of digestion process the digestion efficiency of the you know digesters are affected. So overall what we look into this parameter that this temperature if we operate the digestion at a higher temperature, we can significantly reduce the size of the reactor which is one of the important parameter for optimizing the cost of the treatment of the system.

And then if we see what are the different zone of digestion as I said this is mesophilic digestion the temperature range that is 25-40°C and in this range of temperature there are mesophilic organism bacteria which act upon sludge digestion process and for this zone the optimum temperature condition that is around 35°C and this require a minimum digestion period of 30 days. While if we do the digestion in thermophilic zone then the temperature range for this thermophilic digestion that varies from 40 to 60°C and in this zone basically the heat-loving bacteria that is the thermophilic organisms they are active and they acts upon the sludge and carry out this enhances the sludge digestion process and for this if we see the optimum temperature which is required for minimum digestion period that is 52°C and if we see the digestion period that is significantly reduced from 30 to10 to 15 days. So here in case of mesophilic digestion that digestion period requirement is 30 days whereas in case of this thermophilic digestion process the digestion period requirement that is hardly 50% of the mesophilic digestion zone. So, this is how the temperature affects the digestion process.

And then let's see the pH the accumulation of a city in the biological system that adversely affects the digestion process degradation process and hence the pH of the system that should not be less than 6.5 and for the optimum efficiency of digestion period which that requires a optimum pH range of 7.2 to 7.4 because below this the methanogenic phase which is one of the important pathway of degradation that is getting adversely affected below this period because of certain process subset conditions capacity gets accumulated in the system the best remedy to control that that is to aid some of the alkaline materials some of the basic materials like hydrated lime sodium bicarbonate or some of the basic material that has to be added into the system so as to bring the pH to its optimum range of 7.2 to 7.4. So, this is how this pH affects the digestion process.

Then we see the another important factors what we discussed that is seeding of sludge with the digested sludge. Basically seeding of sludge with the digested sludge from another tanks helps in providing the extracellular enzymes which are required for the growth of bacteria and in turn the rate of digestion is enhanced. So this is another important factor what we see that is the mixing and stirring of the raw sludge with the digested sludge so this is like very important parameter because this the type of mixers the type of mixing arrangements we provide in the digesters the kind of speed of mixing all these parameters greatly affects the digestion process because the homogeneous mixing facilitate that is like faster rate of digestion hence the selection of the type of mixture and the mixing speed at which the sludge mass has to be rotated within the digestion tank so that is very important parameter.

And then if we see that is the end products what are the end products they are generated after this digestion process. So as I said the digestion results into reduction of around 70 to 75 % of the total volume of the sludge and finally results with the three important product of this digestion process which is digested sludge and the top most layer that is supernatant liquor that is the water clarified water and then the gases which are produced during this digestion process.

So these are the three major components which are generated out of this sludge digestion process so if we see the digested sludge. So that is basically the stable and humus solids because whatever the sludge it contains lot of nutrient value also if it is biological sludge generated from the biological treatment process. So after stabilization so they are converted in a humus kind of material and that can be used as a good source for nutrients and then if we see the color of this digested sludge that is like black in color and its moisture content is reduced to around 70-75% volume finally reaches to one-third of the undigested volume of the sludge and it is comparatively free from the pathogenic bacteria and this type of sludge can be easily dewatered dried and then further can be used as a fertilizer. Similarly if we see about the supernatant basically this supernatant is the relatively free layer of water which remains at the top of the digesters so this contains a lot of finally divided solid matters its BOD ranges around 3000 and it may contain around 1500-3000 mg/L of this suspended solid. So this further required treatment and hence they are diverted to again back to the primary sedimentation tank for their entire treatment process. The last component which is like the gases which are generated during decomposition process that is basically a biogas which mostly contains the methane around 60-65% and rest is around 30-35% is the carbon dioxide and rest of the percentage there may be traces of gases like nitrogen, hydrogen sulfide and many more other gases that could be in traces and overall composition that is around 60-65% of CH_4, which has a very high calorific value around 8000 to 9000 kcal/m^3 because of this it can be collected and can be used as a good fuel for energy generation for different options.

And let us see now what are the different types of digesters they are used so mostly there are aerobic digesters and then there are anaerobic digesters. So aerobic digesters are the digesters which are operated under aerobic conditions using where air is being diffused into the sludge mass. So that they are aerated and undergoes aerobic decomposition process whereas anaerobic digesters, they imply the anaerobic group of microorganisms and they are decomposed under anaerobic conditions where there is no requirement of oxygen. So, because of this, this is comparatively cheaper than the aerobic digestion process. So both of these process that we are going to discuss in detail one by one.

So let's see the aerobic digestion process this is the process where the bacteria continue metabolism as they do in case of wastewater treatment system only the difference that is done in presence of lot of food, lot of substrate but in this case of sludge digestion process that the bacteria undergoes under endogenous respiration process where there is no food and they undergo their own decomposition they eat their own protoplasm and decompose their own protoplasm and decompose their own body. So the stabilized sludge basically in this process is very safe for human contact as most of the bacteria they are stabilized and they do not attract any vectors also after this aerobic digestion whatever the end products they do not produce any odor and smell problem as in case of anaerobic digestion there is a lot of biogas is produced. So, they may cause lot of odor, nuisance if not collected and treated properly and then if we see this type of digestion also reduces the total volume of the sludge to one third of the total volume.

So what are the basic fundamentals which are involved in this process, so as I said they the bacteria undergoes endogenous respiration, where the substrate is limited no external food is provided so under this this is the chemical reactions that takes place so here if we see that is the formula ($C_5H_7O_2N + 5O_2 \rightarrow 4CO_2 + H_2O + NH_4HCO_3$) for a bacteria which may contain carbon, nitrogen, hydrogen, oxygen so this undergoes oxidation. So, under aerobic conditions this is finally converted into CO_2,this H_2O and this NH_4HCO_3which when gets ionized it will produce ammonia plus bicarbonate ions, which will increase the both ammonia and alkyl concentration in the system. So what happens if there is a sufficient oxygen is there this ammonia what is produced in the process that gets further oxidized and give rise to the formation of nitrate and finally also reduces the pH of the water because it releases H^+ ions ($NH_4 + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$). So this is like further oxidation is possible only when there is a sufficient oxygen is present. So and but if the alkalinity is dropped in this case so what will happen this will further gets oxidized and will form ammonia and also will form nitrate. So this is like the different pathways different conditions under which the anaerobic digestion process takes place. So if we see the overall theoretically how much oxygen will be required for this aerobic digestion of the sludge. So we find that around $2.0\ kg\ O_2/kg$ biomass. So this is like theoretical oxygen requirement.

So if we see like the different phases of the growth of the bacteria so we all know so bacteria first goes from lag phase to the exponential growth and then they are finally here if we see these are the different phases of the growth of the bacteria. So here if we see this like the stationary phase this like the exponential phase and then this is like log phase and this process basically essentially carried out in this anaerobic decomposition in this endogenous decay phase. So that is basically that is the death phase where the bacteria eat their own protoplasts for their final degradation.

So then in anaerobic digestion process also there is advanced aerobic digestion process which we call that is autothermal thermophilic aerobic digestion process that is ATAD which is basically more advanced than the conventional aerobic digestion process and this basically is operated sometimes in this thermophilic range temperature range that is 45-70°C and involves the pasteurization of the sludge when the temperature is increased. So, the bacteria they cannot survive and causes the pasteurization of the sludge and then if we see because of high temperature the requirement of HRT that is very much reduced and it also results enhance the rate of digestion. So we ultimately results with the higher digestion efficiency and in terms of process robustness if we see this is one of the most robust process its design and operation is little bit complicated and if we see it can achieve around 40-50% of VSS reduction within 4-8 days, which is the minimum digestion period required among different configuration and in this case if we see this also helps in generation of energy that is around 450 to 650 kW of energy is generated per tons of total solid digested. So, this is one of the processes where it yields energy also.

So here this is a kind of ATAD autothermal aerobic digester reactor where if we see these are the different components this entire system that is basically the digesters this is equipped with the insulating material on its external surface so that heat cannot be transferred to the surface there are cladding, pipe work, spiral aerator systems so these are different component system where like this is like for foam control, this is for aeration system to the sludge and this is the pipe used for exhaust gases wherein whatever the gaseous pipe products are formed they are removed from this exhaust gases. So, these are different components of the ATAD reactors which converts the sewage sludge to almost digested sludge and which can be classified as class A biosolids.

So, these are the different advantages and disadvantages of the aerobic sludge digestion process. If we see the capital cost for this process that is comparatively lower than the anaerobic process for a smaller capacity like <5 MGD plant and it is relatively easy to operate does not produce any other nuisance because no methane is generated in the process and then also if we see the supernatant that is low in BOD, low in suspended solids and ammoniacal nitrogen concentration. So this produces relatively better quality of the supernatant compared to the anaerobic digestion process and can effectively reduce the oil and grease which are present in the sludge and this also reduces lot of pathogens which are present in the sludge mass. So it can accept also wide range of waste types like with less chances of toxicity like it can also handle some toxicants which are presented to the sludge. So then again if we see no gas no overpressure issue so all these points if we look into these are the advantages. Similarly there are certain disadvantages of this advanced system like it can produce the digested sludge but that has a poor dewatering characteristic compared to the anaerobically digested sludge and then it has high power costs because it requires a lot of oxygen supply it requires heating of the system. So lot of energy is being used into the system and it is also significantly affected by the temperature and the location of the treatment plant like whether it is in the winter climate and then in the summer climate so depending upon the climatic conditions the efficiency may vary it also depends upon the type of the tank it is designed. Finally see the more residual sludge to handle because it generates a lot of residual sludge solids and possible odors if it is not operated properly undergoes beautification so it may cause a lot of order nuisance also. So, these are different advantages and disadvantages of the aerobic digestion process.

And then let us see what are the different process parameters for which the aerobic digesters are designed. So if we see the design is completely based on the similar activated sludge process as we do for design of ASP tanks but here the process is performed only the difference that is that the process is performed under endogenous phase of respiration and aeration is used for supply of oxygen and for providing mixing within the sludge and hence this process that is mostly suitable for a small scale, like less than 5 million gallon per day and if we see the shape. So it can be rectangular it can be circular and its top should be kept open so as there is no accumulation of gases within the system and then digestion is also if we see can be carried out in batch mode as well as in continuous mode and if finally see the quality of the sludge which is generated from this process that is comparatively better than the anaerobic process has better settleability has better dewatering compared to the anaerobic process.

So these are like few of the design parameters we have to look and then we have to see the design parameters based on which we can design the size we can determine the capacity of the digester. So if we see the design is based on its hydraulic loading rate and its mean cell residence time so this both HRT and MCRT that entirely affects the capacity of the digester required. Similarly the biomass loading rate or the sludge loading rate that is important parameters that also has to be considered while determining the size of the digesters and then there are other many operational parameters like pH and temperature range that overall affects the determination of the size or the capacity of the digester. Complying to this process parameters we have to determine the size and then we have to also determine how much amount of oxygen or air is required for mixing for oxygenating the sludge and then what is the energy requirement for mixing that also we have to calculate.

So let us take the typical design parameters which are used in design of the aerobic digester that is the volumetrical solid loading rate this is one of the important parameters the range of the volumetrical solid loading rate like 1.5 to 4.8 $kg\,VSS/m^3$ of digester volume per day you can adopt to find out the volume of the digestion tank required. And then there are another criteria we can see like hydraulic retention time and that is to be used for 35-45% percent reduction of VS. So that is around 10 to 20 days. If it is a thermophilic range then again this HRT value can be further reduced for that mesophilic range of digestion and thermophilic range of digestion accordingly. So similarly we see that is the solid retention time which is to be taken 15-90 days and for estimation of the air requirement this oxygen requirement ranges from 1.5-2.5 $kg\,O_2/kg$ BOD_5 removed and then there is air requirement that is around 20 to 65 $L/min/m^3$ of the sludge if we have diffuse aeration process so these are the typical design parameters. So, we have to follow this design parameter for determining the capacity of the digester.

So let us take one example so here if we see this, we have to design an aerobic sludge digester to treat the activated sludge which is generated from the treatment of 10 MLD that is the flow of the wastewater. So there is a certain data also given like how much sludge solids are generated that is around 2000 kg, specific gravity of the sludge is also given similarly the percentage solid concentration that is also given and the HRT what we have to follow that is 15 days that is also given and then the volatile solids that is around 80% of the total solids. So, using this data we have to determine the what will be the capacity of the digester required, the shapes and size of the digester is required for this treatment process.

So first of all what we have to determine is the how much volume of the sludge that is being digested per day so here we have the data is given like how much total weight of the sludge that is given as 2000 kg/day and this if we use this equation ($V_{sl} = \frac{W_s}{\rho_w \times S_{sl} \times P_s}$), as we have read earlier so here we we can put the value of density of water then specific gravity of the sludge which is 1.03 and then here that is 0.35% of the solids so here by putting this value we can get how much volume of the sludge solids that are produced per day. And then what we have to determine the volume of the digester which is required so depending upon the per day volume of the sludge which is generated if we multiply with the HRT that is hydraulic retention time so we can get what is the total volume of the digester required ($Volume\ of\ the\ digester = volume\ of\ sludge\ produced \times HRT$), so here if we see the volume of the sludge per day that is 55.5 we have kept and this value is given in the numerical that 15 days HRT. We have to follow so for this the volume requirement we have got that is 832.5 m^3. The next what we have to design how much amount of oxygen is required. So that we can determine how much amount of this air will be required. So here if we see if we assume that amount of oxygen required that is 2.0 kg/VS/d and assume that 40% of the cells that will be destroyed completely as given in the problem also. So this oxygen requirement we can calculate by using this formula $O_2\ required = (Rate\ of\ O_2\ required\ per\ kg\ of\ VS\ dstroyed) \times Total\ VS\ destroyed\ per\ day$. So, we know that 2000 kg of sludge solids are generated out of this 80% is the VSS and then this 40% is the reduction efficiency. So this the product of this will give how much amount of VSS that is being generated per day and this the rate already we have assumed that is 2 kg. So here put this value and then we can get the total amount of oxygen required per day.

And then from this data we know that the air has a density of 1.201 kg/m^3 at standard temperature and pressure and the oxygen content in it is that is 21%. So by putting this value like this much oxygen is required where how much air will be required that oxygen is 21% and by dividing its specific gravity we can find out how much actually the volume of air will be required and if we further assume that transfer efficiency of oxygen through the air in the water through diffusion mechanism that is say 10%, so this will further 10%, if we write 10% of this so this we will get 35.3 m^3/min and this day again if we see convert in minutes, so as to get this that amount of air per minute so this is 1440 min/day that has been replaced to convert the day in minute. So by finally calculation we get this much amount of air will be required and then finally we have to check our design that also confirm the volumetrical solid loading rate criteria. So here we can see that is the total VSS that will be $\frac{2000 \times 0.8\ (kg\ VS/d)}{832.5\ (m^3)}$, we will get how much VSS loading rate would be that comes around 1.92 which is well within the stipulated criteria.

So, it means whatever we have to design that also confirms to the volumetrical solid loading HRT requirements and also the requirement of other parameters so then if we take this is the volume so once we know the volume we can find out its surface area requirement by assuming a suitable depth for the digester so normally it is taken 4 to 6 meters. So here let's take 6 meter as a depth and then this is the volume divided by depth we can get the surface area of the tank which is over 38.75 m^2 and from here we can find out the diameter of the tank which is equal to $A = \frac{\pi}{4} D^2$ and here $\sqrt{\frac{4 \times A_s}{\pi}}$, so by putting value we can find out what is the diameter required that is around 13.5 meter. So this finally we have decided the diameter equal to 13.5 meters so if we further look for the sludge storage that a proper storage depth of around 1.5 to 2 meter that should be provided along with the depth of the tank so as to accumulate the digested sludge. So this gives total height of the digester equal to 8 meter. So this is the final size of the digester 13.5 meter diameter and 8 meter depth. So this is the final design.

And here we can use these references.

Thank you