Aspects of Biochemical Engineering
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Lecture – 44
Design and analysis of anaerobic digestion process

Welcome back to my course Aspects of Biochemical Engineering and we are in the last class. I was discussing of activated sludge process. Now if you look at the biological process that where cells living cells are growing, they usually is grow in 2 different mode; one is aerobic, another is anaerobic mode. The aerobic last activities, last process basically it is aerobic fermentation process and now I shall discuss the anaerobic fermentation process.

Now, I told you that say activities sludge process is used positive wastewater treatment purpose. Now, any industry that whenever they submit any kind of proposal, so they have to show that whatever waste material they are generating that should be properly treated so that the environment should not be polluted.

So, we have found out that 10 percent of the total investment of industry that usually go for the wastewater treatment purpose. Now if you look at the history of waste water treatment process that most of the industry when they invest the money for wastewater treatment process, they considered there is no return from that wastewater treatment process. Whatever money spent with that process that will go invest, but due to the invention due to the, due this anaerobic digestion process, now it is possible to get some revenue from this particular process, some money we can earn from this particular process.

So, this is, so this is a very interesting process through which the lot of industry there operating the process and I want to mention here that in the western country particularly if we visit Germany and Sweden, you will find that some busses, they are operating by using the biogas and biogas is nothing but it mostly contains methane and carbon dioxide and carbon dioxide you can easily remove through the absorption process.

And then, this methane we can use for the operation of vehicles for as they as they. Particularly I can tell you in the distillery industry, they required lot of heat energy for the distillation of alcohol and it has been found that if you if by using this anaerobic digestion process, the 50 percent energy that is required for the distillation process that can be meet from this anaerobic from then wastewater treatment by anaerobic digestion process.

So, with this small introduction let us, let me go to the anaerobic.

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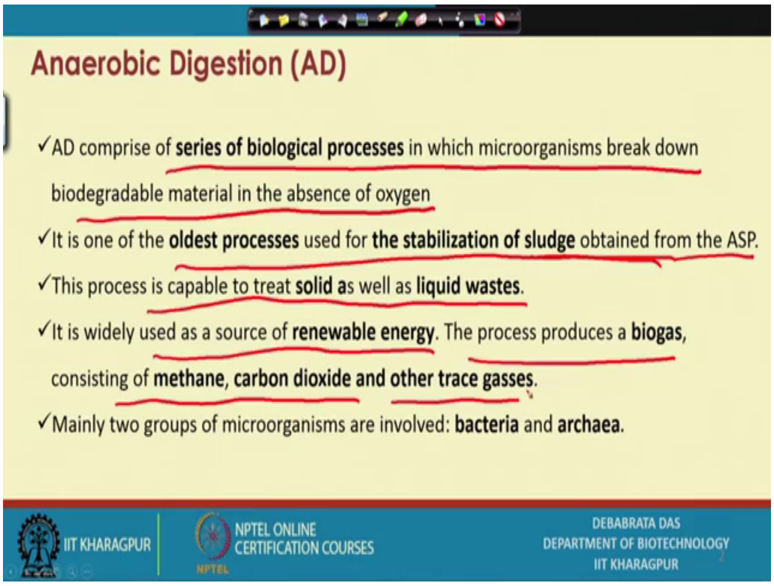

Digestion process, the anaerobic digestion process if you look at, it is comprises of series of biological process in which the microorganism break down; the biodegradable ingradable material in absence of oxygen. So, you know that this is anaerobic fermentation means in absence of oxygen. Only I want to highlight here that organism when grow aerobically, they required there grow that amount of cell mass formation will be very high.

But when they grow under anaerobic condition, amount of cell mass formation will be very less. So, I am also in other way, indirectly I can tell you that you know that are the nutrient requirement for the anaerobic fermentation process will be much less as compared to aerobic process because since the aerobic process, your cell mass growth this about 10 times as compared to anaerobic process. So, your nutrient requirement for the aerobic a fermentation process is much high as compared to anaerobic fermentation process.

So, now, here all reactions is occur in absence of oxygen and this is one of the oldest fermentation process. This is the oldest fermentation processes stabilize the sludge obtained by activated sludge process. Now I was discussing in the last lecture that activated sludge process. Now we should remember that you know I told you that when you talk about this is soluble organics, we are converting to cell mass and carbon dioxide.

The carbon dioxide as is going out of the system, but what is the cell mass that remain in the system that when we cannot throw it out because it contains lot of nutrient. The as soon as you throw it out then all the bacteria, other bacteria present in the atmosphere they will try to grow on this solid material and a degrade the material.

So your environment will be polluted. So, this large if we can with that we further treated. Now this led either you pass through the incineration process. So, you can produce lot of heat the problem is that it contains a very good amount of moisture. So, you have to remove the moisture before you go do you bond the bond this material.

But best way of treating this material if you passes through the anaerobic digestion process so that this organic material can be converted to methane and carbon dioxide. So, this is exactly what we have mentioned here. This is the oldest process used for stabilization of the sludge obtained from the activated sludge process. This is process capable of treat solid as well as the liquid waste; this widely as the source of renewable energy. The process produce a biogas consisting of methane and carbon dioxide and other trace gasses, trace gasses means since the anaerobic we know the anaerobic fermentation process that you know dissolve oxygen concentration of the media is not required, if the absence of molecular oxygen.

Though we know for the desperation of the microorganism dispersion of the living cells, always they require the oxygen. Now question comes from where they get the oxygen. They get the oxygen's from the compound like sulfate, nitrate, nitrite. The sulfate when they use as a source of nitrogen, the sulfate will be convert to sulfide and ultimately is convert to sulfide and H 2 S. So, you know that H 2 S gas that is produce in the system.

So, one of the problem that we have with this bio gas generation process which is the H 2 S present in the gas. Though it is very trace amount, but may causes the may affect the material of construction of the pipeline. Mainly 2 groups are micro fluid present when you call, this is bacteria and archaea, and this is the present.

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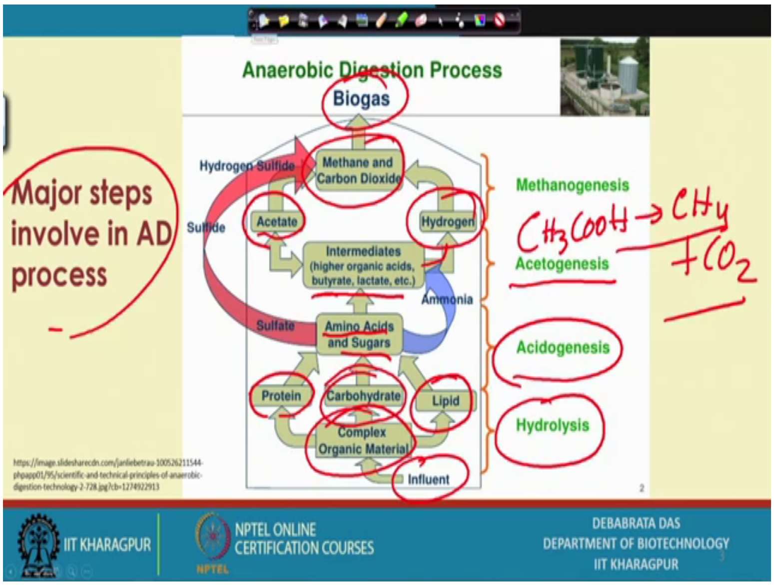

Now, let us see that what are the major steps involved in the in this anaerobic digestion process.

The first what do we have the Complex Organic Material here. This is the influent and then it comprises of what polymeric material. This is protein is the polymer of amino acid, carbohydrate is a polymer of glucose and may be monomer dimer, pintos, hemi cellulose, cellulose might be there then lipid, we have with esters of fatty acid and alcohol and this when hydrolyze it produces the amino acid and sugar. You know that is solve what do you what do you call this is the insoluble material and when we convert it to the amino acid or sugar, we call this solubilization of this process and this process we call hydrolysis.

And this is a hydrolyzed material, then converted to the different volatile fatty acid like acetic acid, butyric acid, lactic acid. So, you know different type of acid formation is there and these higher acids again converted to acetic acid before it produces methane and carbon dioxide. And in this process, this is acid generation processes produce hydrogen also and this in combination toward the methane and carbon dioxide and finally, we call it biogas.

So, basically if you look at this process, it is 4 major steps are involved; one is call hydrolysis process hydrolysis is basically liquefaction process and the Acidogenesis process; that means, the during the Acidogenesis process, this different organic acid volatile fatty acid formation take place like butyric acid, acidic acid, lactic acid, fumaric acid though different type of acid formation is their, propionic acid formation is there and this higher acid they converted to methane by acetic acid formation; what do you call Acidogenesis and this has a when acetic acid. We know what is the formula of acetic acid CH 3 COOH, this is converted to methane and carbon dioxide. So, this is how it is produced.

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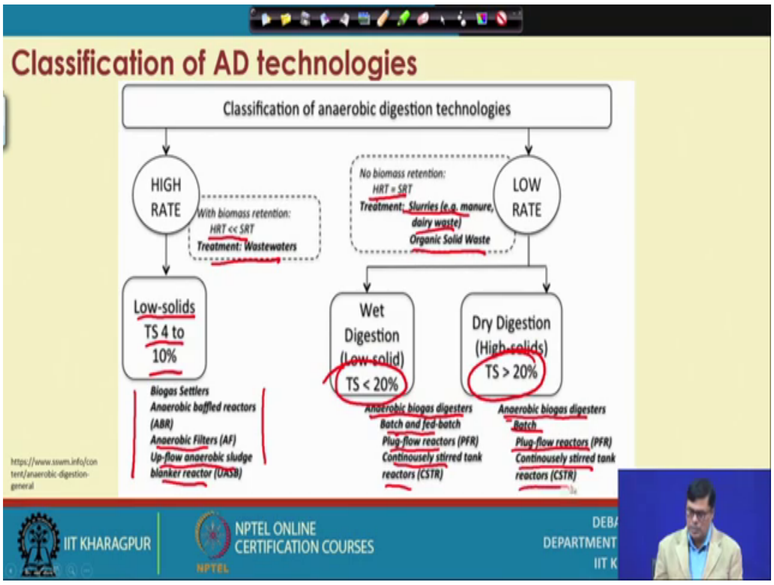

Now classification of anaerobic digestion technologies, this can be we can we can we can classified at the high rate and low rate. High rate this you know that hydraulic retention time is less than a solid retention time and with the treatment of the waste water. This is the low solid content that total solid a 4 to 10 percent with use at the biogas settler, anaerobic baffled reactor, anaerobic filter up flow, anaerobic sludge blanket reactor, these are the different reactor is use.

But in case of low rate reactor where no mass no mass retention is there the hydrate attention is equal to solid retention time. So, here the treatment is slurry or manure or waste water makely the solid material we use. This is content the 2 type of a solid one case, the total solid concentrate less than 20 percent, another is the more than 20 percent.

So, different type of anaerobic biogas digested that is the use here batch and fed batch process plug flow reactor at continuous stirred tank reactor is use and here in more than 20 percent you have anaerobic biogas digester batch process, plug flow reactor continuous starting reactor is use.

This is the how the how we can classified this anaerobic digester process.

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Now, we have we different anaerobic digesters is commercially available throughout the world and this is the up flow anaerobic sludge blanket reactor, up flows sludge blanket reactor appears to be the very efficient reactor. Now what is that reactor. This is the reactor is like this and. So, here we have we have some kind of sludge that here we have this.

So, this is we can we can take out the gas, we can take out the liquid from here. So, this is the liquid we had. So, here sludge formation is there, this is feed we have and this is the gas will coming out from the top and due to the high concentration of cell mass here, when the feed is going like this then it convert it immediately methane and carbon dioxide and main purpose is the this conical things you know particle. They will strike one another and ultimately it will strike here, it will come in then this direction again one particle strike this is ultimately and come in.

Since it is coming in the bottom direction, then all this large slowly this accumulated at the bottom of the of the reactant and time to time we have to denout the sludge because we have to find out what is the optimum height of the sludge for getting the maximum rate of reaction.

So, this is largely used. This is how it looks, then covered anaerobic lagoon digester, this is how it is operated plug flow reactor. Here there complete mix digester this is there and dry digester system and fluidized bed reactor is there. So, these are the different there are design based on the organic wastes, stream type such as the manure municipal wastewater treatment, industrial wastewater treatment, municipal solid waste some commercially available digesters are included.

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Now applications of for anaerobic digester there stable this is the input, input is may be energy crops, may be manure, may be industrial waste, may be the source separated the organic, organics or municipal solid waste, the restraint we have food industry, food waste that wastewater treatment from the plants large. This pass through the anaerobic digestion process and then whatever methane is produced that can be used for the generation of electricity and we have biogas. We can use at the running the vehicles, we can use as the renewable fuel, you have the digested material can be used as the bio fertilizer and reusable usable for water and compose. This is likely used for composting purpose.

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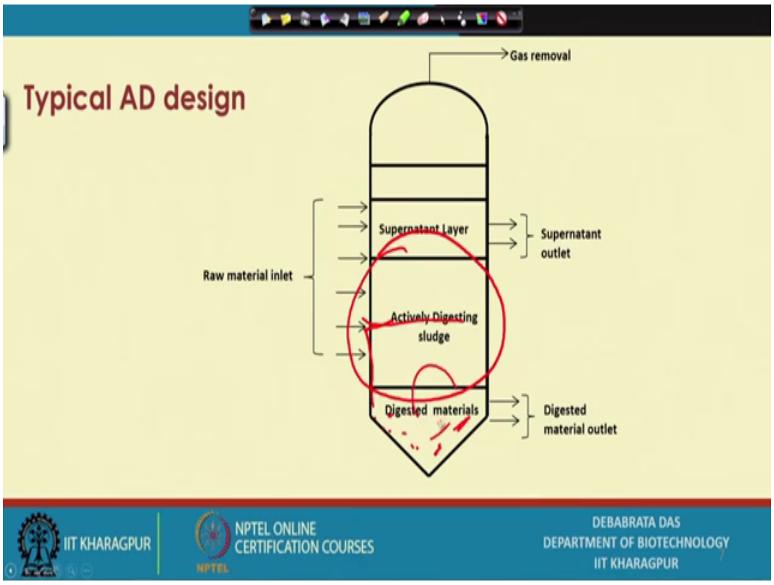

Now if you look at the digester, you have several section in the digester. This is and you know this portion is very interesting. The reason is that in this portion, that in a active digester slides, the most of the organisms they are active in this particular portion.

Now, here the digested material that we that, now we what we have observed, we have the several anaerobic digester plant located throughout the world and when big digester we operated, major problem is that longtime operation may be after a several month of operation, they will find that this digested material their accumulation is at the bottom of the reactor and there this settle in a very thick sludge and very difficult to separate it out.

So, a time will come this sludge will keep on rising and if you rise 50 percent, then you have to stop the operation. And then we shall have to take the material out to regenerate the process again. So, this is very important, this is supernatant layered that we have and gas is removed like this. Sometimes, we have here some kind of cross formation is there.

And we if we if we use some kind of vegetation or you know the scrap the surface then gas will escape out we can. We can increase the gas production this material can be easier that the digested material; we said the bio fertilizer.

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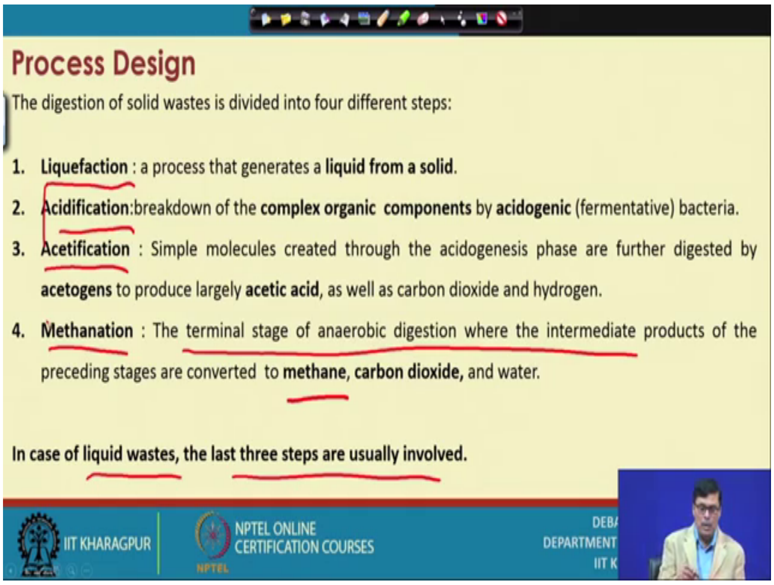

Now, process design that includes that if the liquefaction I already explained, acidification also explained, acetification I also explained that the higher organic molecules like butyric acid, propionic acid they converted to acidic acid it was then carbon as well as carbon dioxide and hydrogen then to methane and carbon dioxide. And methanation, mostly the acetic acid or you know methanol, they converted to or carbon dioxide the hygiene, they convert to methane and. So, in again in case of liquid waste last 3 steps are important because in case of solid waste all the 4 steps are plays very important role.

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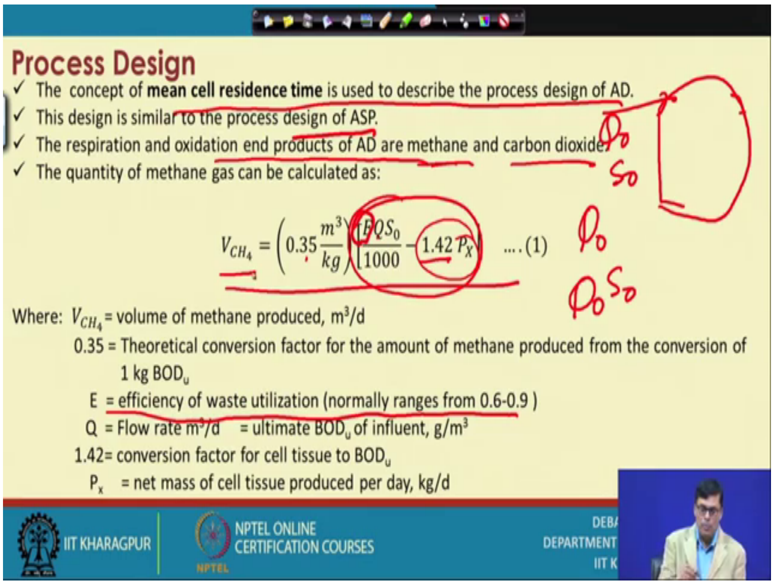

Now, if you look at this you know, this is very important the process design of this process that a concept of mean cell residence time is used to describe the process design of, we say we already explained that what is called mean cell residence time and design in similar to the activated sludge process respiration oxidation in product of anaerobic digestion or methane and carbon dioxide. The equation is V into this is very important.

Now, let me explain what is mean by that. Now Q, Q 0 or Q, Q or Q 0 is same that is incoming flow rate of the digester because suppose later assume this is the digester and this is Q 0 am I right or Q and this is the S 0 is that; what is the input sub amount of substrate input in the system Q 0 into S 0 am I right and then E is the efficiency of the waste utilization normally drains from point 0.6 to 0.9 percent.

So, when the question comes, how what is the percentage of this organic matter that can be converted they can be can be utilized; 60 percent to 90 percent. So, E is that factor and then I told you we need to converted a part also converted to the cell mass and that remain in the system. So, that is to be detected am I right. If you deduct that, then this is the actual the BOD that is removed.

Now, if you multiply it by 0.35, you will get the volume of methane produced. Now question come, how that figure has come let me explain that.

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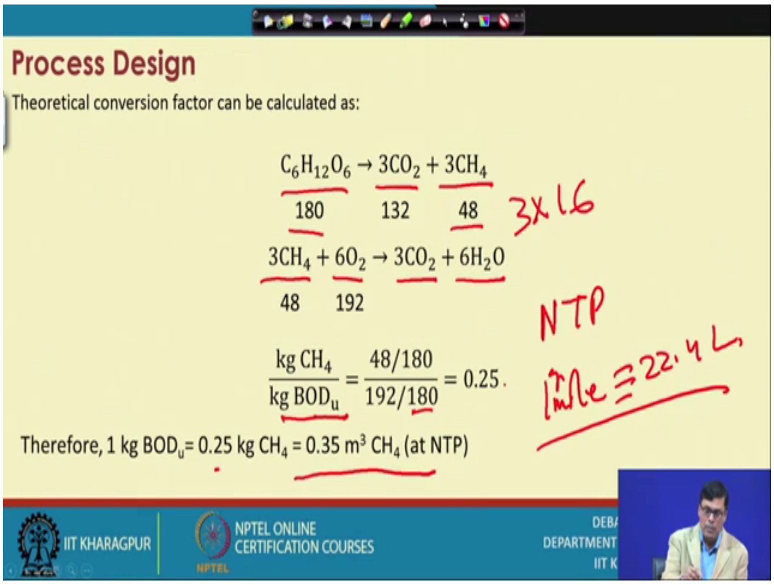

Now, let us assume this here that, what is that, 1 mole of glucose, 1 mole of glucose produced 3 moles of carbon dioxide and 3 moles of methane. So, this is 180 and this is 48 because 3 into 16 is 48; am I right.

And now, if you convert it into BOD, the 3 moles of methane required 6 moles of oxygen to convert it carbon dioxide and water. So, if you have the radio ratio that kg methane produced per kg of BOD, how we can write. The 48 gram methane you can produce for 180 grams of glucose and 190 grams of oxygen required for the oxidation of this methane that is 192 divided by 180; that means, the thing is the coming that 0.25 kg of methane produced per kg u of BOD removed, am I right.

Now, we know at NTP at NTP 1 mole, 1 gram mole of the gas is equivalent to 22.4 liters, am I right. Now if you put that equation here, then we will find this will be equal to 0.35 cubic meter per methane and the cubic meter methane.

So,, so what I what I what I want to tell, now in this equation, you see that this is the amount of BOD removed. So, we know this is per kg of BOD removed. So, you can easily find out the how much volume of methane is produced 0.35. You can find out and if you if you multiply it by 0.25, then you can forget the kg of methane produced per kg of BOD removal.

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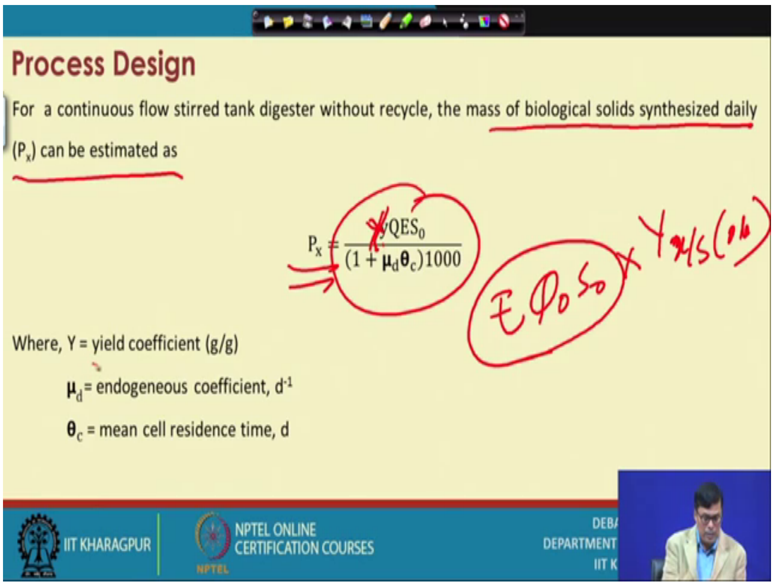

So, this is how you can calculate that. Now in the in the process design another parameter very important that what is the biological solids because if we look at the mass of biological solid synthesized daily that is rate of cell mass formation, how you can calculate that in the Q into S 0 because I told you, that you can remember that Q 0 into S 0 into substrate conversion am I right and if you multiply this that is the actual amount of substrate that is converted.

Now, if you multiply by y, observed by x, x by s observed, then what will happen, you will get what is the exact amount of cell mass that is produced. This is exactly that is the this is capital Y and this is capital Y the x by S that is y stands for that is the yield coefficient.

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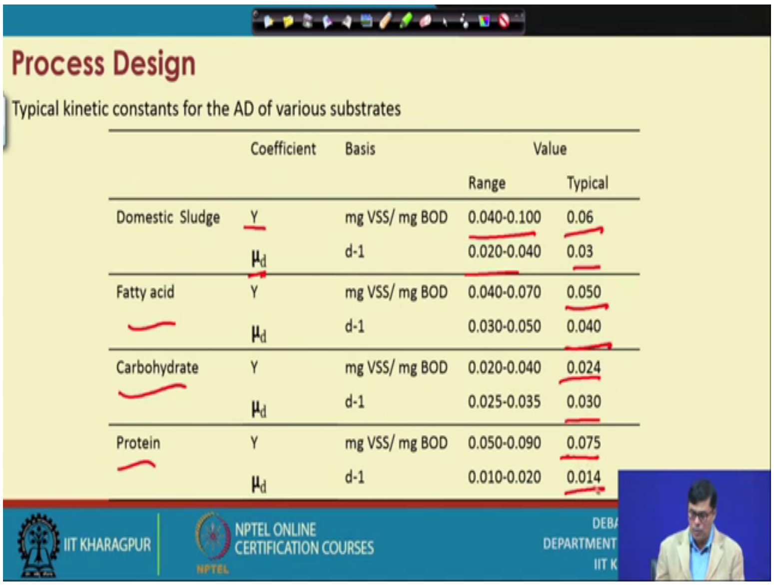

	Coefficient	Basis	Value	
			Range	Typical
Domestic Sludge	Y	mg VSS/ mg BOD	0.040-0.100	0.06
	μ_d	d-1	0.020-0.040	0.03
Fatty acid	Y	mg VSS/ mg BOD	0.040-0.070	0.050
	μ_d	d-1	0.030-0.050	0.040
Carbohydrate	Y	mg VSS/ mg BOD	0.020-0.040	0.024
	μ_d	d-1	0.025-0.035	0.030
Protein	Y	mg VSS/ mg BOD	0.050-0.090	0.075
	μ_d	d-1	0.010-0.020	0.014

Now, this is the typical different kinetic constant that we have as for anaerobic digestion is constant concerned the domestic sludge that the yield coefficient and mu mu d is the specific death rate of the cells that varies from this range and typical value is this ok.

In case of domestic sludge; in fatty acid, we have this typical value is like this and carbohydrate it is 0.02, 0.030 and protein is point 0 0.075 and 0.016.

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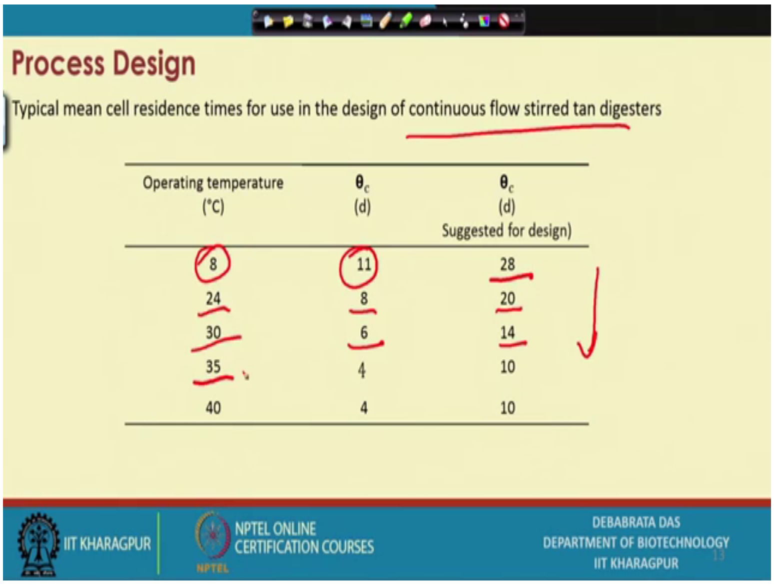

Now, if you consider the mean cell residence time using the design continuous stirred tan reactor, then we find that 8 degree centigrade the theta c value that is the mean cell residence time will be 11, but the suggested is 28 days.

Now, in case of 24, it is 8 and this is 20. In case of that 30 degree centigrade, it is 6 and it is 14. So, what I want to be in as you increase the temperature, your kinetics is better because your rate of conversion of the gas will be more high, it will be higher as compared to low temperature. Your organism will be activated because you know that we find that reaction kinetics as parameters improve as you increase the temperature because we know rnds equation that how the rate constant depends on the temperature.

So, this is the this we observed in case of particular anaerobic digestion process temperature plays very vital role and here I want to tell one particular matters that you might be knowing that in India we have millions of bio gas plant that is located in different rural areas and also China also they have millions of bio gas plant in the rural area because if you look at the social structure of the China and India is more less same and because our standard of living is not as good as the western country and that is why this process largely implemented in India and as well as China.

Now, what we observe that you know that in case of a China that this process is quite successful as compared to India, the reason is that in the China they have they have they have certain analytical devices that how this small this biogas plant can be operated. They have the monitoring system of ph.

Now, I can tell you the anaerobic digester usually governed by 2 type of organism; one is the acid agency and methane agency, the when you when both the organism present in the reactor. So, both the acid conversion and acid to methane conversion takes place. Now if there is a if the rate of acid formation is high as compared to rate of methane generation then what will happen, the acid concentration in the reactor will increase. Now as the acid concentration increases, the ph of the reactor will go down as the ph goes down, the rate of methane formation will be reduced significantly.

So, this is the major problem. So, those things you have to take care. Another thing is that temperature because we have because we know that we are though we are in the tropical country, but during winter our temperature reduce as low as 20, 15 to 20 degrees centigrade. So, necessarily our temperature of the leister we do if we do not have any kind of heating system and though we know that the biochemical reaction is the exothermic in nature, but you know the temperature will go down, am I right. The as the temperature goes down, then your rate of reaction also decreased significantly, that is the major problem that we have with the anaerobic digestion process.

So, temperature is the very important criteria that we shall have to maintain.

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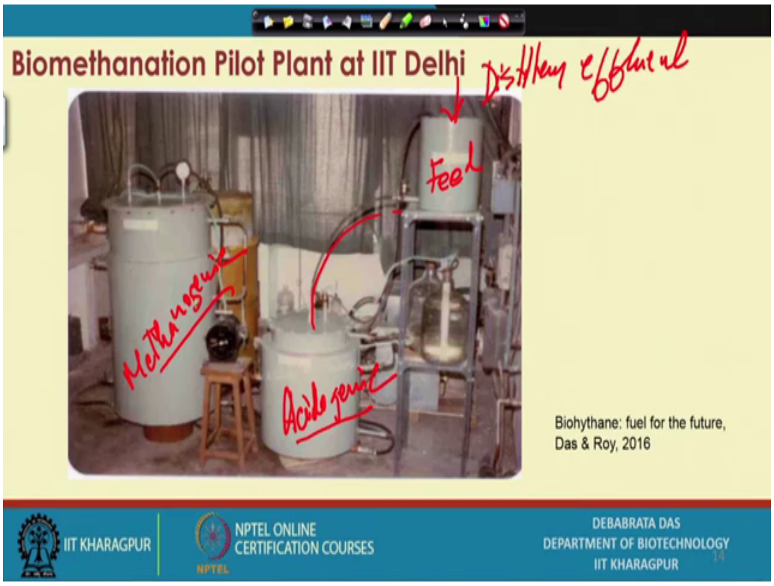

Now, this is the this is the Biomethanation pilot plant that I personally work at IIT, IIT Delhi and here we use the distillery a plant. This is the this is the Acidogenic reactor, acid regions, genic reactor and this is Methanogens, genic reactor and this is the feed tank that we have.

So, what we do? We can put the distillery of 20 here effluent here and then we can we can continuously pass through this and then after that is the though, you can sigh you can easily find out the size of the Acidogenic reactor it is much small as compared to Methanogenic reactor. The reason is that Acidogenic organisms they walk very fast as compared to Methanogenic, Methanogenic reactor is very slow growing organism as compared to acid Acidogenic organism.

So, here the reaction is since it is very fast, the rate of acid formation will be verified is required very small reactor and here Methanogenic reactor based very time consuming, slow growing. So, we have to keep the bigger reactor. So, this is how this we operated this reactor.

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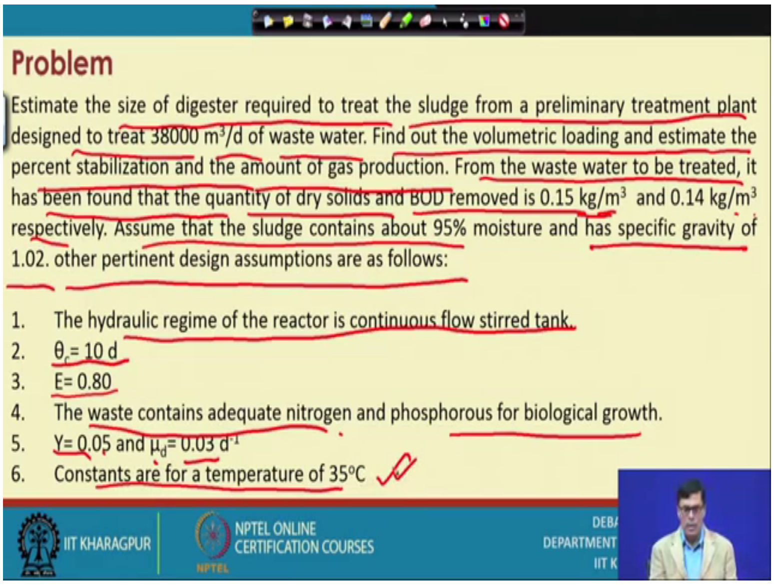

Now, we have we have taken one problem that you know they, estimate the size of the digester required to treat the sludge from a preliminary treatment plant design 3 38000 cubic meter per day of wastewater. Find out the volume loading and the estimate the percentage stabilization and amount of gas produce. From the wastewater to be treated, it has it has been found that the quantity of dry solid and BOD removal is removed is 0.15 kg per cubic meter and 0.14 kg per cubic meter respectively.

Assume the sludge contain 95 percent moisture and has specific gravity of 1.0 to other pertinent design parameter is given, hydraulic regime of the reactor is continuous flow start tank and solid retention time is strained is the E is the 0.8 and waste content adequate nitrogen and phosphorus for biological growth and y x by S is 0.05, mu d is 0.03 the inverts and constraint are all constraint as temperature as 35 degree centigrade.

So, this is the problem that we have. Let us see how we can solve this problem.

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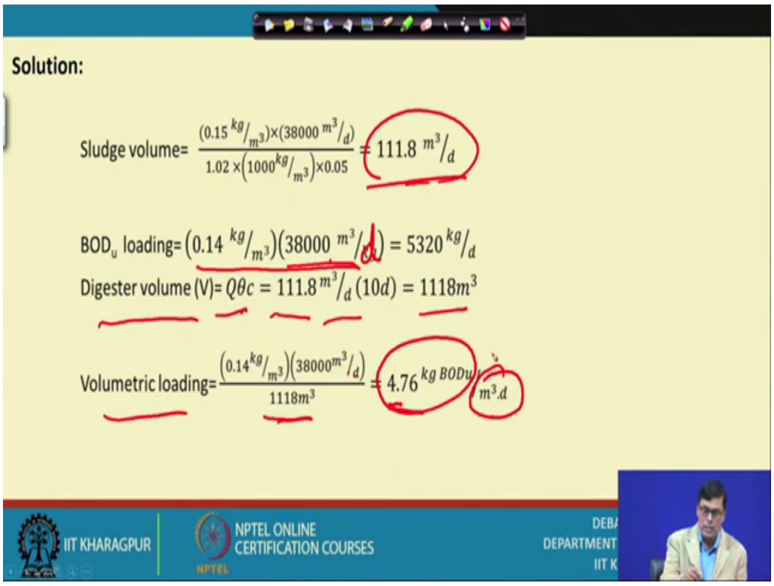

Now, first we still have to find out the sludge volume am I right. Now how you can find out the sludge volume. So, this is what is thus content, the dry solid; this is a 15 kg per cubic meter am I right. So, 15 kg per cubic meter and this is the volume of that liquid is coming in.

So, if you multiply, that you will get the amount of sludge that is, that you know entering into the system. The density of the sludge is point 1.02. So, if you multiply by factor and. So, you will get this and another factor that is given the 95 percent moisture content, then 5 percent is the total solid, am I right.

So, if it is like this, then we can we can find out the volume of is sludge is 100 18 100, 111.8 cubic meter per day. Now BOD loading, we can similarly we can calculate, this is this is the BOD 0.414 kg per cubic meter. This is the amount of, this liquid that is the interning per kg that is, this is per day. This has some mistake is there. So, you correct it and this is, this you can find out. This is this is may be 5320 kg per day.

Now, digester volume, how you can calculate? This is Q, Q is this is volume of the digested and the solid retention time is the 10 days. So, if you multiplied by this that, we can we can find out the volume of the reactor. So, then volumetric loading how you can calculate; this is the amount of sludge that is coming in and this is the volume of the react volume of the reactor. So, amount of solid material that is putting part cubic meter of the reactor per day is equal to that you can calculate very easily.

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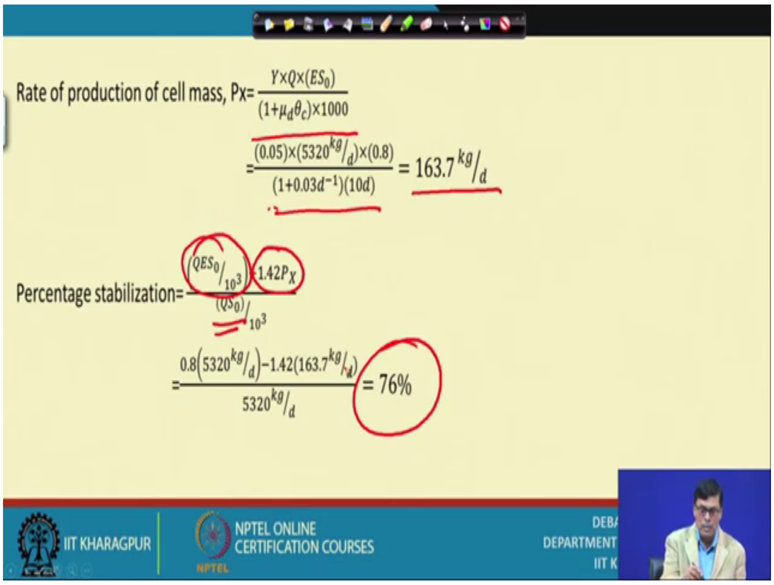

Now, if you want to find out the cell mass formation thus this the equation that we have and we have all the values in this problem. If you put that we find it is 163.7 kg per a day. Now we have the percentage stabilization, how you can calculate that; this is the this is the BOD that is removed and this is the cell mass that is the BOD equivalent to the cell mass. So, actual removal of the BOD is this and this is the Q into S 0 is the total BOD that is the input in the system.

So, if you do that, you can very easily get the percentage stabilization of the solid material that you can easily do that.

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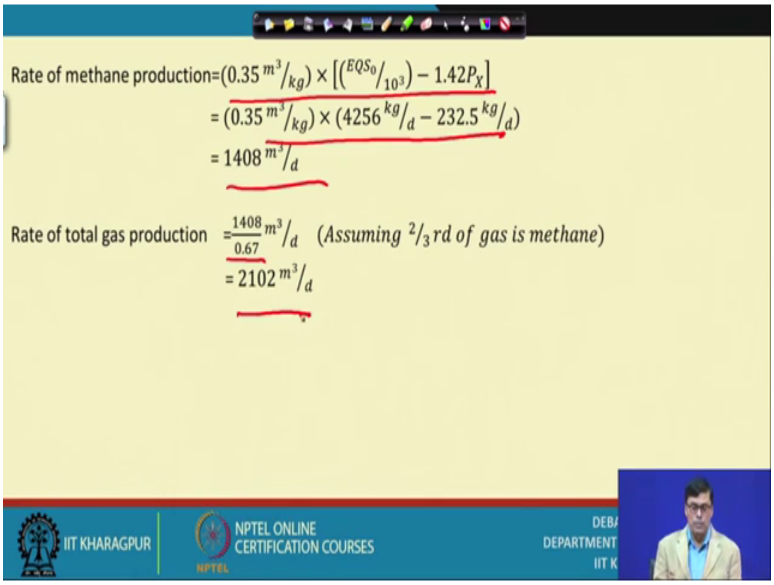

And then finally, we want to find out that; what is the amount of gas produced. The we have already developed this equation that 0.35 into E E Q is S 0 1.4 to in to P x, all the parameters is already estimated. So, we can find out 1408 cubic meter methane produced per day.

Now, if the methane contains, if the gas contains 67 percent of a of a methane, then we can find out the total gas produced about 2102 cubic meter per day. So, we can we can we can estimate this very easily.

So, in this particular lecture, I try to discuss the anaerobic digestion process. The anaerobic digestion process is considered the most useful process because here we can generate lot of methane and this methane can be generated both from the solid as well as from the liquid waste and this I told you, this process has the 4 different steps; one is called hydrolysis, then acid region acidification, then acietification, then methanation.

This is usually governed by 2 by group of Microflora; one is called acid regions, another is methane regions. Purpose of the acid regions is convert the organic material to organic acid and purpose of methanogens is the convert the organic acid to methane and carbon dioxide and we I told you the acid regions grow much faster as compared to Methanogenese. So, size of the axigenic reactor will be much smaller as compared to methanogenic reactor.

So, and we try to, so find out the amount of, find out derivate derive with some kind of equation; how to find out that we have volume of methane or volume of gas produced part kg of the part kg of the BOD remove border from the digester that we can easily calculate. So, one problem we try to solve and we will show you that how this can be estimated.

Thank you.