Water Quality Management Practices

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Week-09

Lecture - 43

Factors Affecting Anaerobic Treatment Systems

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Dhar Bhowmick. I am from the Department of Agriculture and Food Engineering of Indian Institute of Technology Kharagpur. In this particular lecture we will be discussing about the factors which affects the anaerobic treatment systems which is a part of the anaerobic process for wastewater treatment with the module 9. So, here the majorly I will be discussing about the overview of anaerobic digestion parameters affected by the environmental factors, temperature, hydrogen and concentration, physical parameters, nutrient like nitrogen and phosphorus, trace metals and inhibitory substances. In general we all know that the anaerobic digestion processes it follows you can see in this figure like normally we target this say like energy crops, lignocellulose biomass, manures and all or say like food waste or sewage sludge and all.

We put it inside the anaerobic digester and from there we will get either biogas or digested right. The digested we normally use it for nutrient recovery, we will put it as a we will use it as a fertilizer as well and the biogas we use it for energy production ok. In general what are the major parameters that it actually depends on I mean like I mean like those parameters those are actually depending on other factors and all. Those parameters are very important first one is the specific growth rate.

So, we have there are certain environmental parameters or the physio chemical parameters which affects this digestion parameters anaerobic digestion parameters like specific growth rate, gas production, startup duration, decay rate, substrate utilization rate and the response to changes in effluent characteristics. So, these parameters are like the primary ones which are being influenced by some other parameters about which we will we are going to discuss today in this today's lecture. So, how these factors are important specific growth rate? Obviously, because the changes in the parameter changes in temperature changes in a inhibitory substances presence of heavy metals excessive amount of heavy metals this will definitely put a end put an end on the life of a microorganisms which are majorly responsible for the anaerobic digestion process to occur. So, because of

that the substrate grows like because of that the growth rate of this biomass can drastically reduce the gas production if the biomass production if the reproduction or say like you know if the process I mean like the biomass presents present in the system will reduce obviously, it will affect the gas production it will depend in some cases the some parameters are actually elongate the startup reaction startup duration for any kind of react any anaerobic digester, but because in general we know that anyway methanogenic microorganisms they are very they are having a very slow growth rate. So, anyway the in a way that this startup period is quite longer in case of anaerobic digestion, but there are some inhibitory substances which can actually make it further long.

The decay rate can increase the substrate rate can drastically reduce if the substrate rate will reduce definitely the effluent even for the same HRT you will see after a certain moment of time certain I mean like after certain moment of time what will happen this effluent will not be having enough the removal of pollutants. So, effluent may still be having some amount of pollutant left and the suppose initially the efficiency of say like let us say COD ok. The efficiency of COD removal say like earlier it was 80 percent, but because of certain environmental physicochemical parameters that will change because of that what will happen the efficiency will drop down to say like 50 percentage. So, substrate utilization rate will reduce and because of that the ultimately the efficiency will reduce isn't it and also the response to some other influent characteristics. So, what are these major parameters upon which this anaerobic digester performance or the parameter will influence first one is the temperature.

So, how temperature is important because we know that the higher the temperature the higher is the microbial activity until a optimal temperature is reached. In general if we further increase the temperature beyond its optimal value there is a sudden decrease in the bacterial activity further because they will die or they will not be able to perform their regular cellular activities. In general anaerobic process can take place a wide range of temperature theoretically 4 to 60 degree Celsius, but most of these anaerobic reactors are majorly operate in the 30 to 40 degree Celsius in that mesophilic range only ok. So, what happened in case of increasing temperature on the biological reaction rate in the range of 4 to 25 is quite profound and also anaerobic digestion anaerobic digestion below the 20 degree Celsius is quite slow and it further elongate the start up time and because of that there will be a difficulty in the operation to occur. In situation where the ambient or ambient and the wastewater temperature are low start up will be benefited if initiated at temperature approximately 35 degree Celsius by providing additional heating arrangements or not that is what being performed in the temperate regions.

If you go to Europe, if you go to US, Canada so, they are following this kind of systems they are what they do they initially they try to moderate the try to you know change the temperature inside the anaerobic reactor and to make it to the in the range of 30 to 35 degree Celsius. So, that it will start working the start up time will reduce and the microbial digestion will start working very fast. If you see in this graph this some microbial activity it

picks in the 35 degree Celsius again at 55 degree Celsius also and almost in the range of thermophilic also it starts it there are some microorganisms which actually acts anaerobic microorganisms which acts quite well which start performing quite well in this thermophilic zone also. In general the temperature of less than 25 degree digestion rate decreases like anything and because of that the conventional systems will take almost detention time of around 12 weeks and which is quite high isn't it. Increase in the microbial reaction rate and this elevated temperature in case of thermophilic processes 50 to 60 degree as I as I showed you there is a sudden peak and because of this increase in the reaction rate we can have a we can have we can reduce the SRT.

If you can reduce the it can decrease the SRT what will happen at it may improve it may cause advantages in some certain circumstances. Thermophilic digestion is most practical where the wastewater stream is to be treated and discharged at a high temperature and the digester is present on site only. In case of psychrophilic like below 20 degree Celsius mesophilic which is 25 20 to 40 degree Celsius and thermophilic above 40 to 50 degree Celsius we have to maintain the uniformity of temperature over the entire reactor so that the anaerobic digestion can take place. We can lower the temperature up to a certain degree, but it has to be done gradually. There is a certain decrement will cause the upset on in the microbial metabolism and it will rapidly alter the reaction performance there ok.

In general our target is to gradually decrease the alter the temperature with only 1 degree per day with this changes. So, in that case is this sudden this gradual slow changes will help the microorganism to actually adapt to the temperature change temperature and all. Second is the hydrogen ion concentration. Hydrogen ion concentration majorly the pH actually by pH only we can actually determine the passive way of like that is the one of the most famous way of determining the you know hydrogen and concentration present in your system. So, we determine it on the with the parameter called pH.

In this pH what is happening due to this anaerobic processes it is normally results in interaction with the carbon dioxide bicarbonate buffering systems and volatile ammonia formed in this process. Because of that what is happened this accumulation of acid will happen and because of that the pH may go down. This pH if it goes down what will happen it will create a I mean like the problematic for the methanol microorganisms they will start dying in this changes in the pH ok. So, it is very important that there should be a sufficient buffering capacity present in the reactor ok, which will prevent the accumulation of VFA volatile fatty acid inside the system. There are most famously we normally we use the carbonate and bicarbonate of sodium and calcium salts, but sometimes it is better to use it the lime also ok.

This limes are also having a like you know having a good capacity to act as a buffering chemical. In general there is if there is no lag period prior to the system recovery after pH restoration from high pH value, but in case of considerable time is required when low pH is there and you have to recover it within the certain pH value. So, you need to have a preload

of a period more than 3 days just to have a lag period just because of the change in pH which will which may affect your microbial consortia. And in order to recover them you need to provide them with couple of days of time ok. Reactor configurations like fluidized bed reactor is quite beneficial because it has it promotes the increased tolerance to the influent pH fluctuations because of the its inherent buffering capacity.

So, we normally there are fluidized bed reactors are quite beneficial like they have the capacity to actually withstand the shock loads and all ok. In case of methanol microorganisms they are very much vulnerable to the minute changes in the pH values and optimal range of pH is 6.6 to 7.6 is considered as favorable for this methane producing archaea ok. In case of non-methanogenic microorganisms anaerobic microorganisms they do not exhibit strong sensitivity over the environmental conditions, but their functionality is range between the 5 to 8.5 of pH. Now, the physical parameters what is this physical parameters like the mixing fluid flow the gas sparging that you are supplying from the bottom this paddles or the impeller that you use for you know reactor volume like you know for the available reactor volume and to minimize the inhibitory effect of local buildup of volatile fatty acids and other digestion products. It is these are normally used this kind of physical parameters are influenced the buildup of volatile fatty acid concentration inside the system as well as the digestion product ok. And by this way they are allowing the more dispersion of suspended materials in the systems and such as granules or the flocs and it promote the maximum biomass to wastewater contact. If the biomass to wastewater contact is higher there would be more amount of substrate exchange I mean like more amount of substrate will be utilized is not it. So, and also providing an adequate amount of mixing it permits a rapid and uniform distribution of fresh influence throughout the reactor volume and which allows the maintenance of the constant temperature over the content of the vessel and reducing the convection current or thermophoresis for a season.

How convection current because of the changes in there is way if there is a strata of you know different temperature in the systems because of the change in temperature there will be a convection current right. So, if you provide some mixing arrangement anyway additionally. So, it will definitely help in mix first of all it will help the influent to get completely mixed into the system. So, at each point of the reactor each vessel of the each side of the reactor I mean like the microorganisms will get the its food which gets its like you know food equally evenly distributed. So, it will consume and it will reduce the pollutant load of the wastewater plus it will reduce the convective current flow its automatically it is making the mixing.

So, it will make the constant temperature all around you know. Its biogas which produced in the reactor is also responsible for some amount of mixing and the rate of biogas production is directly proportional to the volumetric loading rate that you need to apply isn't it. And also this mixing also partly control the flocculated or granulated bioactive particles in UASB reactor off flow anaerobic sludge blanket reactor ok. We know that in the case of UASB they form this granulated biomass and all this granulation process will

actually being influenced by this mixing up to certain extent. Inactive debris can also accumulated at the bottom of this kind of reactors if insufficient agitation is applied the buildup of this inorganic solid which will have you reduce the effective system volume or the tank volume of this kind of reactor because it will keep on accumulating in the bottom ok.

So, that is another reason we need to provide reason why we need to provide the mixing by a mechanical means or by the gaseous the biogas which will form it will also act on mixing. So, anyways we need to provide some amount of mixing in the system. In case of low shear rates this larger flocs which maintain their basic structure, but tend to aggregate while shear stresses encountered at the higher shear rates are generally large enough for cause complete floc disintegrations and all. So, we need to be we need to be like when we design any fixed stream reactors and all we such as the anaerobic filter and all we need to extend the fluidized bearings and extended or expanded or the fluidized bearings in such a way that it will have a good hydraulic distribution and maximal substrate availability to the digested digester or microorganisms. As fluid velocity increases at higher flow rate biofilm accumulation decrease and detachment can occur and a condition which eventually culminate the process failure.

Also maximum volume of biofilm attached to the surface media surface in a turbulent flow region could be limited by fluid shear stress. You have to also remember that the physical forces which result among those in the in the reactor in which will vary with the different conditions and it will actually change in the different digester configurations. It depends I mean it change the digester performance drastically. These forces are majorly the consequence of the external applied energy such as the such as as such can be controlled by proper attention to operational parameters and careful system designs and all. Another important parameter is the nutrient that is nitrogen or the phosphorus.

So, how nitrogen and phosphorus is playing a major role here because they are used for supporting the growth of anaerobic microorganisms right. However, their presence I mean like if they are not sufficient that can cause drastic changes, drastic problem in the system in the microbial growth and their performance. Optimal nitrogen to phosphorus ratio for any anaerobic treatment processes can be 7 ok. And the theoretical minimum COD to nitrogen ratio which needs to be provide you need to provide it will be will around 7 and 350 is to 7 350 by 7. So, the same way so, COD/ nitrogen to phosphorus ratio is 350/7 ok.

This is the standard ratio that we normally adopt in case of designing of anaerobic reactors. The value around 400/7 for COD/N is considered reasonably for reasonable for high rate anaerobic reactors with the sludge loading rate of around 0.8 to 1.2 kg of COD per kg of VSS per day. In case of low rate of process where at the sludge loading rate is as low as like even below than the 0.5 kg of COD per kg of VSS the COD to nitrogen ratio can be drum it increase drastically and it can be in as in the range of 1000 by 7 or more this ratio. So, you just remember this thing is a very important ratio that important parameters when we

design your systems you have to make sure that you may see that the it is not performing well. So, you have to make sure that the you check this ratios like whether the COD to nitrogen ratio and the nitrogen to phosphorus ratio is being followed or not ok. Press metal another very important parameter in general the inability of a great number of anaerobes to synthesize some essential vitamin or amino acid necessitates the supplementary of bacterial medium with certain trace metals ok. So, what are those test metals? Majorly the cobalt, molybdenum, selenium, tungsten, nickel.

So, they are very much necessary for the activity of several enzymatic system that is running those micron they are running the cell running the cellular performances of those microorganisms those anaerobic microorganisms. This microbial nutritional requirement may also be interdependent in the presence of low concentration of this of the other cation such as potassium. So, for example, sodium can be replaced this potassium requirement up to a certain extent. In addition the nutrient are not obligatory for growth such as calcium may however, be needed for process stability. So, in general for their growth performance for microorganisms calcium is not required, but their process stability in case of process stability they may require this calcium may require.

So, what we need to do if they are not if the wastewater that you are treating if they are not reached with this need to micron nutrients and all what we need to do we need to supplement it either chemically or by addition of another waste stream to supply this micron nutrient into your system. So, that your anaerobic by microorganisms can grow optimally ok. The design and the optimization of this growth environment however, it should include the consideration of the technical and economical constraints as well imposed by the nature and the quantity of waste that you are converting. Classification of metal ions based on the concentration of the cell in the cell major ions present in the major cations that is needed the potassium, magnesium, calcium, micronutrients and manganese, iron, cobalt, copper, molybdenum, nickel, selenium, tungsten etcetera. So, what happened this iron which is utilized in the transport system of methane archaea for the conversion of carbon dioxide to methane and it functions both as a electron acceptor and donor in this reaction in this in this the formations processes and all.

So, it is very important it acts like how to say it is like a catalyst to this reactor. So, because of the presence of this iron presence because of that presence of iron is very much essential for my this performance to happen this reaction to happen and because of that it is very important for us to have this iron present in your wastewater stream for treating the it anaerobically. Manganese which acts as an electron acceptor in the anaerobic respiration process while zinc takes part in the functioning of enzymes involved in the methanogenesis. All these trace metals are responsible for the functioning of one or another enzyme. So, that is why this micronutrients are very much essential for us to supply if it is not there in the wastewater you have to somehow supply it supplementary by chemicals by means of some addition of chemicals or some additional waste streams.

So, what are the inhibitories inhibitory substances? The inhibitory inhibitory substances in anaerobic digestion process have the impact on the efficiency of the systems which are nothing, but the sulfide volatile acids mainly the volatile fatty acids ammonia alkali alkaline earth metals and the heavy metals. These are responsible these are the major inhibitory substances present in the wastewater. So, how we can get rid of it we normally what we need to do what will happen if they are available in a high concentration in the wastewater. It can lead to the decrease in the methane production and also even operational failure of the complete operation failure of the anaerobic reactor. Just example sulfide concentration if it if it exit a exits the 100 milligram per liter value in the reactor it will start noticeable reduction in the methane production from the anaerobic reactor.

One important reason is sulfide this sulfate to sulfide this is this process is also a COD consuming right. So, it will the COD consume. So, whatever the wastewater I mean the sulfate reducing bacteria it will react on the COD it will react it needs some additional amount of COD it will consume. Whereas, the final production that the methane for the final production the COD available for methane production will drastically reduce. We will discuss we already designed one problem in last class and also in coming class also will be in coming lecture module lecture also we will be discussing about the design of anaerobic reactor specifically we will be targeting the UASB a flow anaerobic sludge blanket reactor and while designing it you will be able to understand it more in deeper way ok.

Volatile acid inhibitions the disruption of the shock loadings like the nutrient depletions and the presence of this innovative substances can drastically decrease the pH and if it will decrease the pH it will affect the methane population obviously, because it is an acid right. Maintaining the volatile fatty acid concentration below certain level is very crucial for optimal performance of your anaerobic digester. So, in any cases it should be below than 500 milligram per liter measured as acetate at any point of time preferably below 200 milligram per liter for optimum performance. Please remember this value it will be very useful for you know for your as to be used as a thumb rule for you know real life situations that what will be the volatile fatty acid concentration present in your system in your anaerobic digester. Suppose all of a sudden it does it started performing and it is not performing well.

So, you can check the pH you can check the you can do the gas chromatography using the gas chromatography you can find out the VFA concentrations. So, with this VFA concentration you can confidently tell that because of the increment in the VFA concentration it reduces the pH and thus the macro well performance the performance of your anaerobic digester is in is at stake ok. Ammonia nitrogen inhibition the ammonia is important for anaerobic process. However, the high concentration of this ammonia can lead to the operational failure which drastically cause a rapid increase in the volatile fatty acid and the decrement in the pH value. Free ammonia concentration of 100 milligram per liter will completely dent the methane production in the anaerobic reactors and inhibition of the methanogenesis occur even higher concentration of ammonia as well.

Heavy metal inhibitions like which are the major common cause of reactor failure heavy metals like iron, zinc, chromium, lead, nickel they should be they should have a certain concentration they should have a acceptable level of concentration present in the wastewater. If it increases if it if it exists that value it will definitely have major implications in the wastewater for in the treatment performance of anaerobic digester. See this graph in this sorry in this table the metal concentration with a safe concentration of each and every heavy metals are given by some researchers and they found out that this values if it will exceed these values it will definitely have an impact on the performance of anaerobic bi reactors anaerobic digester performance. So, what we have learned from this class in this lecture that various environmental factors which significantly influence the anaerobic digestion process it impact on the crucial parameters like the growth rate, gas production, substitute digestion etcetera. We also understood the effect of temperature particularly in the mesophilic range it is commonly preferred if it is less than that or it is higher than that it will be problematic, but in some cases the thermophilic digestion some of some of some of these cases specific scenarios it can be also come as a handy and like it can be useful as well.

Maintaining an optimal pH of 6.7 6.6 to 7.6 is vital for methanogenic organism to perform well to avoid the inhibitions ok. This physical parameters such as the mixing and the fluid flow are essential for efficient reactor operations which ensures the temperature uniformity and prevent the local accumulation of volatile fatty acids. It also we have to understand the adequate nutrient concentration specifically nitrogen and phosphorus with the recommended nitrogen to phosphorus ratio of 7 are necessary for microbial growth ok. Trace metals such as cobalt or monipdunums are essential for enzyme system activity their supplementations are required, but inhibitory substances including the sulfide volatile acid ammonia and heavy metals can hinder the process digestion process and we should necessitate the control measure for optimal reactor performance. The variability of this reported values emphasize the need for the careful considerations in design and operating of anaerobic digestion system.

So, it is not that easy you have to be very much aware of all the process implications and all and you better be you know if you are going through this syllabus going through this kind of subjects if you read the references that I have suggested you will become an expert in these subjects you will be able to you know choose this subject as your career and actually been having a you having a very good opportunity in Indian context right now because India is still under development stage and there are lot of cities and the new smart cities are being under construction and also where we need to be focusing on the production the proper mechanism of waste you know management proper mechanism wastewater management. So, this wastewater management involves a huge amount of like you know financial involvement at the beginning, but it has a drastic implications on the environment. So, that is why it is needed to be designed it needed to be constructed and it should be mandatory and government of India right now in like you know different government

bodies like you know central pollution control board and the national green tribunal they have actually come up with the very strict norms and regulations and they are trying to like convince the people to actually focus on actually relying on actually being able to follow those rules. So, that whenever they were going to design any new industry they are going to design a new smart city. So, that they will follow those rules before you know throwing that water into the surface water bodies or any regular water bodies present in the surrounding vicinity.

So, we need to understand this anaerobic digestion systems though it comes with a very lot of advantages and all, but it may have some problems the issues that we already discussed and you have to be an expert or you have to be at least very much careful while designing and operating this kind of anaerobic digestion systems. These are the references that you should follow this you can take a picture you can just simply go through these papers and this even the links are also given. So, if you go through this paper you will get to know about more in details about this anaerobic digestion systems and what are the applications of it ok. Good. So, that is it for the day I will see you in the next class. Thank you.