Waste to energy conversion

Dr. Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Lecture – 27
Energy production from Organic waste through Anaerobic Digestion-2

Hi friends, now we will start discussion on the second part of the module energy production from organic waste through anaerobic digestion.

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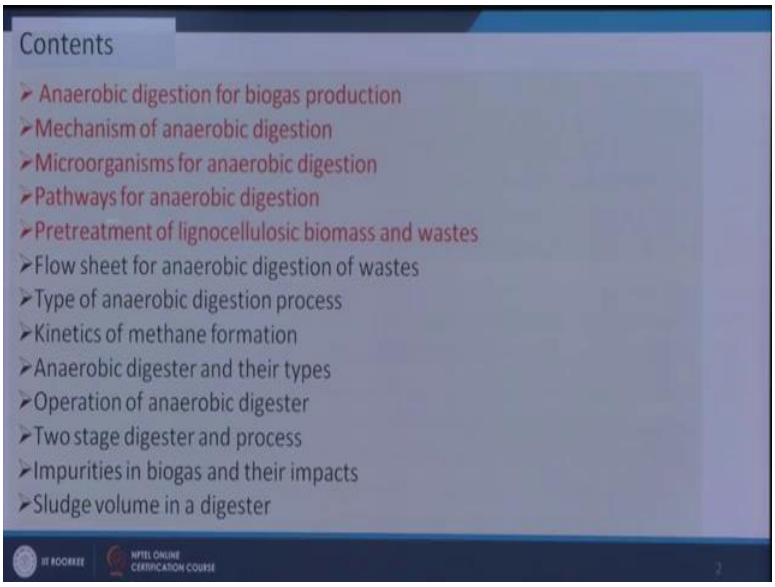

In the first part of this module, we have discussed on the fundamentals of anaerobic digestion different steps and the reactions path wage and we have also discussed on microorganism types and the pretreatment of lignocellulosic biomass and wastes. And in this module we will discuss on the anaerobic digestion flow sheets and then type of anaerobic digestion process and the digesters and then operation of digesters and 2 stage digester and the process impurities present in the bio gas which is produced through this process and its impacts and finally, we will also discuss how to calculate sludge volume.

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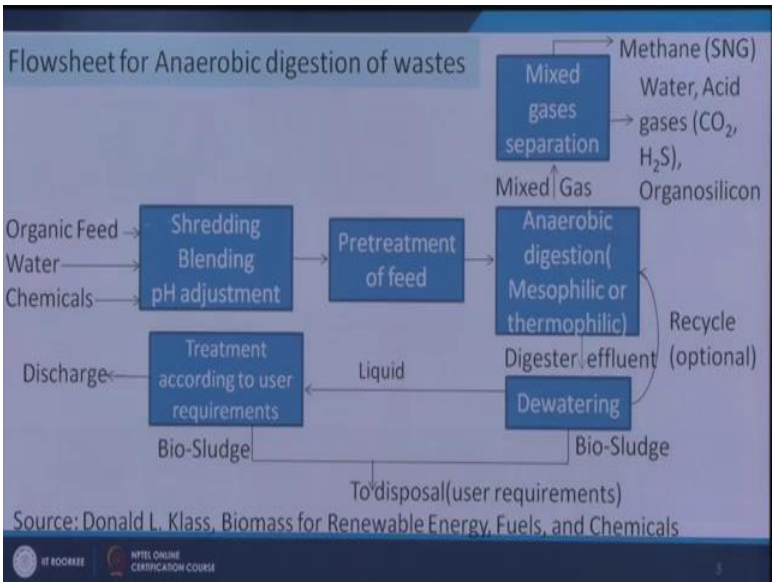

So, now let us start with the flow sheet of the anaerobic digestion process unlike thermal process in this process we need to add water with the feed stocks. So, an organic waste or organic feed is mixed with water and some chemical some chemicals means those are required for the growth of microorganisms. So, these are mixed at first, so blending is required and pH adjustment is required for that the microorganisms will grow effectively and in some cases shredding of the wastes are required. After this step we need to do some pretreatment of feed the extent of pretreatment will depend upon the nature of organic feeds which you are using like say example if we use organic feeds rich in glucose only. So, in that case pretreatment requirement is very less not required, but if it is a lignocellulosic biomass if cellulose content is higher lignin content is higher we need more pretreatment steps.

After pretreatment the slurry will come to this anaerobic digestion chamber anaerobic digester either mesophilic or thermosphilic conditions are maintained and then in this digester biogas is formed. So, biogas rich in methane will goes up from this anaerobic digester and which has to be treated first. So, after treatment we will get the pure bio gas rich in methane and other impurities like CO2, H2S and organosilicons are will be removed from the gas stream and the digester effluent will be containing very large amount of water because in conventional processes the slurry content the solid content is this in this anaerobic digestion reactor is around 8 percent.

So, 92 percent water; after the treatment after the reactions, large amount of effluent is generated. So, we have to treat this effluent, we have to dewater it and that liquid has to be treatment first if you do not treat it. So, it will create another environmental problem. So, you have to treat it and then we will use the water for other applications and here the bio sludge will be generated here also some bio sludge will be generated. So, all those sludges will be used for other applications like say fertilizer or manure or this can be used for the composting purpose and here some amount of digester effluent can be recycled that can be used for giving say microorganism seeds.

So, this is the flow sheet through which the anaerobic digestion takes place now if you think about the flow sheets the heart of this process is anaerobic digester. So, anaerobic digester depending upon its type we will get different quantity of the methane and its composition.

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Type of anaerobic digestion

Processing mode	Dry	Wet
Total solids content	High 25-45 %	Low 2-15 %
Reactor volume	Minimized	Increased
Solid liquid separation	Simple	Expensive
Energy Balance	More Improved	Less improved
Economic performance	More improved	Less improved
Retention time	Shorter	Bigger
Type of feedstock accepted	Greater flexibility	Lesser flexibility

Conventionally this wet anaerobic digestion process is used where 2 to 15 percent solid content is normally applied, but people are trying to improve the process by reducing the water content; that means, increasing the solid content. So, in the previous module the first part of this module we have mention that 20 to 25 percent solid content is used in dry anaerobic digestion process, but some reports are available up to 45 percent of dry solids are used in a slurry for the anaerobic digestion process.

And in this dry process it has some advantages over the wet process which are regulated here like say reactor volume solid liquid separations energy balance economic performance retention time and type of feed stocks accepted. So, on the basis of these parameters we can compare dry and wet processes and we see the dry processes are having more advantage over the wet processes. Now we will discuss on the kinetics of the process anaerobic digestion process in the first part of this module we have seen that anaerobic digestion process is a complex process and there are number of steps the first is hydrolysis acidogenesis, acetogenesis and then methanogenesis.

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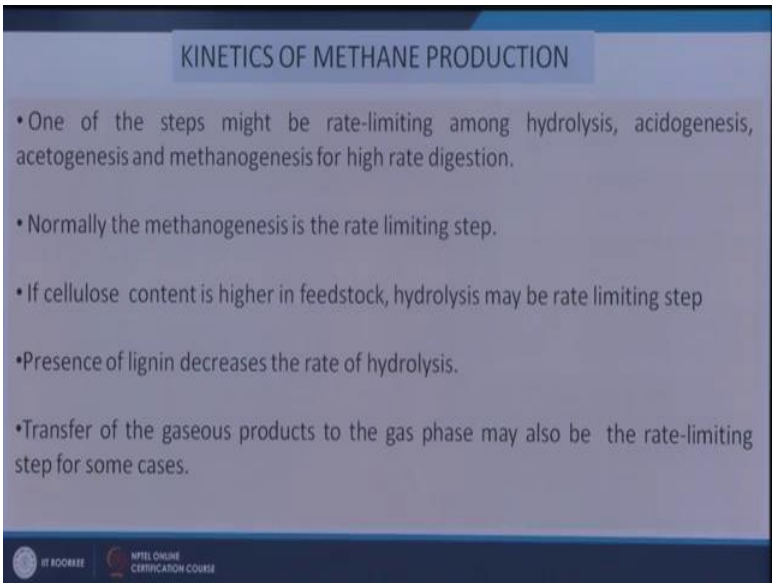

So, any one of these step can be very slow step and that will control the overall rate kinetics of the process.

So, normally the methanogenesis is the rate limiting step this is the slower process slower steps. So, this is the rate limiting step, but if the cellulose is present in higher extent then hydrolysis may be the rate limiting step and particularly if lignin is present then the hydrolysis is very very slow process and that inhibits the process and decreases the overall kinetics apart from this other factors like transfer of gaseous products. So, if in the anaerobic digestion unit the gas is produced and it is stored at the top of this anaerobic digestion unit then if we can remove the gas from the units continuously the rate will be higher if we store the gas inside this. So, that will influence the performance of the reactor.

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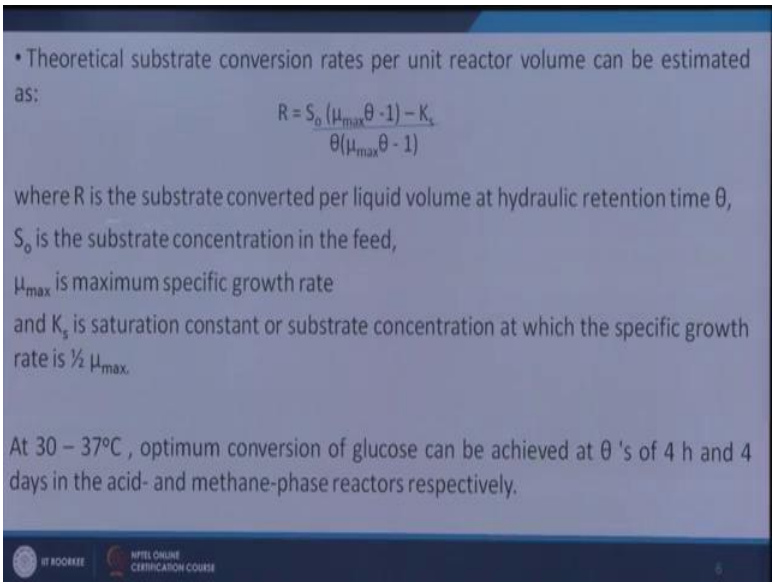

Now, we will see the typical expressions of the rate of the reactions that R rate is equal to S o into Q max theta minus one minus K S divided by theta into Q max theta minus 1. So, what are this theta S o, Q max and K S? Thetas are retention time, so retention hydraulic retention time and Q max Q max is the maximum specific growth rate and S o is the substrate concentrations in the feed and K S is the saturation constant or substrate concentration at which the specific growth rate is half of the mu max. So, when the growth rate specific grow rate is half of the mu max at the time the; we will get the substrate concentration presume K S. So, it has been seen that a 30 to 37 degree centigrade temperature optimum conversion of glucose can be achieved within theta of 4 hour and 4 day in case of acid acidogenic phase and methanogenic phase.

So, acidogenic phase is faster in case of glucose whereas, methanogenic phase is very slower. So, 4 hour in case of acidogenic phase where as it is 4 days for methanogenic organic phase.

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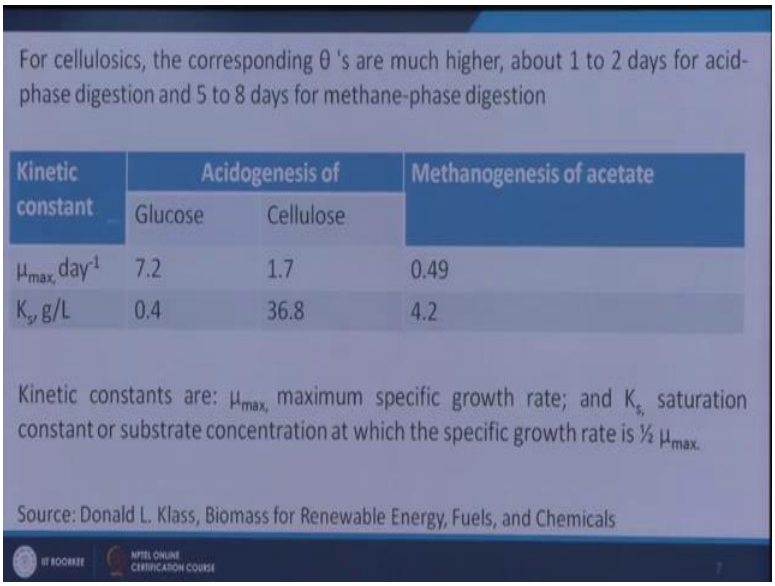

However if the cellulose is higher in the feed stocks then the corresponding thetas are much higher about 1 to 2 days for acidogenic phase and 5 to 8 days for your methanogenic phase. So, in both the cases whether it is cellulose or glucose, but methanogenic phase is higher that is 5 to 8 days. Now this table gives us some parameter that is kinetic constant mu max and KS where mu max is the maximum specific grow rate and K S is the saturation constant or substrate concentration at which the specific grow rate is half of Q max.

So, if you compare these values if the substrate is glucose then the mu max value is 7.2 very high; that means, very first rate, but if it is cellulose the rate decreases and here the methanogenic phase further the rate decreases. So, rate of methanogenic phase is slower where K S value of also very low in case of glucose and then cellulose and this is for methanogenic phase.

Now, we see some important facts related to anaerobic digestion. So, what are those that methane fermentation thermophilic temperatures increases the methane production rate because of higher reaction rates; that means, reaction if we use thermophilic temperature. So, it is a higher temperature say more than 45 degree centigrade temperature at the time rate of reactions increases, but difficult will be there.

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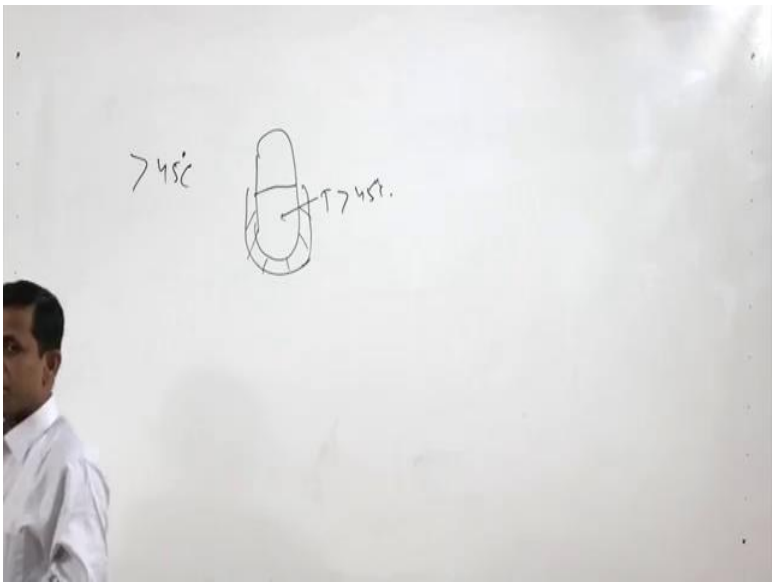

If we want to get the higher rate at say temperature above 45 degree centigrade we have to heat the material inside the digester also above t greater than 45 degree centigrade. So, external heating is required. So, in that case external heating is required.

So, if we increase the temperature inside temperature more than rate will also be more, but we need to provide some heat. So, there will be some optimizations what will be the optimum temperature we can use for the production of biogas, now reduced pressure also provides the little or no benefit reduced pressure has no that much of importance on the process.

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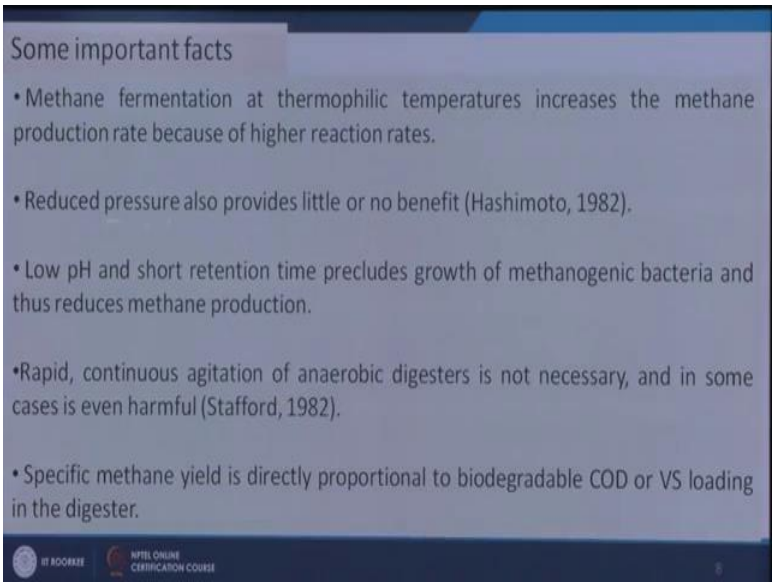

And low pH and short retention time precludes growth of methanogenic bacteria. So, if the pH inside the anaerobic digestion reactor is very less. So, less pH that will inhibit the growth of the mechanogenic microorganisms methanogenic microorganisms reacts well at the pH of seen 0.2 or 7.4 to 7.9 whereas, acidogenic bacteria reacts with would very result gives very good result at 5.4 to 5.9 pH.

So, the lower pH and short retention period that precludes growth of methanogenic bacteria and thus reduces methane production other important information is rapid and continuous agitation of anaerobic digester is not necessary we do not need to agitate the digester slurry because it will give some negative impact on the biogas production and specific methane yield is directly proportional to the biodegradable COD or volatile suspended solids loading in the digester. So, in the digester how much loading we are putting inside what is the solid content that is volatiles solid content that is important for the production of biogas.

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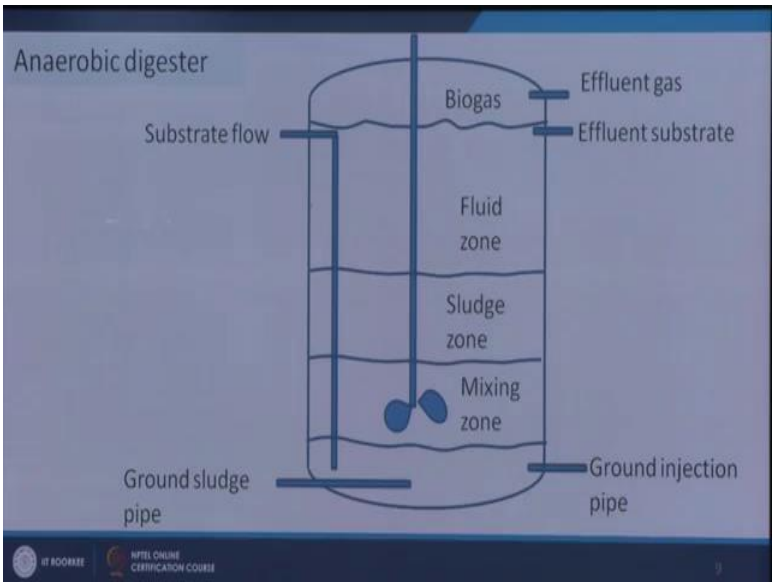

Now, we will see different zones in an anaerobic digester. So, if this is the anaerobic digester we put here the substrate flow we e put here substrate. So, substrate comes inside the digester and microbial activities starts on it we needs slight mixing zone we give slight mixing here so, but vigorous mixing is detrimental slide mixings helps by reducing the stratifications inside this. So, temperature difference is reduced. So, that uniform temperature is mentioned in time inside this anaerobic digestion reactor. So, better performance we get, but more mixing is detrimental. So, at the bottom part we get sludge. So, sludge zone and the middle part we get fluid zone and in the top part we get bio gas zone. So, in this case which feed is coming here after reactions the more suspended or more the solids are coming in terms of sludge. So, this is your liquid supernatant and it will be going out as effluent and substrate effluent substrate and biogas will be going from the top of it.

So, this is the different parts of the anaerobic digester and different zones we can say different zones of the anaerobic digesters and from the bottom we will get ground sludge pipe. So, sludge will be getting out from this. So, we cannot get the sludge out as per our wish we have to do some calculations and we have to see how much sludge should be taken out and after how many days etcetera. So, we will be discussing in the subsequent lectures. So, mixing helps to reduce the natural stratification thus to we have discussed then this mixing we can do by some mechanical means by use by providing some air or by supplying recirculation pumps because it is anaerobic digestion.

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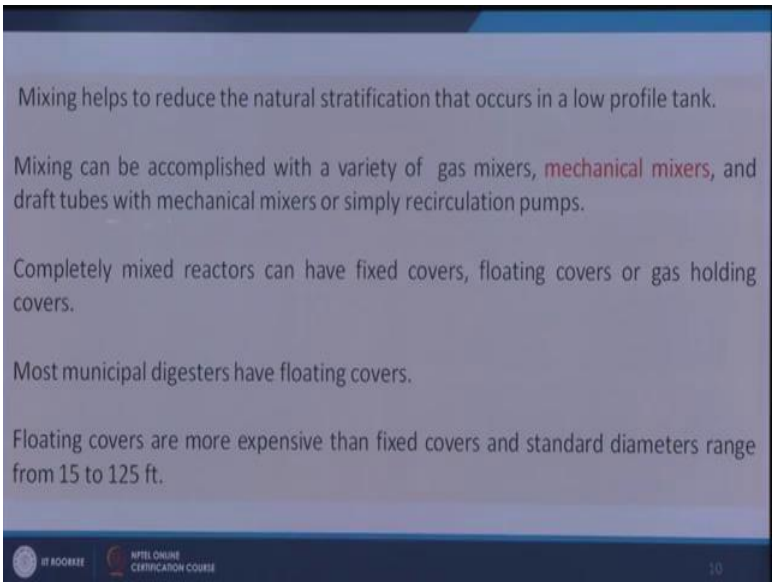

So, we have to draft we have to use draft tubes mechanical mixers or simply recirculation of pumps. So, now, completely mixed reactors can have fixed covers. So, this reactor what will be the cover of this that that can be fixed one or that can be adjustable with the pressure. So, that floating covers or gas holding covers. So, these are the different types of heads which are used for anaerobic digestion reactors and most municipal solid waste digesters have floating covers and floating covers are more expensive than fixed rates and some standard diameters are given.

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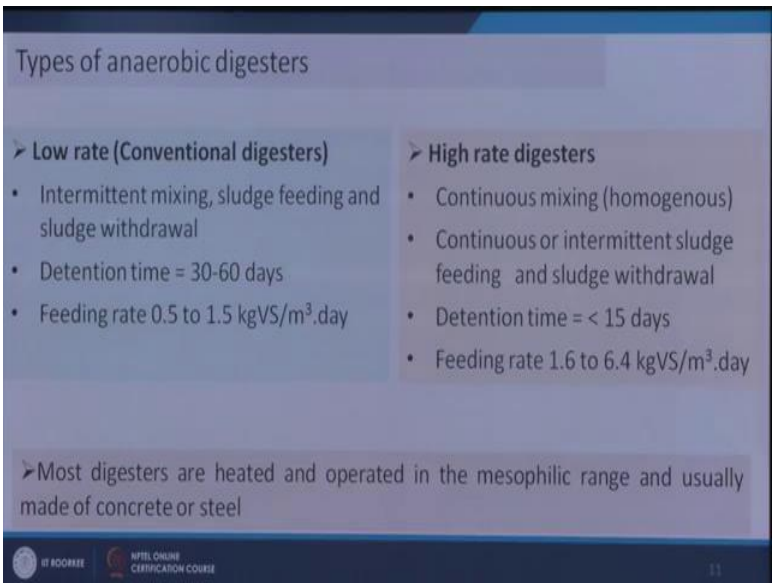

Here that is 15 to 125 feet here we will see types of anaerobic digesters. So, anaerobic digesters can be used as low rate process or as high rate digesters. So, low rate higest digesters means its feeding rate is lower; obviously, 0.5 to 1.5 K g volatile solid per meter cube per day and its detention period is also higher that is 30 to 60 days.

Whereas for high rate digesters our feeding rate is higher that is 1.6 to 6.4 K g volatiles solid per meter cube per day and detention time is less than 15 days. So, these 2 low rate is intermittent mixing sludge feeding and sludge withdrawal options is available for high rate continuous mixing and then continuous or intermittent sludge feeding and sludge withdrawal. So, these are the basic characteristics of these 2 types of anaerobic digesters and most digesters are heated and operated in the mesophilic range and usually made of concrete and steel structure. So, mesophilic range means in the 20 to 45 degree centigrade temperature.

So, just now we have discussed that if you increase the temperature you will get mode higher rate of gas production, but there will be some economy of heat; that means, there will be some situation or some conditions and we will get the process more economic and more optimum conditions that is mesophilic conditions.

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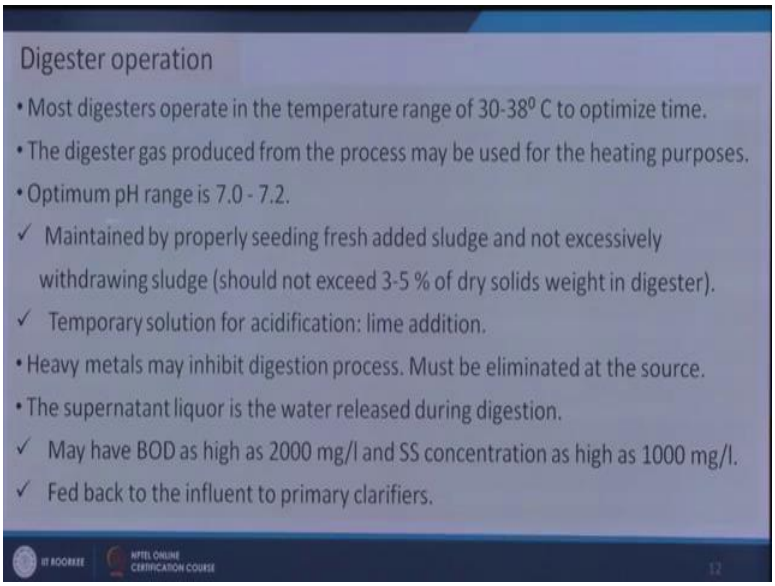

So, these are some conditions which are considered as a optimum conditions like say temperature 30 to 38 degree centigrade pressure seen to 7.2, this is obviously for a single chamber anaerobic digestion only single chamber we will be using a single chamber. So,

in that case pH is 7.2 and maintained by properly seeding fresh added sludge and not excessively withdrawing sludge. So, we have to withdraws sludge in such a way that pH is maintained is 7 to 7.2 if still we are not able to then we have to add some other chemicals. So, then that can be used that is lime addition we have to do to maintain the pH of the solution.

Heavy metal inhibits the growth of the microorganisms. So, we have to take precaution so that our feed stocks will be free from the heavy metals and the supernatant liquor which is produced here. So, this is our supernatant liquor which is going out that has to be treated it contents good amount of BOD and COD, I had mentioned here around say 2 thousand mg per liter BOD and S concentration is 1,000 mg per liter. So, these are beyond above the permissible limits. So, you need to treat it and or this can be partially feedback to the digester.

So, now we have come to know that 7 to 7.2 pH is maintained for a anaerobic digestion process when only single digester is used, but S 2 step process has been developed in later stage because the single step process are having some difficulty.

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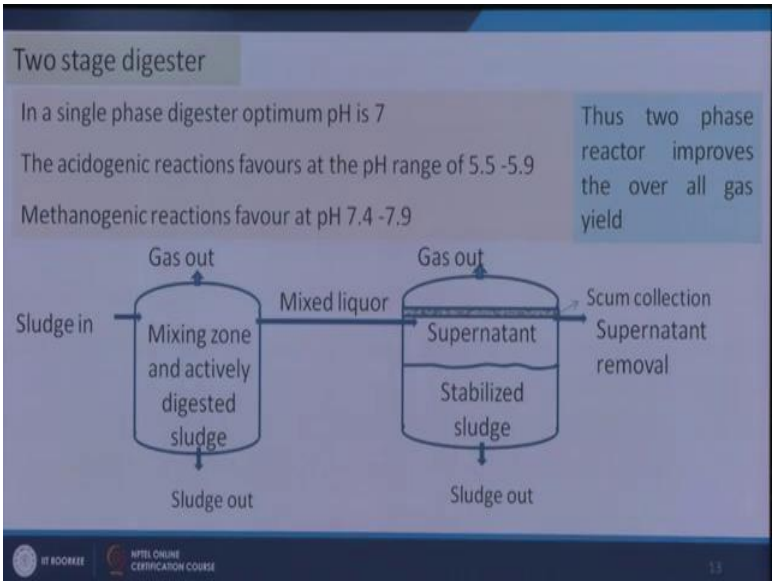

What is that you see if you use only one reactor and maintain 7 to 7.2 Ph, it will not satisfy the condition of growth of the methanogenic bacteria and the growth of the acidogenic bacteria acidogenic bacteria 5 to 5 to 5.9; 5.5 to 5.9, further methanogenic 7.4 to 7.9.

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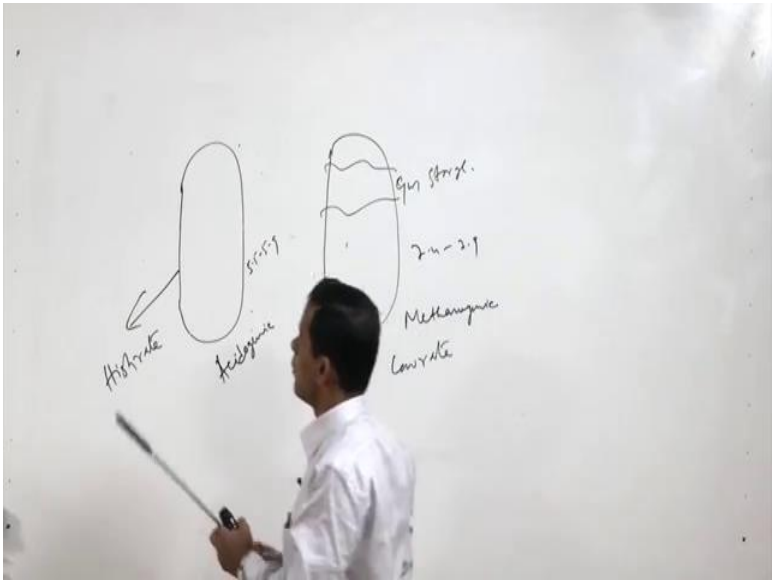

So, if we use to 2 different reactors 2 digester one is for acidogenic phase another is methanogenic reactions. So, here 5.5 to 5.9, 7.4 to 7.9, the rate of the first reactors, this reactor acidogenic microorganism will be working here very fast. So, this reactor will be very high rate type high rate reactor and this will be low rate reactor because methanogenis, methanogenisisis, is will take place slow process. So, low rate reactor high rate reactor 2 different type of reactors we are getting here and as a result these systems will give us more efficiency. So, in the first sludge is in it is coming. So, this is acidogenic reactions is going on gas is produced and then sludge also produced. So, mixed liquor is send to this second anaerobic digestion unit where methanogenic phase reaction will goes on and gas will go out and then we will get the supernatant for the treatment and the sludge we are getting those sludge will be further managed.

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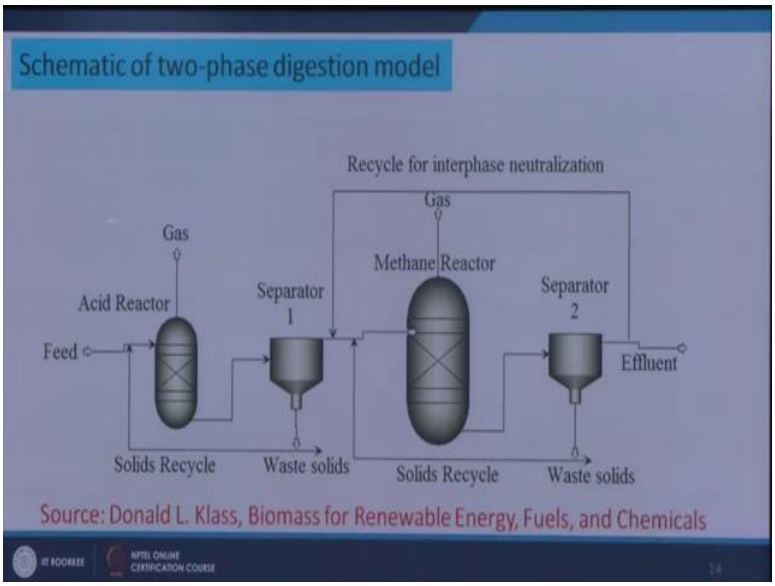

So, this is the schematic of 2 phase digestion model how actually the plant looks likes. So, if you put feed here the acid reactor acidogenic phase gas out it is going to the separation for the sludge and then it is coming supernatant here then the second phase that is methanogenic phase methane production will take place. So, again the sludge will be settled and recycled back in both the cases the sludge can be recycled back or the sludge can be taken out.

So, as we have discussed at this if this we have 2 stages then the first stage will be of acidogenic and second is a methanogenic and this is high rate and this is low rate that same information are provided here.

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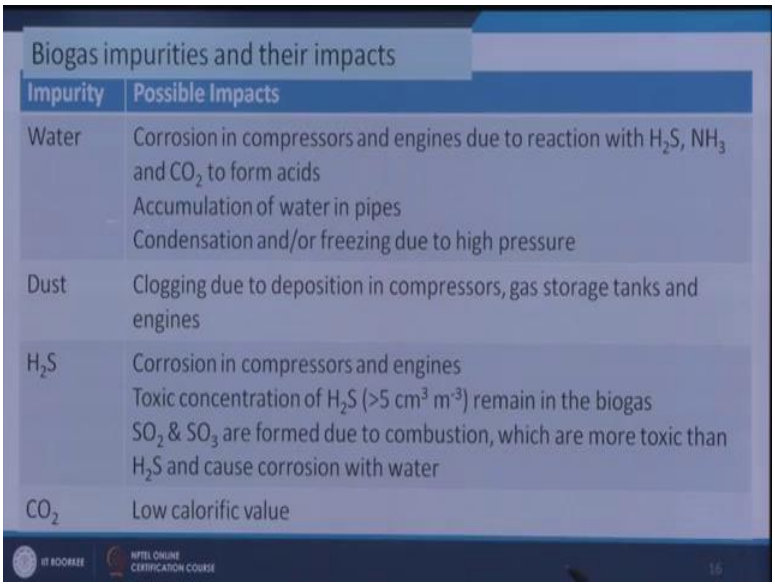

So, maximum gas production in this process will be taking place here maximum gas productions will be taken place here and not only. So, the objective of these 2 different reactors objective of these 2 different reactors are different here to acidogenesis acidic higher molecules will be converted to fatty acids and then here the as actually gas production will take place and gas storage will also be there gas storage will also be there, but here gas storage is not that much important the conventional digester with a floating cover and intermittent mixing this one and whether for high rate this is usually high rate digester with fixed cover and continuous mixing.

So, now we will see; what are the impurities present in the biogas produced from this anaerobic unit? So, from the gas which is produced from this anaerobic digestion unit basically contains methane and carbon dioxide apart from these is also contains some impurities like say water it may contain dust it may contain H2S it may contain CO2.

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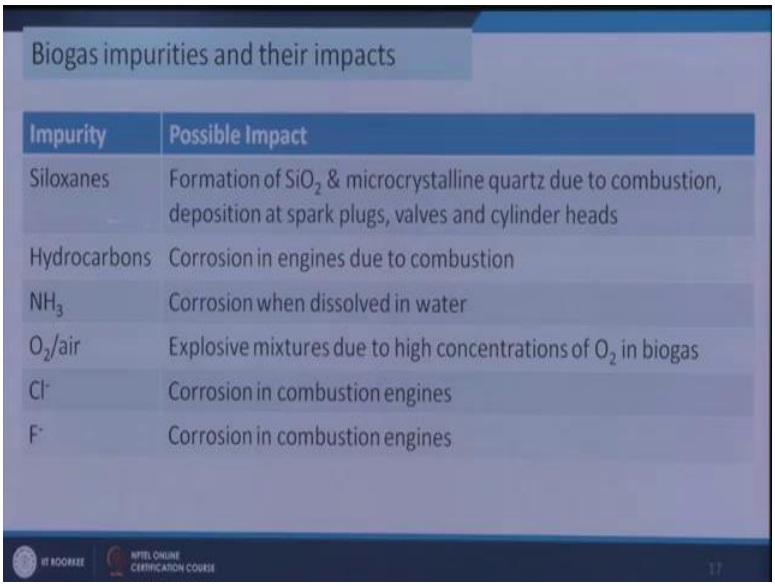

It may contain siloxanes it may contains hydrocarbons it may contains ammonia or oxygen or air or chloride and fluoride all those impurities are present and these impurities have different impact. So, if water is present then when the gas will be used in downstream in an engine. So, that will that water will make corrosion in compressors and engines due to reactions with H2S NH 3 and CO2 to form acids and accumulation of water in pipes another problem is there.

So, condensation and the freezing due to high pressures the water can be condensed and freeze due to high pressures in the line and dust if it is present in the gas. So, that clogging due to deposition in compressor gas storage tanks and engines. So, these are the impact for the dust particles if H2 is present then H2 will also make corrosion in the compressor. And engines and CO 2 will lower the calorific value of this gas and siloxanes that they will form SiO2 when the gas will be combusted and that SiO2 that will be deposited at spark plugs valves and cylinders heads and hydrocarbons will also give some corrosion NH3 will also give corrosion O2 and air if it is present in it.

So, that will be explosive mixtures due to high concentration of O2 in bio gas and chloride and fluoride all will gives the corrosion problems. Now how the moisture can be removed? We have already discussed on the removal of different types of gas components from a gas streams including particulate matters, but we have not discussed on the moisture removal from the gas stream. So, this part is discussed here. So, moisture

from the gas stream can be removed through condensation method demister pad moisture using moisture trap using silica or absorptions with glycol or absorptions with hygroscopic salts.

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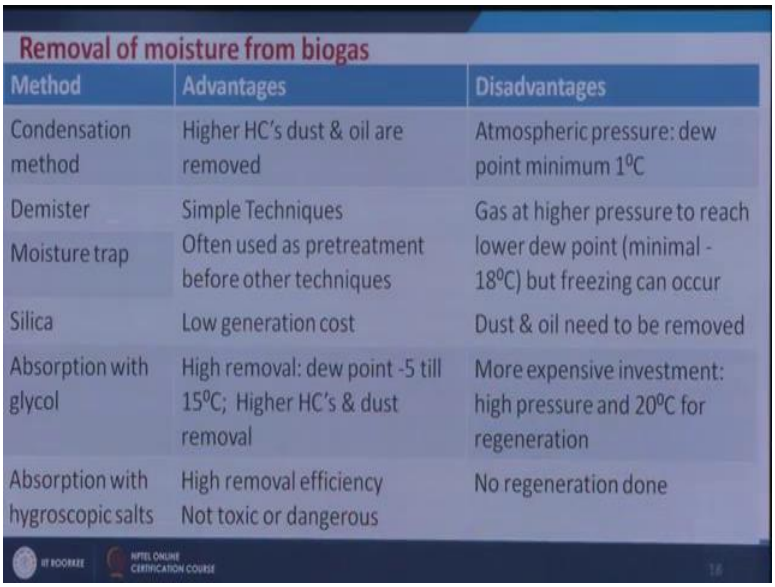

So, all these methods are having their advantage as well as disadvantage. So, advantage and disadvantage of all these processes are provided in this table, now we will discuss on how to calculate the sludge volume in the anaerobic digestion reactor, in an anaerobic digestion reactor or anaerobic digester how the sludge volume can be calculated.

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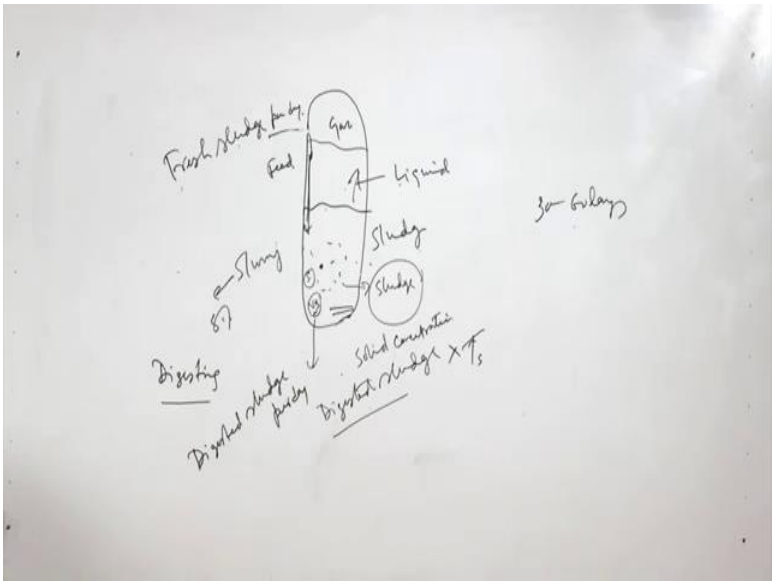

Let us see we have one anaerobic digestion unit we are putting here feed. So, this is a sludge this is a liquid and this is a gas. So, material which is coming inside that is reacted by the microorganisms. So, microorganisms are acting on these substrates which are coming inside it as a result the sludge is formed.

So, this sludge which we are putting that is also slurry that is say 8 percent solid content. So, gradually the liquid is going on. So, concentration of solid concentration will increase we will increase at the bottom part now the sludge which we are getting here we can define it this sludge in terms of 2 types, one is your digesting sludge and another is digested sludge digesting sludge means some materials which has come here suspended solids are volatile volatile solids. So, which is present in the waste, those are being degraded after degradation how much sludge is there that is digested, digested sludge and the sludge which is present in the reactor and micros are reacting on it that is called digesting sludge. So, total sludge is digesting sludge plus digested sludge.

So, now what is the digesting sludge say we have retention time of say 30 to 60 days retention time; that means, the material which is coming out that will stay here for 30 to 60 day and within these 30 to 60 day some sludge is formed that is digested sludge is produced. So, that has to be stored. So, sludge storing is there digested sludge is being stored and digesting sludge is converting per day. So, digestion time into digesting sludge is the total digesting sludge digesting sludge per day into digestion time is the total digestive digesting sludge present in the reactor and digested sludge per day into time for storage times for storage. So, this is equal to total digested sludge.

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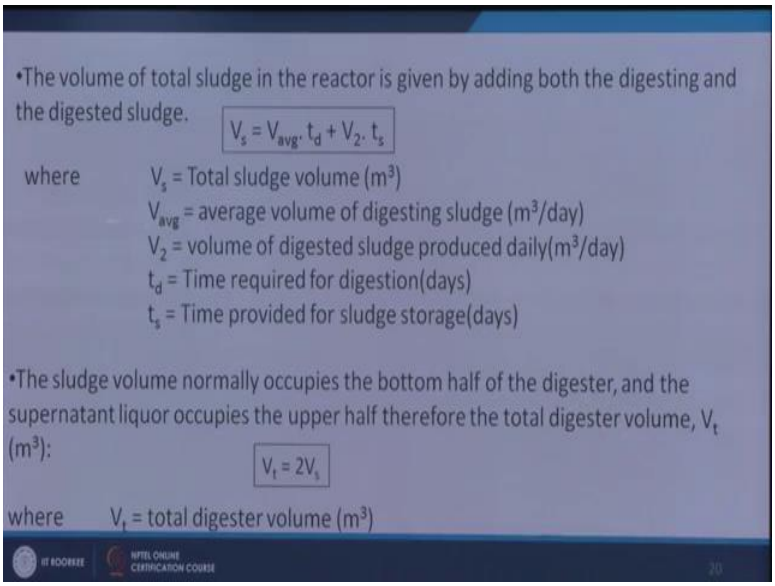

So, that will be the total volume. So, total volume sludge volume will be V average t d V average is averaged volume of digesting sludge and t d is the time required for digestion and t S is time provided for sludge storage and V 2 is volume of digested sludge produced daily per day how much digested sludge is produced into the time provided for sludge storage. So, that is this part and this is for digesting sludge per. So, that is the total sludge; that means, we have to put the sludge certain days inside the reactor that is why the sludge volume inside the reactor will be V S total sludge volume V average in to Td plus V 2 into T s and as you have seen that the lower part is sludge and upper part is liquid. So, we can assume that 50 percent 50 percent is liquid and sludge.

So, in that case total volume will be total digester volume is equal to 2 into Vs2 into Vs. So, now, the question is how can we get the V average how can we get the V average.

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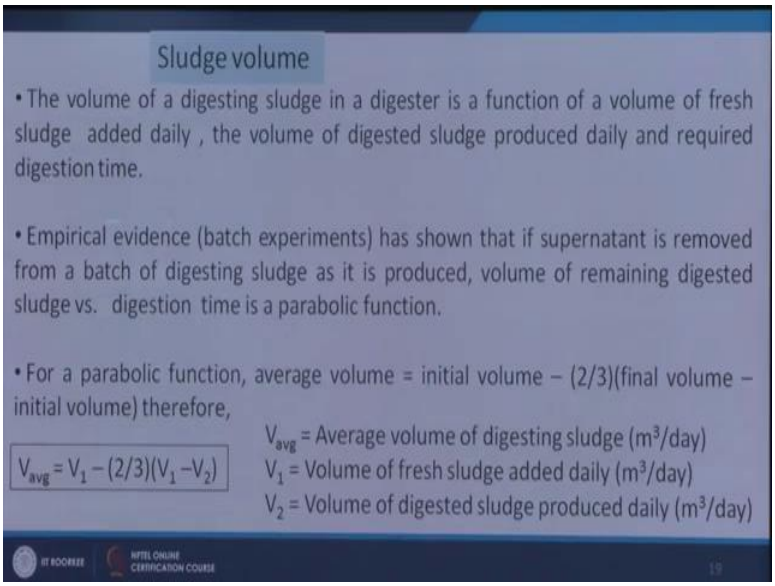

So, V average means the average value of the digesting average volume of the digesting sludge. So, average volume of the digesting sludge will depend upon V one and V 2 how much fresh sludge we are adding daily. So, how much fresh sludge per day how much we are adding and how much digested sludge per day per day. So, these 2 will influence the V average values. So, that V average is had been proved it has been shown in batch reactor that this is in this form that average volume is equal to initial volume minus 2 third of the final volume minus initial volume.

So, if we know the V 1 volume of fresh sludge added daily and V 2 volume of digested sludge produced. So, that will be V average equal to V one minus 2 by third into V 1 minus V 2. So, that way we can get the V average and once we get the V average, we will put here the average V average value here. So, we will get the V s that is the total sludge volume. So, on the total sludge volume the total volume is equal to 2 into V s. So, this is one way to calculate the total volume of the reactor of the anaerobic digestion process and also the sludge volume, up to this in this module.

Thank you very much.