

Water Quality Management Practices
Dr. Gourav Dhar Bhowmick
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur
Week – 09
Lecture – 41

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 first lecture of this module 9 where we will be starting discussing about the Anaerobic Treatment Systems. So, in the very first treatment first module lecture we will be discussing about the principles of aerobic anaerobic process for wastewater treatment and the methane production. The concept that we will be covering are majorly the anaerobic process for wastewater treatment, the advantages and the limitations of aerobic processes, anaerobic process, principles of anaerobic digestion and the estimation of methane production.

In general we all know that we already had very like you know almost in depth idea I would suggest like if you go through the all the lecture videos that we have done so far. So, you already have an idea about what is the basic difference between an aerobic process and the anaerobic process right. In case of anaerobic process in general it is a biological wastewater treatment process which where they use the carbon dioxide, organics, nitrates, sulfate, permutative reduction reactions without the presence of any molecular oxygen. In case of anaerobic processes it normally produces the methane, carbon dioxide, trace gases such as hydrogen sulfate, hydrogen, ammonia and digested a liquid or the semi liquid byproduct of the this anaerobic digestion process.

Mostly the biodegradable organic substances may decompose the anaerobically most of the biodegradable organic substances making the wastewater treatment as more efficient and the cost effective process if we go for the anaerobic processes. We will discuss about the advantages and disadvantages of this anaerobic treatment processes very soon. In general this anaerobic digesters they have been used for treating the agricultural animals, sewer and municipal wastage and all not only limited to that, but also different kind of industrial wastages also are also being clean also being like you know treated by this kind of anaerobic treatment processes and all. If you can see in this picture it is very nicely you know demonstrate that the waste were coming from the slurry or the manure or the crops or the residues from the agricultural waste, the wastewater coming from industrial or say municipality and the food waste majorly coming from the municipality or even say like the food processing industries and all. From there also this can be

considered as an input for any anaerobic digestion processes and as a by-product we have the biogas and the digested.

Digested it is nothing, but the sludge the anaerobic sludge this sludge has a quite a good amount of capacity like you know application in as a fertilizer and all. And the biogas that it produces this biogas can be used for biomethane production for further transportation fuel as well as gas grid. It can be used for generating the electricity and also it can be used for generating the heat. So, based on the purpose of use like you know you can use this biogas for different purposes. Most of the anaerobic processes mostly the 70 to 80 percent is 70 to 90 percent of the waste biodegradable organic matter is transformed into biogas which leaves the reactor in the form of a gas.

And this anaerobic digestion it does not require the adhesion that is the best part of it because by because of that we are reducing the economic component like anything because the adhesion requires a energy right external energy that into you need to apply. So, because of the anaerobic digestion it does not need adhesion. So, it actually reduces the economic involvement at in general the overall recurring expenses like you know required for designing any treatment plant. Additionally this also remediate the biological sludge blanking bulking and all which happens during the aerobic processes in the secondary sedimentation tank and all. Although a very modest as little like you know extra sludge from the aerobic treatment systems are produced which are more concentrated and it is it has a very good dewatering capacity.

That means, if you want to dewater it it can I mean dewater it to reduce the moisture content you can easily do it and because of that it is it is becoming much easier to handle. So, remember that anaerobic sludges are much more easier to handle because it you can dewater it easily and that dewater sludge can be handled very like you know you can easily handle it in follow up treatment plants units and all. The volumetric loading rate of this kind of treatment systems can be much higher than the aerobic treatment process because you know the and because of this anaerobic because of this higher capacity to lead to tackle the higher volumetric loading rate it is saving the reactor volume like anything. So, for the same amount of volumetric loading rate the size of the aerobic reactor will be much higher than the anaerobic reactor. Anaerobic reactor this also remove the nutrients from the wastewater with higher concentration than the aerobic process that is also additional weightage that is also an plus point for the anaerobic treatment systems in terms of nutrient removal capacities and all.

What are the basic limitations as I was discussing the major limitation is the very long start up time it can be as high as 24 months I mean like for 2 years you just just wait for your treatment system to work perfectly you cannot just wait for this long. So, there are different procedures by which you can actually accelerate the procedure accelerate the

generation of the you know I mean the process of start up time reduces reduce the process of start up time. And however, a major reason because of this long time is that methanogenic microorganisms which develops very slowly. Other than that this methanogens which are also very sensitive to the even like very much susceptible to the minutely minute change in environmental factors. I mean like there is a change in temperature there is a change in pH volatile fatty acids it will definitely drain the the amount of methanogen concentration like anything.

And because of this changes in the methanogen concentration the performance will also vary. So, because of that a very very good trained operator is needed and you need to have some basic expertise if you are actually constructing a constructing an anaerobic treatment systems and you are employing that anaerobic treatment unit in your treatment plant. There are in terms of principles of anaerobic digestion it normally occurs in four stages ok. So, if you actually like literally deep inside the actual pathway of enzymatic pathway how we actually it is happening and all we it is like a it is very complicated and all. But in order to make it much easier for you to understand so, we can actually divide it in grossly in like four different parts the very first part is the hydrolysis.

What is happening in the hydrolysis the complex organic molecules which are supplied through the waste water it normally has the carbohydrate protein and lipid content. So, these are hydrolyzed into the simpler component in the anaerobic processes. What is happening here during the hydrolysis specific enzymes present in the system in the treatment unit they catalyze the reaction by adding the water molecule into the chemical bond of this complex molecules. This complex organic molecules which are coming in along with the waste water like which comes in the waste water and what it happens because of that it result in a cleavage of this bond and producing a smaller and soluble compounds ok. This hydrolysis it steps also releases the substrate such as sugar, amino acid and fatty acids which are then available for further stages of anaerobic metabolism like the acetogenesis or acetogenesis we will discuss about it in very soon.

It also does not need directly to create energy, but it offers the substrate for energy yielding activities and allowing the microbes to break down the organic matter without any without the presence of oxygen. So, now, the hydrolysis is like you know it is like a pre polishing process it is like you it is making the system ready for actual anaerobic system a process to start working on it. So, in the hydrolysis process you see this hydrolysis of in the figure a hydrolysis of the carbohydrate this glucose molecules convert into maltose and the protein it converts into glycine and alanine this triglyceride its presence of water it converts into glycerol and free fatty acids and all. Now, in the second stage where actually the I would say like you know the as the anaerobic titrant system starts working in its full allegedly. What is happening here? Here the actual breakdown of carbohydrates, proteins and lipids are happening in a much smaller organic acids organic acids ok.

What is happening? This hydrolysis happens because of the hydrolysis this degradation product this can be further fermented into volatile fatty acids, lactic acids and the pyruvic acid. So, because of the presence of this acidogenic acid and all what is happening pH is getting lowered and because of this lower pH it allows the acidogenesis and the methanogenesis to occur in the anaerobic digestion process ok. And it also requires the acidogenic bacteria which ferment this hydrolysis intermediates into the organic acids including the acetic propionic and the butyric acid. So, please remember that the first process is the hydrolysis, second one is the acidogenic bacteria acidogenesis in acidogenesis what is happening? This this hydrolysis degraded products will further converted or fermented into some acid some form of acid form of acids majorly the volatile fatty acids the VFA other than the lactic acid pyruvic acid etcetera is also there in the comes as an intermediate ok. You see this process from the hexose it comes to the pyruvic to pyruvic and from there to propionic acid and butyric acid and the acetic acid this process involves the acidogenesis process and all.

What is the acidogenesis process then? Then this see after the aerobic treatment is done like you know this anaerobic acidogenesis is done this bacteria break down the sugar into fatty acids in the simpler molecules ok. And once it is converted into this simpler molecules and at that time it converts into this acetate braden intermediate products into acetate ok in the form of pyruvate and hydrogen gas. If you see the same the next same process happens in the next stage which is called as a I mean some same I mean like the follow up process is called the methanogenesis what is happening there? All this acetate and acetic acid that is formed in the acetogenesis process it transforms into organic molecules into methanes. So, majorly the microbial commodity it convert this carbohydrate or fatty acids into the acetate hydrogen and the carbon dioxide during the methanogenesis process. And this acetate and hydrogen is further actually utilized by the methanogenic microorganism to convert it into the methane.

So, this actually the methanogenesis process is to act on the acetate hydrogen and the carbon acetate and hydrogen these are the major food for them ok. What they do they this methanogens they they consume this acetate and hydrogen and convert it into some additional byproducts. You see there are based on their food based on the type of the you know see either if it is a hydrogen it is acting on hydrogen it will be called the hydrogenotropic methanogens, if it is acting on the acetate it is called acidotropic methanogens. This acidotropic methanogens can also be like you know like you know it depends like you know some hydrogen dependent methanotropic methanogens some methylotropic methanogens some or hydrogen independent methanotropic methanogens are also present in the systems. In general after all these processes are done this hydrolysis, acetogenesis, acetogenesis and a methanogenesis.

After these 4 steps what is happening what is the final product? Final product is the biogas. Biogas is nothing, but the methines majorly the majorly it constitutes a methane,

but not only methane please try to remember that biogas does not only have to the methane it does have carbon dioxide it does has trace amount of hydrogen, nitrogen it has a trace amount of hydrogen, sulphur it has it may even have the oxygen as well in the biogas ok. It is not necessary that it is completely biogas means it is only methane ok. Based on the because it is like the pretty much it is the output from the anaerobic digestion systems and all. So, the gas component that comes out of this digestion process is the biogas.

So, this biogas may have other component as well ok. So, in general it does contain the carbon dioxide and say ammonia ok. So, if you have see in this particular case suppose the in this Bouswell's stoichiometric equation is given which normally we use for estimation of production of methane for a from a given chemical composition of organic matter present ok. So, suppose in this particular organic matter which does have a formula of $C_n H_a O_b N_d$ for them if it will act with the $N - A$ by $4 B$ by 2 plus $3 D$ by 4 of H_2O then it will form 1 mole of a CH_4 plus $N - A$ by $8 B$ by 4 plus $3 D$ by 8 of a mole of carbon dioxide plus D mole of ammonia ok. So, this is how the if this here the $C_n H_a O_b N_c$ is the chemical formula of the biodegradable organic compounds subjected to the anaerobic digestion process ok.

And the output can be easily calculated and from there are from there output you can actually calculate the its hydrogen its oxygen demand as well ok. So, in general how we can calculate the estimate the methane production there are another method by which actually we can do that. In general if you see in this equation the production of methane is like by we can easily calculate by estimation of the COD degradation with from the following equation CH_4 plus in the presence of oxygen it forms carbon dioxide and 2 H_2O . So, that means, 1 mole of methane requires for 2 mole of oxygen to completely oxidize into carbon dioxide and water. 1 mole of methane here so, what is the molecular weight of it? So, C has a atomic weight of 12 plus H is 1.

So, 12 plus a 1 into 4 16 gram. So, 60 therefore, 16 gram of methane produced and lost to the atmosphere corresponds to the removing 64 gram of COD. 64 gram means why because oxygen O_2 , O_2 is 32. What is the molecular weight of oxygen is 32 multiplied by 2 that is 64 64 gram that means, for 16 gram of CH_4 you need 64 gram of CO_2 to be to be removed from the waste. Under normal temperature and pressure conditions this corresponds to around 350 ml of CH_4 for each gram of degraded COD ok.

Further discuss about the theoretical production of methane in general the volume of methane the volume of methane produced in liter is equal to the COD removed from the reactor in gram per gram of COD divided by the temperature correction factor which is also gram per COD per liter ok. So, this temperature correction factor can be easily calculated by P into k divided by R into 273 plus T where P is the atmospheric pressure in 1 or the 1 atm k is the COD corresponds to the 1 mole of CH_4 that is 64 gram of COD

per mole. R is the gas constant which is 0.08206 atm atmospheric pressure liter per mole per kelvin and T is the temperature in degree Celsius. So, with this equation you can easily get the temperature correction factor that you can use it for putting it you can put it in the COD removal removed for reactor from the reactor divided by the temperature correction factor you will easily get the theoretical production of volume of methane.

Further the anaerobic reactor also if the influent waste water contain the sulphate which normally in anaerobic digestion process it convert into sulphides ok. Using the sulphate reducing bacteria this sulphate reducing bacteria also consume some amount of COD ok. So, normally it uses around 0.67 kg of COD per kg of sulphate ok. So, using this equation you see this sulphate plus 2 mole of oxygen and it will convert into sulphide.

So, 1 mole of sulphate requires 2 moles of oxygen for the for its oxidation process. 1 mole of what and what for 96 gram of sulphide present in the waste it normally consumes 64 gram of COD why 96 where it is coming from sulphur it has an anaerobic weight of 32, oxygen is also oxygen in 16 into 4 there are 16 into 4 plus 32 it will become 64 plus 32 96. So, 96 gram of sulphate sulphide needs 64 gram 64 gram of COD means 2 mole of oxygen 1 mole of oxygen is molecular weight of 32 32 into 2 that is 64. So, 96 gram of SO_4^{2-} or the sulphide needs the needs to consume at least 64 gram of COD ok. That means, some amount of COD is being consumed at the same time if you simply do it for the per kg you will see like it is becomes 0.

67 kg ok. If you just convert in for 96 gram at the so, 100 gram how much it will be and then 1000 gram how much it will be for 1000 gram or 1 kg. So, some portion of the biogas will remain in soluble form in the reactor effluent due to the high partial pressure of the biogas inside the anaerobic reactor and because of that some amount of methane you will lose through the effluent of anaerobic reactor that is also some losses that may occur in the in this kind of system. So, typically about 15 to 20 16 milligram per litre of methane will be lost along with the effluent of anaerobic reactor and in a typical concentration we take 16 milligram per litre as a standard value that may loss through the effluent of your treatment you may be like the in a supernatant ok. So, let us do one numerical. So, it will be much more clearer for us this calculations will be much more easier for us to apprehend.

What it says that the calculate the energy output from anaerobic treatment of 4 MLD, 4 MLD means 4 million litre per day, 1 million litre means 1 million litre per day means 1000 meter cube per day ok. 1 million litre means 1000 meter cube 1000 meter cube per day so that means, this is 4000 meter cube per day. So, 4 MLD means 4000 meter cube per day just write it down ok. Having a COD of 500 milligram per litre. So, what is the initial COD? 500 milligram per litre, sulphate of 80 milligram per litre.

So, initial sulphate 80 milligram per litre ok. The COD removal efficiency of the reactor is 75 percent and sulphate removal is 80 percent. So, this information is also known to us. So, we need to calculate the amount of energy generated from the anaerobic reactor. Just imagine just if you know this very much information this much information that is more than enough for you ok.

We will discuss how we will calculate the energy ok. It is very interesting solution it will be useful for you also in a daily life also I mean like you can design some small bioreactor you know and you can check you know you can have those anaerobic digested and you can check the amount of biogas and that biogas how you can actually use that biogas for generating the electricity or any further energy forms. So, in general how we can calculate the methane production in litre? $1.28 \times \text{temperature}$ ok in this case. So, consider say like 30 degree Celsius just like say Indian context 30 degree Celsius temperature is there.

That means, the $1.28 \times 273 + 30$ in Kelvin ah that will be the kg of COD removed ok in ah I mean a per kg of COD removed. So, from there you can get the value of methane production in litre that is 387.84 litre per kg of COD removed.

387 litre means 0.387 metre cube. So, please remember this value 0.387 metre cube of methane is being produced per kg of COD removed ok. Now, the COD removal efficiency is how much? 75 percent. What is the total COD removed? That means, flow is how much? 4000 metre cube per day multiplied by initial COD is how much? 500 ah milligram per litre or gram per metre cube milligram per litre means gram per metre cube is equal to then gram to ah kg you have to multiply it with 10^3 to the power minus 3.

So, it will become kg per metre cube. So, 4000 metre cube per day multiplied by 500 kg per metre cube metre cube metre cube will cancel out and multiply it you multiply the whole whole ah expression with the 0.75 because react ah efficiency is 75 percent. So, you will get 1500 kg per day. That means, 1500 kg of COD is being removed each day ok. Now, how much of this COD is actually ah removed because of the sulphide production ok because we know that the influent also consists of sulphate which ah normally it reduced to the sulphide and consume about 0.

67 kg of COD per kg of sulphide we just discussed ok. So, what is the sulphate removal ah percentage? Efficiency 80 percentage. So, total sulphate reduction how much? Initial sulphate is sulphate is given as 80 milligram per litre. So, 4000 milligram metre cube per day multiplied by 80 milligram per litre or gram per metre cube into 10^3 to the power minus 3 that will become kg per metre cube multiplied by 0.

8 because that is the efficiency. You will get the value as 256 of kg kg of COD kg per

day. So, this much kg of sulphate is getting reduced. So, now, what is the COD how you can calculate this total COD consumed per ah in sulphate reduction is the 0.

67 kg of COD per kg of sulphate. So, 256 into 10.67 that will become 171.52 kg per day so that much that much kg of COD is being consumed for sulphate reduction. Now, COD available for methane production is how much? Total COD ah reduced is ah removed is 1500 how much is consumed because of sulphate reduction 171.

52. So, the remaining is 1300 1328.48 kg per day. Also some portion of the biogas will remove remain in soluble form. Remember we discussed about it that some amount of biogas will remain in the soluble form which will get out of the system in the form of in the in in as a soluble form from the waste water using the in the effluent itself. So, that value is typically 16 milligram per litre of methane which will be which will be lost in the effluent. So, this methane that can be calculated ah collected first total COD available multiplied by 0.387 that is the value that we got 387 metre cube of methane can be produced per kg 0.

387 metre cube per kg ok. So, one total how much kg of COD is available ah 1328.48 kg per day multiplied by 0.387 you will get it in metre cube per day of ah methane production some methane will be lost. How much is the percentage of the value of that value of that methane loss 4000 metre cube per day multiplied by the 16 milligram per litre. So, into if you calculate it multiplied into the minus it will become in kg per litre in between become in kilo and then from there you can easily subtract in and you will get the final value as 450.

122 metre cube per day ok. So, that much of methane is removed from the system every day. So, every day you are removing how much 450.122 metre cube per day 450 metre cube per day ok. Now, suppose you have a biogas collection efficiency ah in the system ah will be around 85 to 90 percentage.

So, if suppose 85 percentage removal efficiency. So, the 85 percent actual methane that you can collect by the biogas collection ah system. So, what will be the actual methane collected at 85 percent collection efficiency a ah 450.22 multiplied by 85.

85 450.22 that is the total methane right that much into 0.85 you will get the value 382.60. We just do it in a with a calculator 450.

22 that will get in the last slide 450.122 metre cube per day. Now, multiply with 0.85 you will get 382.60 metre cube per day. So, this value can again be multiplied with the density of the methane in STP which is 0.656 kg per metre cube you will get total the amount of ah the methane that can be actually collected is 251 kg per day.

So, we know that per kg of methane contains 13284 kilo calorie per kg of methane. So,

what is the total energy that you can get out of it 251 kg per day multiplied by 13284 you will get 3334284 kilo calorie. And we know that kilo calorie to weight what our conversion is we need to simply multiply with 1.

163. So, 1 kilo calorie is equal to 1.163 whatever. So, if you multiply with it you will get a value in what hour if you divided with 1000 you will get in kilo what hour. So, that is coming as 3877.8 kilo watt hour that much of energy can be obtained. Even if we have a 30 percent conversion efficiency of this energy into electrical power still the electrical power output using any system that you can employ with the existing units. You can actually get a power output of around 3877 kilo watt hour multiplied by 0.

3 that is the conversion efficiency that is almost 1163 kilo watt hour 1163 kilo watt hour. So, just realize just by having this 4 MLD reactor 4 MLD treatment unit from there if you if you made the system in a very like you know proficient way efficient way and all if you design it in such a way only from the bio gas that you will get out of it from there only you will get almost 1000 more than 1000 kilo watt hour. We know that kilo watt hour means the this normally this normally this BTU unit the unit the per unit normally when we talk about that per unit of electricity and all this is the unit this 1163 kilo watt hour. So, if we have this 1163 kilo watt hour you are getting this much of input in one day just imagine the the use the you can use it in for ah even small industrial scale as well.

So, this energy can be used for industrial scale applications as well. So, here we play with the ah this kind of systems and you can realize that only by having this much of information only very few information if it is given to you if you know this design criteria if you thoroughly solve solve this ah numerical and all you will be able to ah have an idea the expertise to actually tell exactly the value of the energy that can be harvested from a ah anaerobic treatment system like ah USB and all ok. But we will further do the detail ah more in detail like design ah problems we will solve this design problems ah about the design of USB systems in coming lectures. So, in this USB off-flow anaerobic sludge blanket reactor it is one of the very typical type of anaerobic reactor for ah we will discuss about that and we will first understand the how it works and then slowly we will discuss about the design problems and all. So, I hope you get to know about the anaerobic process in general that how it works like ah why what are the different advantages of it. ah We discuss about the advantages like it is energy saving it is sludge is reduced or reduced sludge production high loading rate is possible and the methane production that can be used for ah different ah energy problem solving energy issues and all.

Major limitations it is a very slow start up time, but that can be accelerated by there are some additional means nowadays people are following by which they are accelerating

the start up time. Sensitivity to environmental factors which we cannot do it is very important and we need to be very cautious about it and very low nutrient removal efficacy that is that is in some cases it is little bit problematic, but the, but still it is ah much better in other senses. What is the we also discuss about the principle of anaerobic digestion which we know that in involves 4 main steps hydrolysis, acetogenesis and acetogenesis and methanogenesis which converts this complex organic molecules into simpler compounds and ultimately into methane and carbon dioxide only ok. I mean like the I mean like the in the ah biogasomally ok. We also estimate the methane production ah using this Bose-Boltz-Torschometric equation for severity degradation equation and also theoretical production equation and considering the effect of sulphate reduction and biogas solubility in the effluent as well.

And at the end we also solve the solve 1 problem ah numerical out of it and we are now confident enough that we can actually design a anaerobic digester ah. At least if we do not know how to design it we will do it in coming lectures we can actually say in from the very beginning that what will be the possible biogas production rate ok. These are the references I would like you to be follow it through for getting more in details idea about it and I hope you get to know some details some very brief or I would say like more effective information on the methane production on the anaerobic digestion process and its limitations and pros and cons. So, we will continue with this discussion with the type of anaerobic reactor in the coming lecture ah till now ah till then thank you so much.