Basic Environmental Engineering and Pollution Abatement
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Lecture 43
Sludge Management - 3

Hello everyone. Now we will discuss on the topic sludge management part 3. And in the previous classes, we have discussed on the sludge management topic and we have discussed different techniques or the sludge treatment methods and then composting as well. And in this class we will be focusing on anaerobic digestion.

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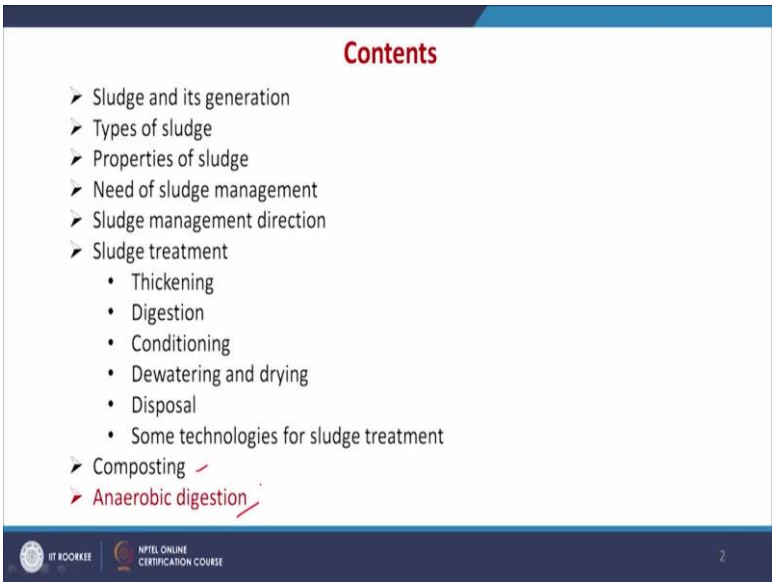

Already we have mentioned in the previous class that anaerobic processes used to digest the sludge, which is followed by dewatering and then drying and disposal etc. Here we will be focusing on the mechanism part, what type of microorganisms are used, what are the kinetics of it, so all those things we will discuss, because this anaerobic digestion is not only applicable for the management of the sludge, this is also applicable for the solid waste management. So we will not cover this in our solid waste management part and we will be discussing this in this class both for sludge as well as the management of the solid waste.

So anaerobic digestion, what is this process? The name itself indicates that it will be happening in absence of oxygen, because it is anaerobic and suddenly it is a biological process, so microbes will be working on the organic compound and will degrade these organic compounds into the lower molecules and ultimately methane and CO_2 containing gas will be obtained. At the same time the water will be losing the COD values and it will be

improving its quality. So what will be remaining after this anaerobic digestion method that slurry, the liquid from the slurry we will be able to separate and that can be used for further treatment and for different application as well.

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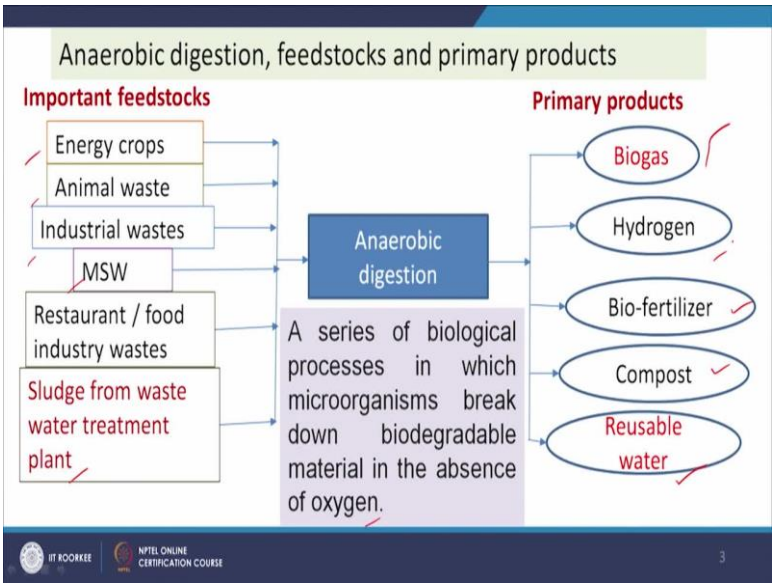

So here you see this anaerobic digestion a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen and different types of feedstocks can be used, like say, energy crops can be, animal waste, industrial waste, MSW, that is municipal solid waste, and then restaurant food industry waste, food industry waste, sludge from wastewater treatment plant. So this is our main focus here, but these other materials can also be the feedstock for this anaerobic digestion process.

And after these reactions will be getting basically the biogas that will be our one important product for the energy recovery from this feedstock and the reusable water. So this water will be having better quality in terms of its regions of BOD, COD, etc. so that will be further treated and used for other application. At the same time the sludge which will be generated here, the solid part that will be used as bio fertilizer, that can be further used for composting and as a compost that can be used and along with the biogas, the hydrogen can also be produced. So this is the advantage of this anaerobic digestion process.

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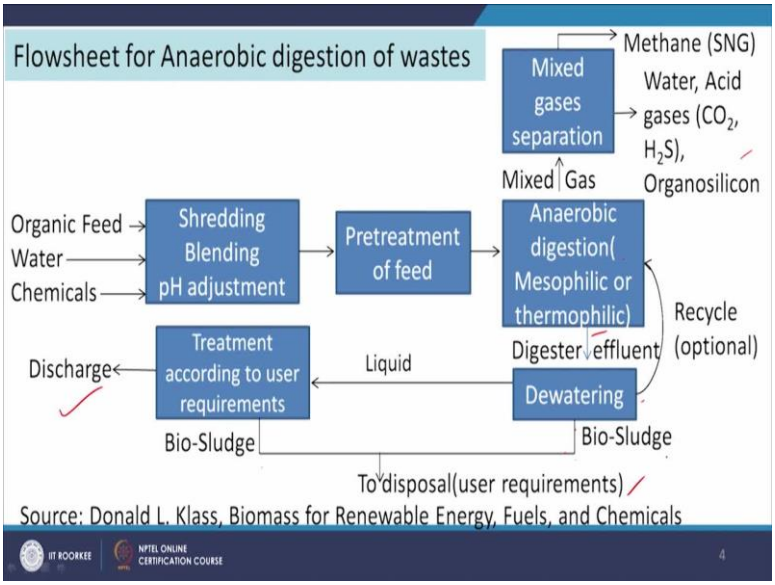

Now, if we want to see the flow sheet of anaerobic digestion of the waste. So then the feed will be there, and then that will be shredding, blending, pH adjustment, so these are the preliminary steps. So sewage sludge can be directly used or that can be mixed with some other feedstocks that is co-digestion can also be possible, so the steps will also be similar shredding, blending and pH adjustment. And then pretreatment of feed depending upon the nature of the compounds present in the sludge as well as in other biomass or other materials were using with it, so that pretreatment will be required.

And after that pretreatment the material will come into the anaerobic digestion chamber and mesophilic or thermophilic condition will be maintained, so that biogas production rate will be more. And then, after biogas production, the biogas will go off from the reactor and that will be purified and will be used for different application. And then which we are having the digester effluent that will be dewatered, so after dewatering we will be getting one liquid.

So liquid will be treated, and then we will be getting the discharge for different application or the sludge will be getting here or dewatered or after dewatering we will be getting sludge and liquids, some part will be recycled, the sludge will be recycled for maintaining the microbial biomass here. And then here the liquid part will be further treated, so here also will be some sludge generation, here will be some bio sludge generation, so both sludge can be disposed or managed through proper route for the production of fertilizer, etc.

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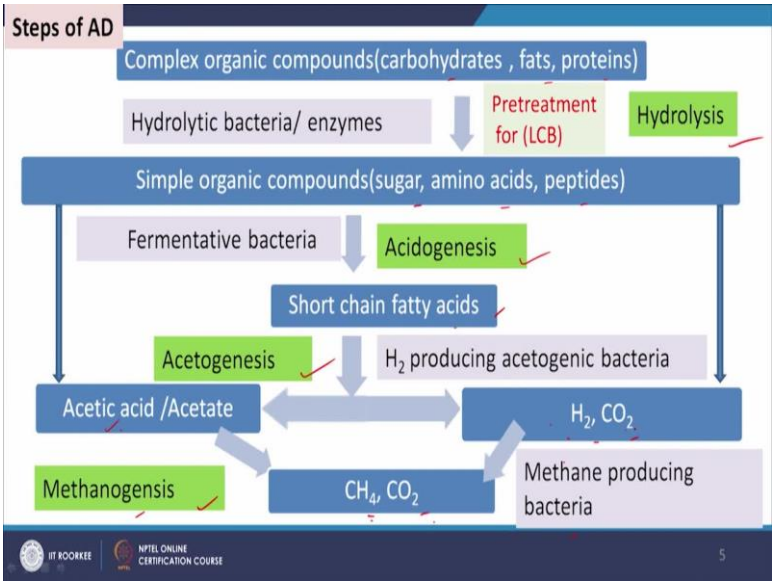

Now, we will see now what is the mechanism or what are the chemistry behind the production of biogas. So if we consider in that way, if we look in this way on the system, then we will see that there will be major 4 steps, one is your hydrolysis, then Acidogenesis, then Acetogenesis and Metanogensis that will also be applicable for the sludge management through anaerobic digestion. And in the previous class, we have also discussed that through thermal hydrolysis followed by anaerobic digestion gives us more biogas production.

So this hydrolysis is necessary to degrade the complex organic compounds into the simple organic compounds like sugar, amino acids and peptides from carbohydrates, fats and proteins. So this is the main role of hydrolysis and if lignocellulosic biomass is used or if it is present with sludge or sludge used with these and for this particular anaerobic digestion process, then pretreatment of the lignocellulosic biomass is needed. And this treatment is requirement.

Then after hydrolysis, the sugar, amino acid and peptides all type of compounds will be converted to source chain fatty acids, and this is called Acidogenesis step or fermentative bacteria, and this hydrolytic and fermentative both microbes simultaneously work and they give the product and ultimately short chain fatty acids generated. At the same time some simple organic compounds are also converted to this acetic acid and similarly H_2 and CO_2.

And then short chain fatty acids that can further converted to acetic acid at H_2 and CO_2. And then acetic acid and acetate will in the later state be converted to methane and carbon dioxide through this methanogenesis step and this H_2 and CO_2 can also be combined and give CH_4

and CO_2 that is methane producing bacteria are responsible for this reaction. So these are the different reactions which are involved for the production of biogas through the anaerobic digestion of the organic compound.

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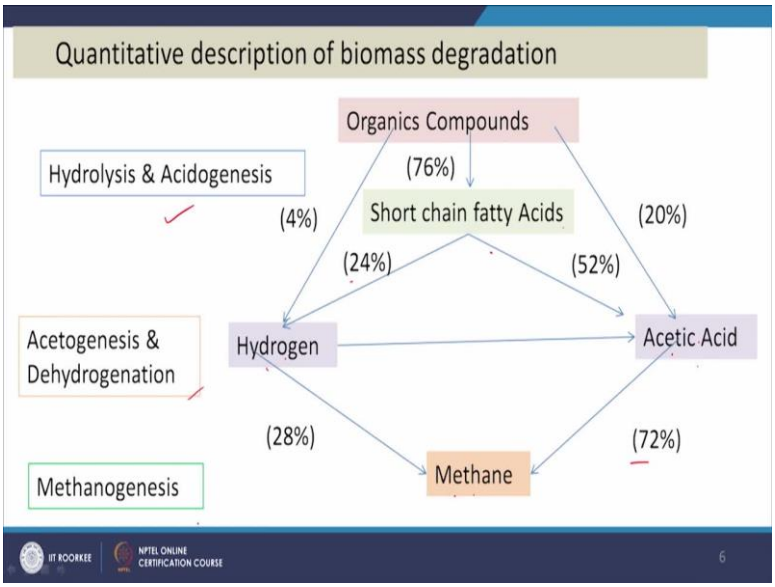

Now we will see the relative contributions of different types of reactions. So if we have organic compounds 100 % out of this 76 % is converted to short chain fatty acids, 20 percent converted to acetic acid, and 4 % to hydrogen out of this 100 %. Then 76 % the short chain fatty acids out of these 52 % is converted to acetic acid and 24 % is converted to hydrogen. Now from this hydrogen to methane, and acetic acid to maintain this reaction if we consider around 72 % methane is produced through the acetic acid root and then 28 % through the hydrogen root. So these are the relative contribution of different processes, these are some typical values provided in literature that may vary also. So this type is hydrolysis and acidogenesis, this is acetogenesis and dehydrogenation and this is your methanogenesis step.

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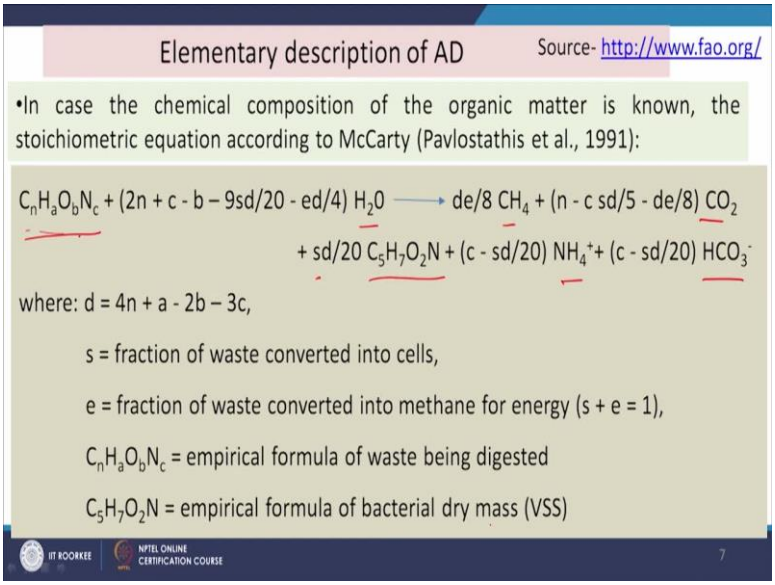

Now, we will see how can we mathematically represent these chemical reactions. So as it is involving the microbial growth and the degradation of the organic compound, the chemistry or the biology is not very well known, basically on modeling point of view. So some empirical models have been used, like say this is our composition of the feedstock

$$C_nH_aO_bN_c + (2n + c - b - 9sd/20 - ed/4)\ H_20 \rightarrow de/8\ CH_4 + (n - c\ sd/5 - de/8)\ CO_2 + sd/20 C_5H_7O_2N + (c-sd/20)\ NH_4^+ + (c - sd/20)\ HCO_3^-$$

So these are the different products which you are getting through the anaerobic digestion process from the organic feedstocks.

And these different coefficients have been proposed and the relationship has also been given here, where s is the fraction of the waste converted into cells, so this what s value we are considering. And e is the fraction of waste converted into methane for energy that is (s + e = 1) and d = (4n + a - 2b - 3c), n, a, b, c are nothing but the molar ratio of this in a feedstock. And then $C_nH_aO_bN_c$, this is empirical formula of the waste being digested and $C_5H_7O_2N$ empirical formula of bacterial dry mass.

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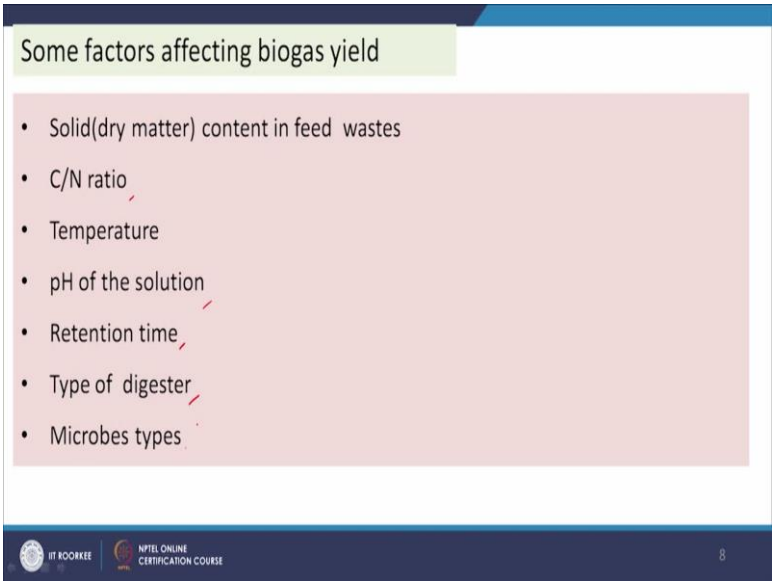

Now, we will see different factors which influence the performance of anaerobic digestion. So in this case solid or dry matter content in the feed wastes, so what are the solid content in the feed? Now it may be sludge, it may be any slurry containing any organic compound or biomass etc. And then C/N ratio what is the carbon to nitrogen ratio, so that was 25 to 30 we have discussed in the previous class. And then temperature that is also important because for the growth of microorganisms certain temperature is required, and pH of the solution that is also important because microbes are susceptible to the pH of the solution.

And retention time that requires for the degradation of the organic compounds, and type of digester what type of digester we are using, single step, or 2 step, so that will also influence the performance. And then whether we are getting we are using a upflow sludge blanket reactor or simple anaerobic digestion reactor or any other modified form with superior performance, so that will be type of digester. And microbes types, what types of microbes you are using? There are diversified microbes, and they are having different capacities, so what type of microbes we are using that will also influence the performance of the process.

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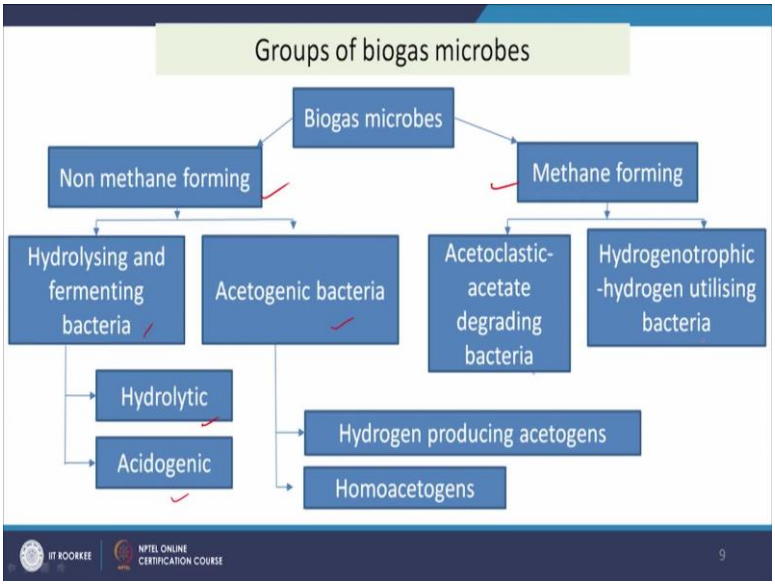

Now, we will see here different groups of biomass microbes. So biomass microbes can be methane forming or non-methane forming, and non-methane forming basically, that will be for hydrolyzing and fermenting bacteria and acetogenic bacteria. So this hydrolysis and fermenting bacteria, fermenting bacteria are basically called acetogenic bacteria and these hydrolyze is called hydrolytic bacteria. And acetogenic bacteria we have 2 types of acetogenic that is hydrogen producing acetogens and homoacetogens. And here for methane forming there are 2 types of reactions we have seen. So one was acetoclastic acetate degrading bacteria and another your hydrogenotrophic that is hydrogen utilising bacteria. So these are the different types of microorganisms or bacteria which are used for the anaerobic digestion process.

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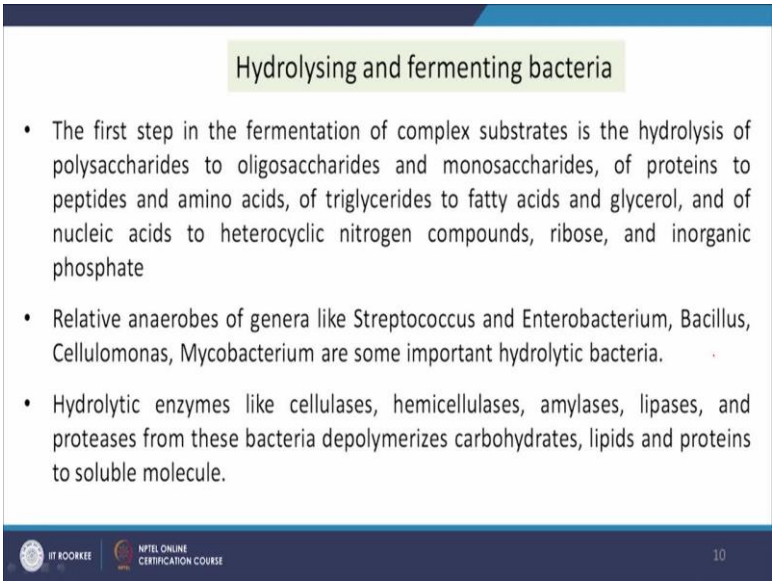

Now, we will see hydrolyzing and fermenting bacteria. So hydrolyzing bacteria hydrolyzes the complex organic compound and converts it into simple sugar like say, the first step of the fermentation of complex substrate is the hydrolysis of the polysaccharides to oligosaccharides and monosaccharides of proteins to peptides and amino acids, of triglycerides to fatty acids and glycerol, and of nucleic acid to heterocyclic nitrogen compounds, ribose, and inorganic phosphate.

Then relative anaerobes of genera like streptococcus and enterobacterium, bacillus, mycobacterium are some important hydrolytic bacteria. So hydrolytic enzymes like cellulases, hemicellulases, amylases, lipases, and proteases from these bacteria depolymerizes carbohydrates, lipids and proteins to soluble molecule.

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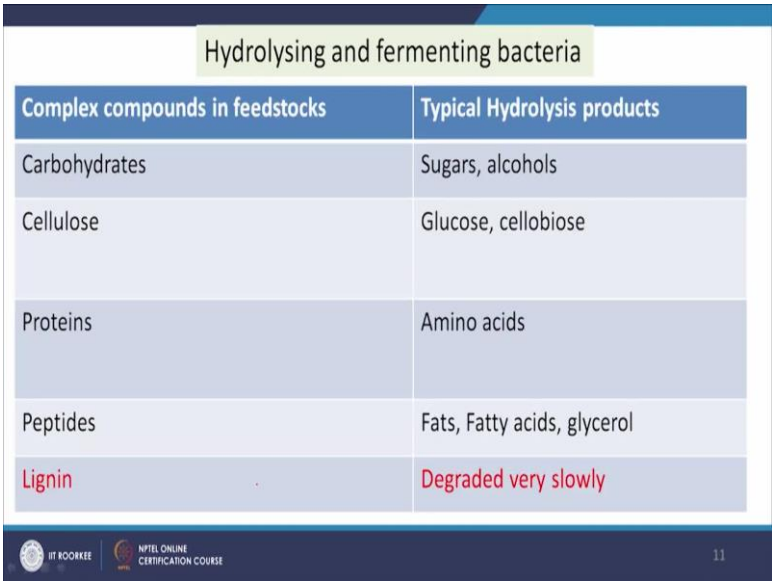

These are some examples say for carbohydrates, cellulose, proteins, peptides, lignin, will be converted into different hydrolyzed products as given here, like say sugar, and alcohols from carbohydrates, glucose, cellobiose from cellulose, amino acid from proteins, fats, fatty acids glycerol from peptides, but in case of lignin, deradation will be very less.

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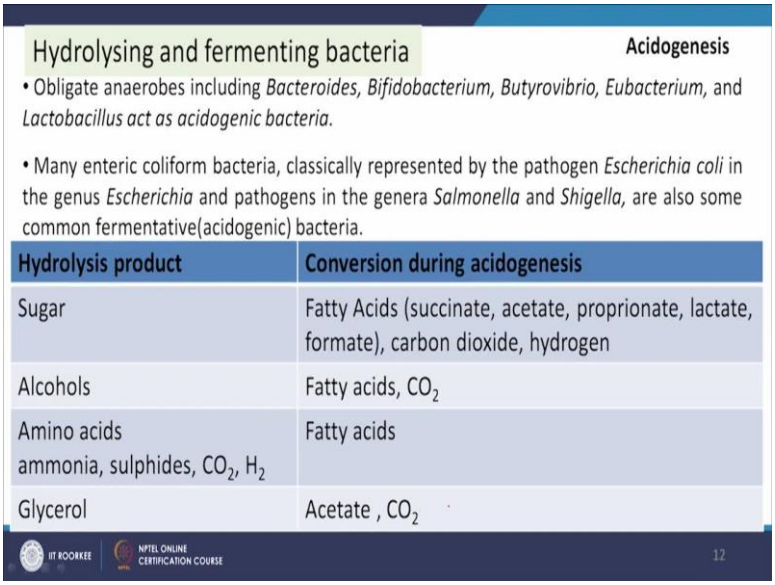

And there are some microorganisms which are responsible for the acetogenic reactions acidogenesis that means, the simple organic compounds which are produced like sugar, fat, lipid etc. So those will be converted to fatty acids, short chain fatty acids, so that is the role of the estrogenic bacteria. And obligate anaerobes including bacteroides, bifidobacterium, butyrovibrio, eubacterium and lactobacillus act as acetogenic bacteria. Many enteric coliform

bacteria classically represented by the pathogen Escherichia coli in the genus Escherichia and pathogens in the genera Salmonella and Shigella are also some common fermentative or acetogenic bacteria both fermentation and acetogenic reaction can be performed by these microorganisms.

And after these both reactions, that is hydrolysis and acetogenic reactions, sugar will be converted to fatty acids, that is succinate, acetate, propionate, lactate, formate, carbon dioxide and hydrogen, alcohols will be converted to fatty acid and CO_2, and amino acid ammonia, sulfides, CO_2, H_2 will be converted to fatty acids, glycerol will be converted to acetate and CO_2.

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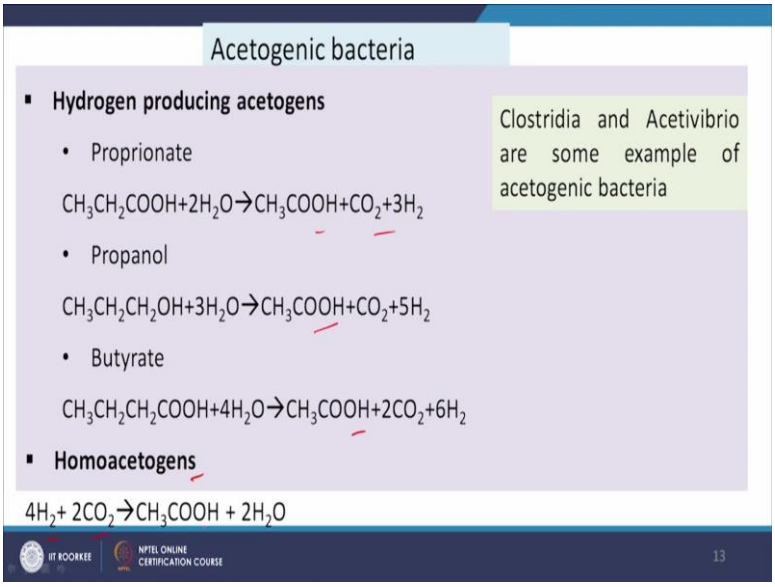

Then we will see the acetogenic bacteria that free fatty acids will be converted to acetate now by this action of these microorganisms or may be converted to H_2 and CO_2 and that H_2 and CO_2 will be converted to acetate, so there are 2 routes. So hydrogen producing acetogen, so that is like clostridia and acetivibrio are some example of acetogenic bacteria that is propionate will be converted to acetate and CO_2 + CH_2, propanol again will be converted to acetic acid and butyrate will also be converted to acetic acid and homoacetogens this is other type of microorganisms that is H_2 and CO_2 will be combined and that will be converted to CH_3COOH.

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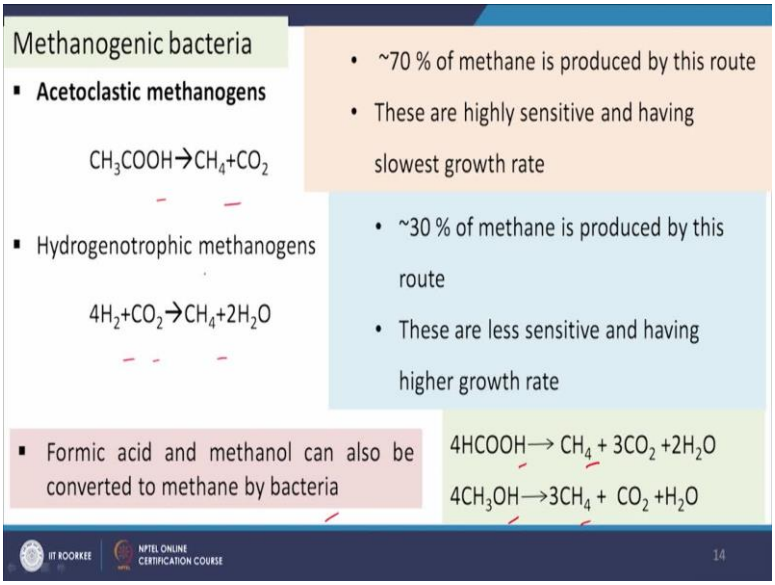

And then the last type of microorganisms which are also responsible for the methane formation from the acetate or from the CO_2 and H_2. So the acetoclastic methanogens, so they convert acetic acid or acetate to methane and CO_2, and hydrogenotrophic methanogens hydrogen $4H_2 + O_2 \rightarrow CH_4 + 2H_2O$. And formic acid and methanol can also be converted to methane by bacteria like formic acid to methane and methanol to methane also possible by some bacteria like say enteric bacteria. And 70 % of methane is produced by this route that is acetoclastic methanogens and 30 % of methane is produced to the hydrogenotrophic methanogens.

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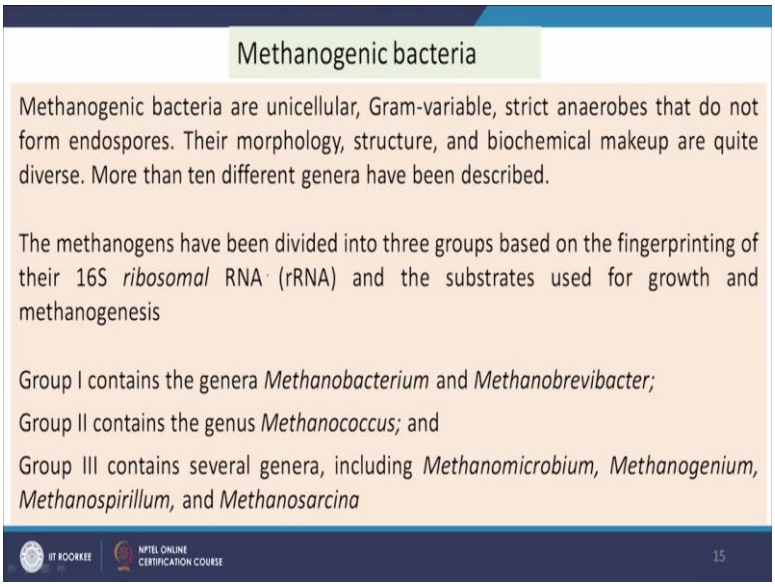

And methanogenic bacteria, some methanogenic bacteria are unicellular, gram variable, strict anaerobes that they do not form endospores, their morphology structure and biochemical makeup are quite diverse. More than 10 different genera have been described. The methanogens have been divided into 3 groups based on the fingerprinting of their 16S ribosomal RNA and the substrates used for growth and methanogenesis. Group 1 contains the genera methanobacterium and methanobrevibacter. Group 2 contains the genus methanococcus and group 3 contains several genera including methanomicrobium, methanogenium, methanospirillium and methanosarcina.

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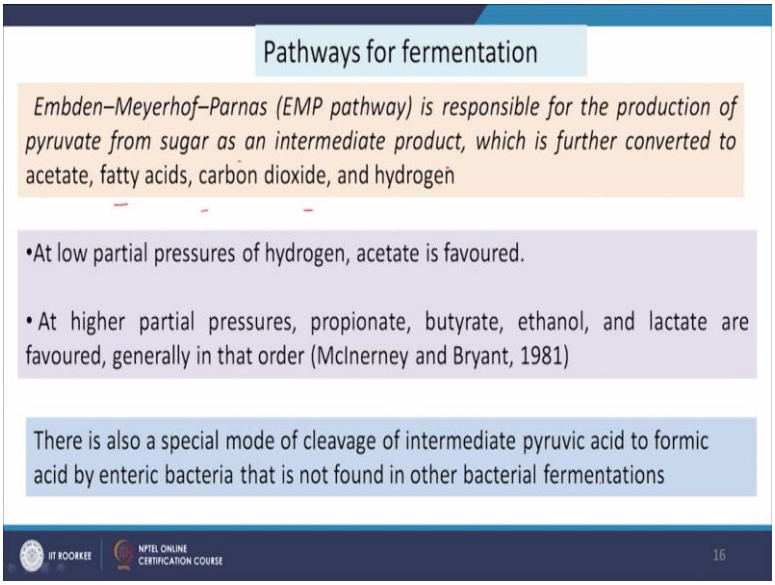

So what do we see that sugar, fatty acid, amino acid all compound are converted to acetic acid. So this conversion takes place through the EMP pathway that is Embden Meyerhof Parnas pathway it is responsible for the production of pyruvate from sugar as an intermediate product, which is further converted to acetate, fatty acids, carbon dioxide, and hydrogen. At low partial pressure of hydrogen acetate is favored, but partial pressure is hydrogen if more then butyrate, propionate, these type of products are preferable or favored generally in that order. There is also a special mode of cleavage of intermediate pyruvic acid to formic acid by enteric bacteria that is not found in other bacterial fermentations. So formic acid to meet information can take place only by the enteric microorganisms.

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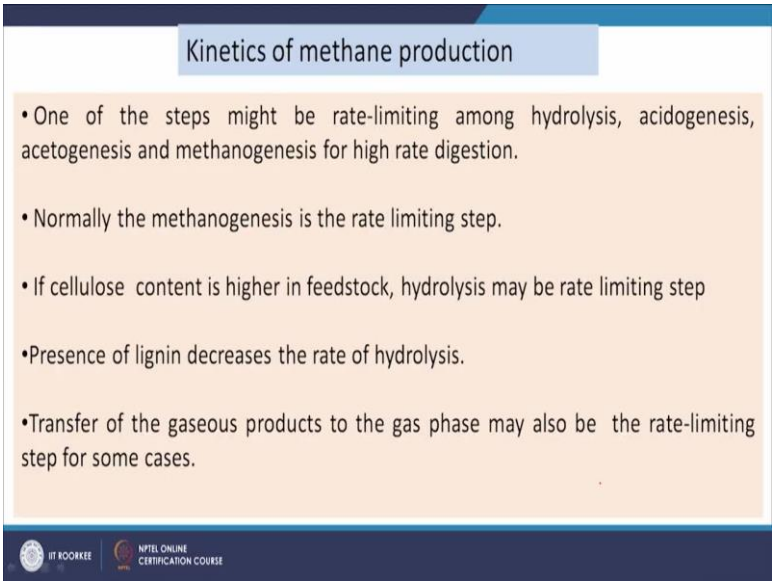

Now we will discuss on the kinetics of methane production. So we have seen that methane production takes place through number of steps. So any of the steps may be slower step and the rate of that slow step will be controlling the rate of the overall process. So normally, the methane production step is very slow with respect to other steps and that is rate governing step. But if cellulose content is very high in a feedstock, then the hydrolysis step may also take more time and if it is say if lignocellulosic biomass is present after pretreatment also that we will be having more cellulose, hemicellulose etc. So that will also be having more hydrolysis step, the hydrolysis step maybe longer. So that way, but in general for simple type of compounds, the methanogenic step is rate limiting step.

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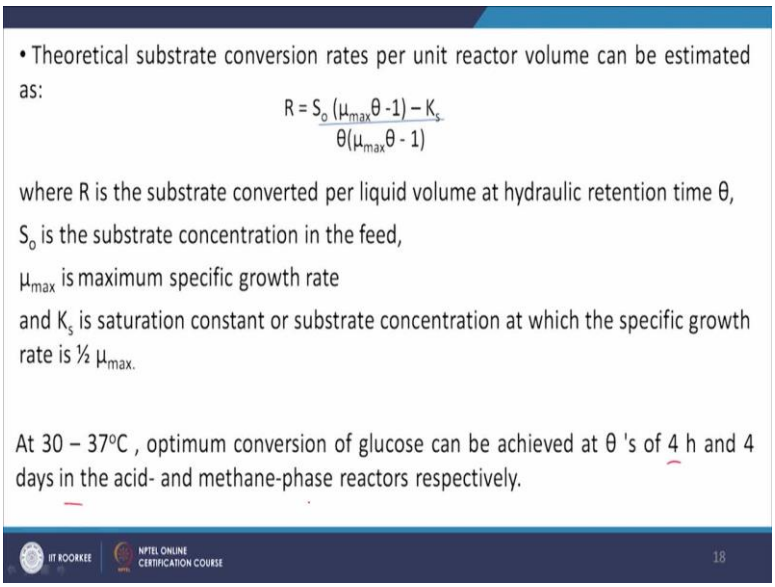

And the theoretical substrate conversion rates per unit reactor volume can be estimated by this formula,

$$R = \frac{S_o\ (\mu_{max}\theta - 1) - K_s}{\theta\ (\mu_{max}\theta - 1)}$$

Where R is the substrate converted per liquid volume at hydraulic retention time theta and S_o is the substrate concentrations in the feed, and μ_{max} is maximum specific growth rate, and Ks is saturation constant or substrate concentration at which the specific growth rate is half of Q max. At 30 to 70 ^oC optimum conversion of glucose can be achieved at theta's value of 4 hour and 4 days in acid and methane phase reactors respectively. So it is very clear that methanogenic step takes longer period and it is a rate limiting step for the glucose.

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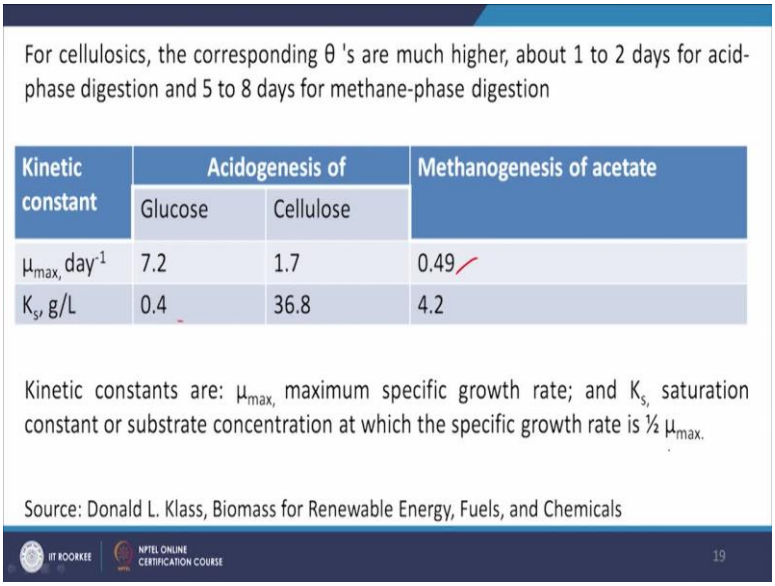

So this table shows some values for glucose and cellulose the μ_{max} and Ks values. So here μ_{max} is more for glucose than cellulose and Ks value is less for glucose than cellulose, this indicates that the glucose is more easily degradable than the cellulose. And whereas in case of methanogenic step so you see the μ_{max} is 0.49 and 4.2 for methanogenesis of acetate. So that way this is slower step with respect to all. Kinetic constant μ_{max} maximum specific grow rate, Ks saturation constant of substrate concentration at which this specific growth is half of the μ_{max}.

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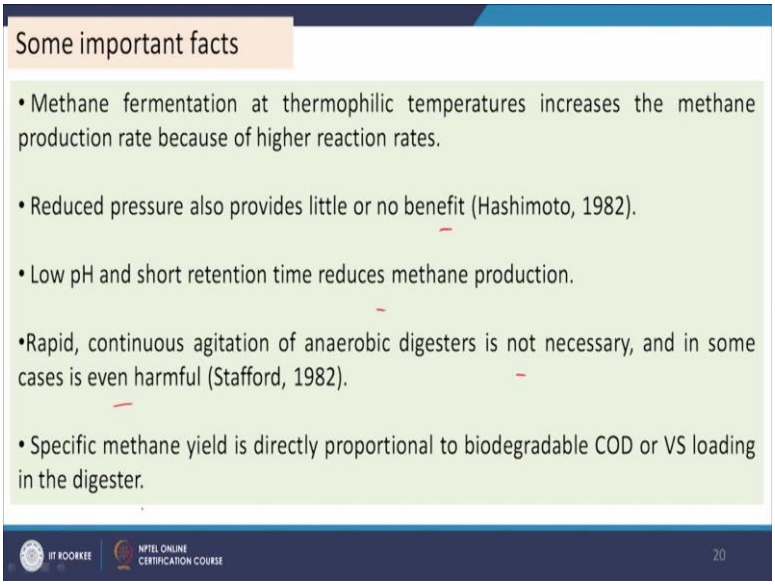

Now we will discuss about some important facts, like say methane fermentation at thermophilic temperatures increases the methane production rate because of higher reaction rates, higher the temperature we get more methane production. And reduced pressure also provides little or no benefit. Low pH and short retention time reduces methane production and rapid continuous agitation of anaerobic digester is not necessary, and in some cases is even harmful. We will see that agitation or slight mixing is needed, but vigorous mixing or agitation is not needed, it reduces the performance of the reactor. And specific methane yield is directly proportional to the biodegradable COD or VS loading in the digester.

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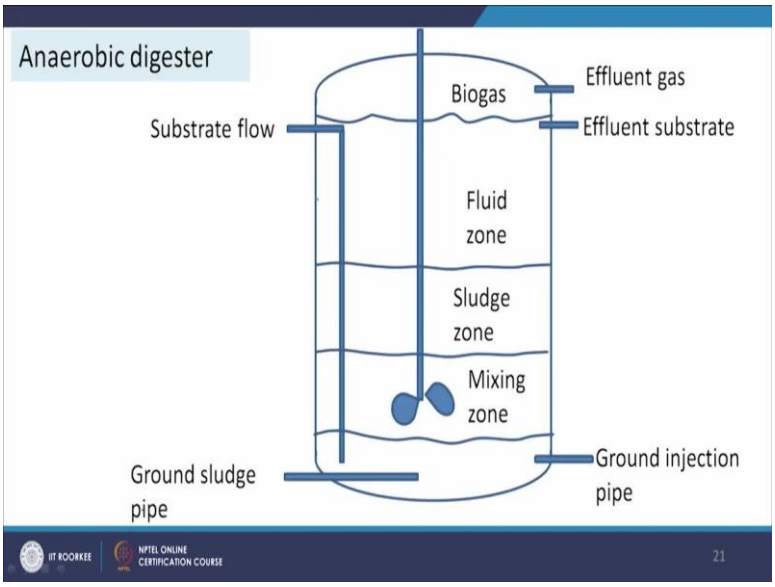

And if we see the digester, then we will get different layers like say, we will be having one mixing zone, then here we will be having the sludge zone, and then we are having fluid zone and then biogas. And from at the bottom we will be having ground sludge and ground sludge we can take it out from it and from the top will get effluent substrate and the topmost portion is the biogas collection and the biogas is collected and used for different applications. So these are the different layers. So if we do not mix it here, so there is some sort of stratification, so to maintain the uniformity, some mixing is necessary.

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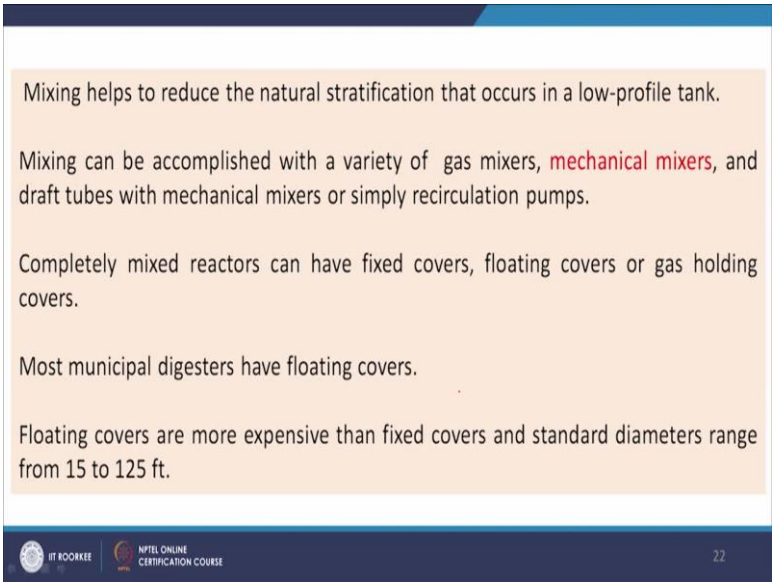

So mixing helps to reduce the natural stratification that occurs in a low profile tank. Mixing can be accomplished with a variety of gas mixers, that mechanical mixers and draft tubes with mechanical mixers or simply circulation pumps, but we will not provide oxygen for this purpose, because that will be detrimental to the microorganisms and the production of biogas. And completely mixed reactors can have fixed covers, floating covers or gas holding covers. Most municipal digesters have floating covers and floating covers are more expensive than fixed covers and standard diameters range from 15 to 125 feet.

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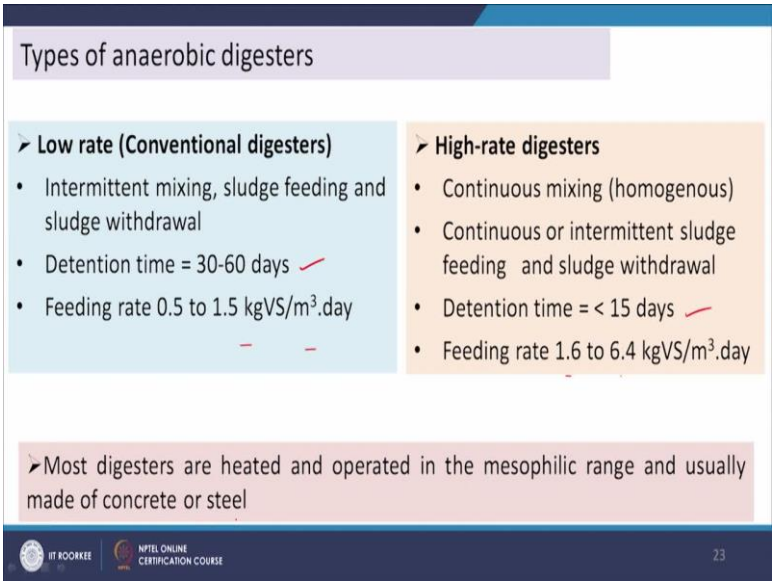

And we can get 2 types of anaerobic digesters, one is low rate and other is high rate digesters, low rate means its capacity or throughput is less, its detention time is more and in case of high rate the retention time is less that is less than 15 days whereas, it was for low rate 30 to 60 days. And feeding rate in case of low rate is 0.5 to 1.5 kg volatile solid/m^3-day. Whereas or high rate this is 1.6 to 6.4 kg volatile solid/m^3-day. So most digesters are heated and operated in the mesophilic range and usually made of concrete or steel.

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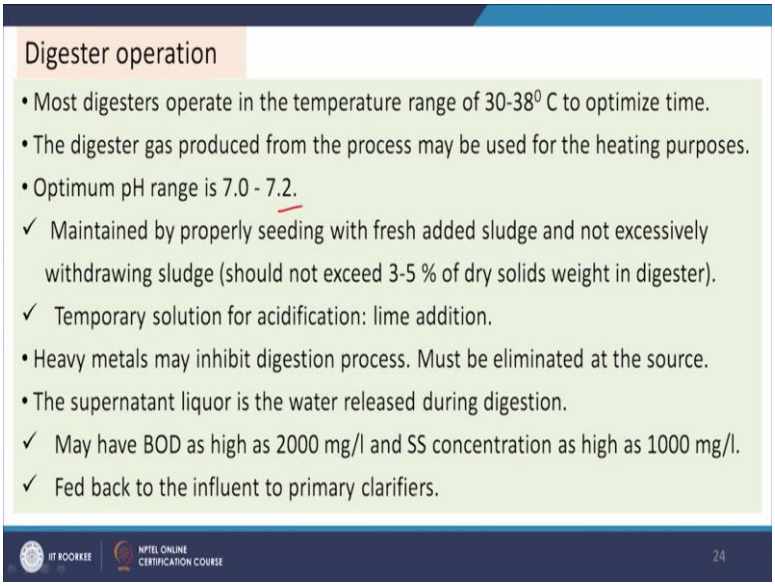

And regarding digester operation. If it is a single chamber digester, then the pH is maintained around 7 to 7.2. And maintained by properly seeding with fresh added sludge and not excessively withdrawing sludge, should not exceed 3 to 5 % of dry solid weight in the

digester. And temporary solution for acidification can be done by adding lime addition, so if pH changes then you can add temporarily some lime addition. And heavy metals may inhibit digestion process, so must be eliminated at the source. The supernatant liquor is the water released during digestion and this can content BOD, COD as high as say 1000 mg/l, COD and 2000 mg/l BOD, so that requires further treatment for utilization in different application.

So sludge when we will be going through the anaerobic digestion, so that will be giving us the supernatant liquid that requires further treatment. But by this process we get some solid so that is useful and we also get biogas from it. The water which we are getting here, that can be feed back to the influent to the primary clarifiers. So again, it will be entering to the effluent treatment plant.

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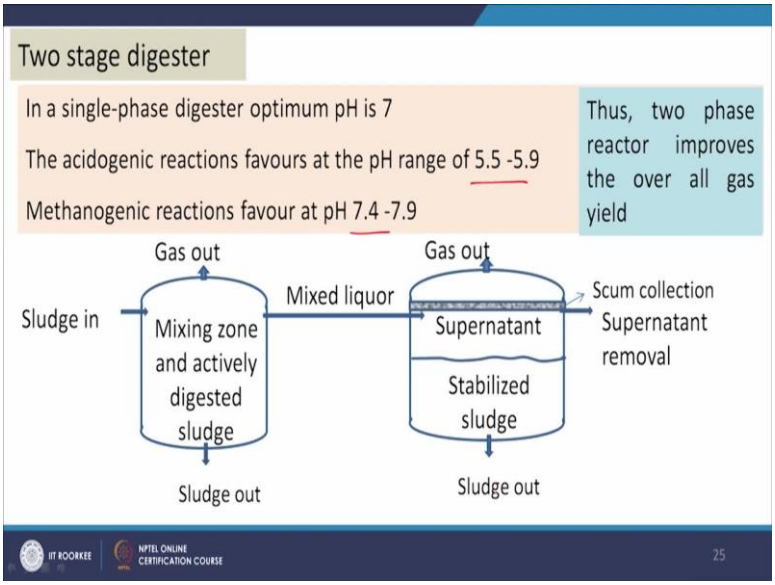

And in single step reactor, there are some disadvantages, because we see that in case of acetic reactions that is acetogenic and acetogenic reaction that happened at lower pH high rate methanogenic reaction takes place at higher pH. So the acetogenic reaction favors at 5.5 to 5.9 pH, whereas the methanogenic reaction takes place at 7.4 to 7.9. So if we can perform these 2 different types of reactions in 2 reactors are 2 different pH value so the performance in both the reactors will be high as a result the overall performance of the process will be very high, unlike in a single step maintaining pH 7 or 7.2.

So that is the in the in this case, the first step, the biogas is produced in the acetogenic phase and then the liquor is sent in to the second stage, second stage the methanogenic reaction takes place and we get the biogas from both the cases and it is collected and is used. And

sludge is generated in both the reactor as well. So after this in this class, thank you very much for your patience.