Biomass Conversion and Biorefinery
Prof. Kaustubha Mohanty
Department of Chemical Engineering
Indian Institute of Technology - Guwahati

Lecture – 29
Biogas Technology, Fermenter Designs, Biogas Purification

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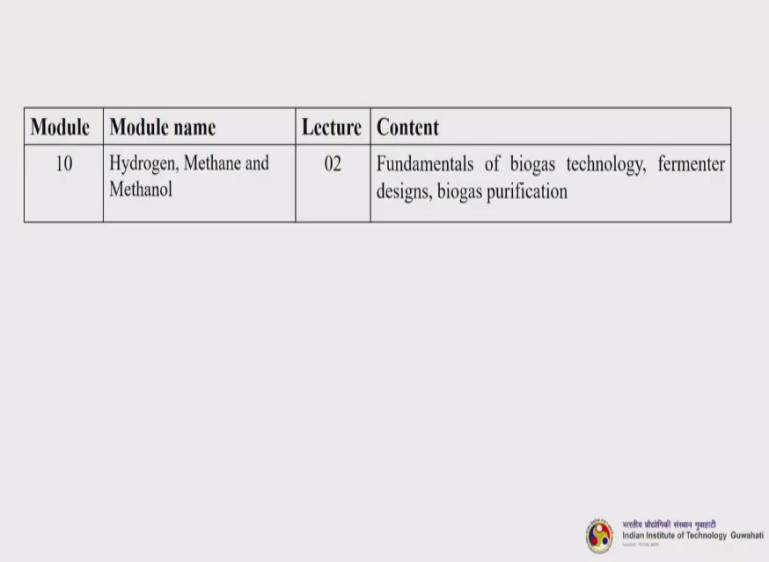

Good morning students. Today is lecture 2 under module 10. As you know that we are discussing hydrogen, methane and methanol in this particular module. And in today's lecture we will be basically discussing about the fundamentals of biogas technology that includes the different types of microorganisms, what are the process conditions, then what are the different types of fermenters that can be used or has been used and how do you purify biogas once it is produced, because as you know that you cannot use directly the biogas that is getting generated into some application. So let us begin.

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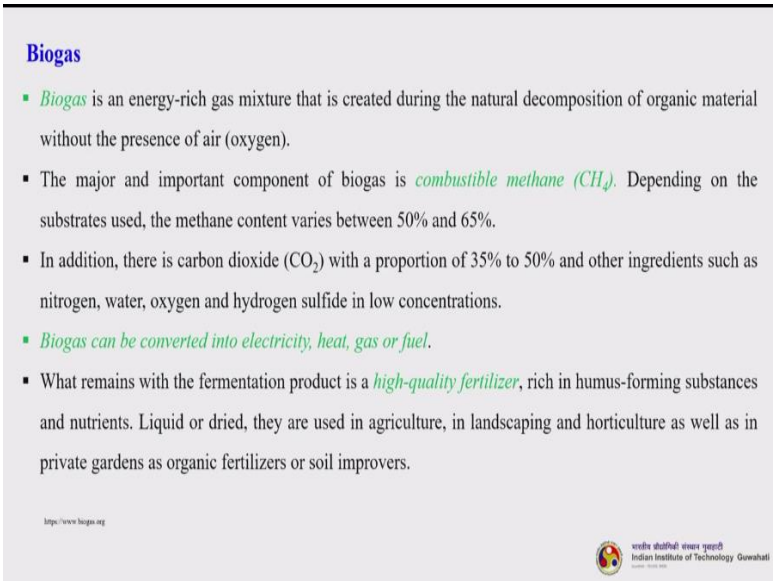

Fundamentals of the biogas process. So, biogas is an energy rich gas mixture that is created during the natural decomposition of organic material without the presence of air or we can say precisely oxygen. The major and important component of biogas is the combustible methane. Depending on the substrates used, methane content varies between 50% to 65%.

In addition, there is also carbon dioxide with a proportion of almost 35 to 50%, the second major component after methane of course. Apart from carbon dioxide, there are other ingredients also which are present in very minuscule quantities such as nitrogen, water, oxygen and hydrogen sulfide. Especially hydrogen sulfide creates lot of problem but it is present in low concentrations. However, for certain applications you need to scrap it.

Now, biogas can be converted into electricity, heat, gas or fuel. What remains with the fermentation product is a high quality fertilizer - that means after the gas is produced whatever left out is the solid residue that is actually a good quality fertilizer. It is very rich in humus-forming substances and nutrients. Liquid or dried, they are used in agriculture, in landscaping and horticulture as well as in private gardens as organic fertilizers or soil improvers or soil enhancers.

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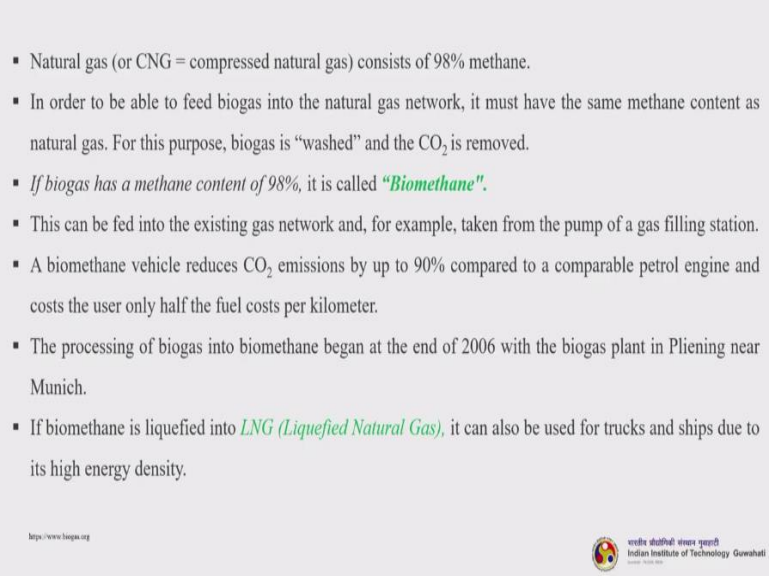

Natural gas consists of 98% methane. Now, in order to be able to feed biogas into a natural gas network, it must have the same methane content as the natural gas that means 98%**.** Now for this purpose biogas is washed and the carbon dioxide is removed so that methane content increases. Now, if biogas has a methane content of 98%, it is called biomethane. You must have heard about biomethane many times.

Many people get confused about what is the difference between biogas and biomethane. So essentially if biogas contains 98% methane we can call it biomethane. Now this can be fed into the existing gas network and for example taken from the pump of a gas filling station. A biomethane vehicle reduces carbon dioxide emissions by up to 90% compared to a comparable petrol engine and cost the user only half of the fuel cost per kilometer.

The processing of biogas into biomethane began at the end of 2006 with the biogas plant in Pliening near Munich in Germany. So if biomethane is liquefied into liquefied natural gas that is LNG, it can also be used for trucks and ships due to its high energy density.

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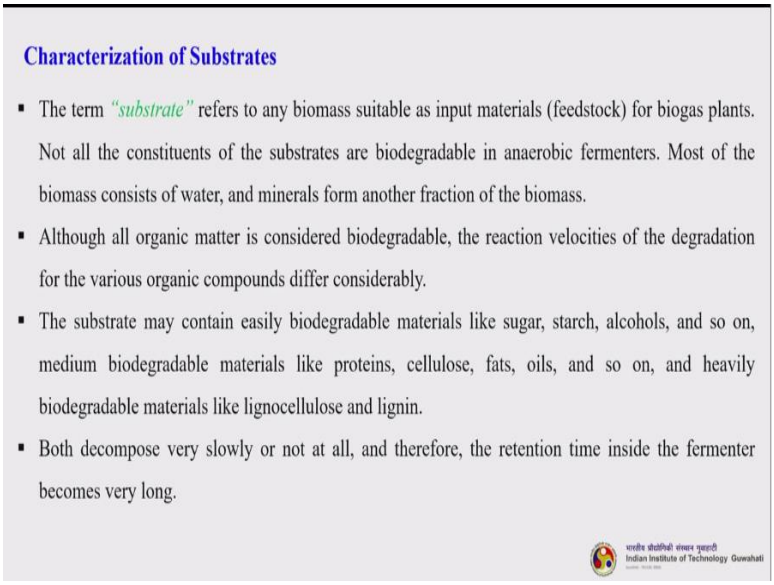

Now, we will try to understand the characterization of the substrates; what type of characterization they require for the substrates or we can say basically the feedstocks for the biogas plants. So the term substrate refers to any biomass suitable as an input material (feedstock) for the biogas plants. Not all the constituents of the substrates are biodegradable in an anaerobic fermenter.

Most of the biomass consists of water, and minerals form another fraction of the biomass. So although all organic matter is considered biodegradable, the reaction velocities of the degradation of various organic compounds differ considerably. The substrate may contain easily biodegradable material likes sugar, starch, alcohols, and so on; then medium biodegradable materials such as protein, cellulose, fats, oils, and so on.

And then heavily biodegradable materials like lignocellulose and lignin. Now, both decompose very slowly that means the lignocellulose and lignin and sometimes not at all and therefore the retention time instead of the fermenter becomes very long due to the slow decomposition of these particular components.

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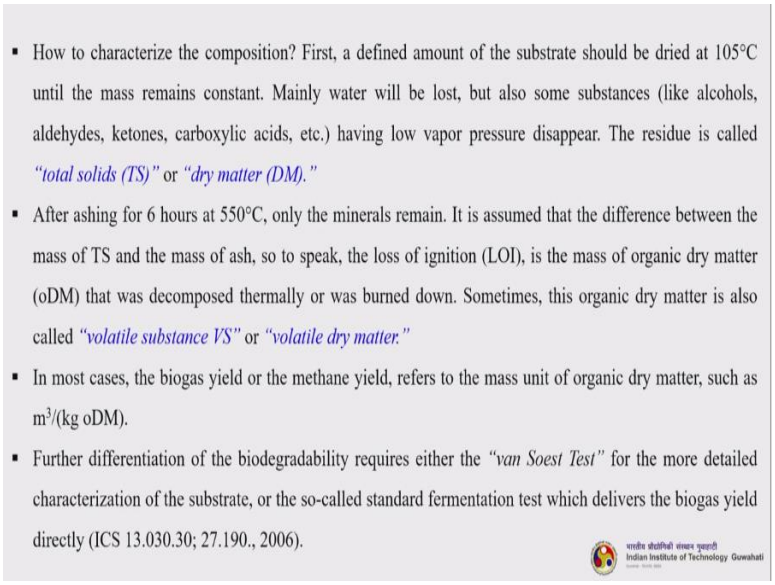

How to characterize the composition? First a defined amount of substrates should be dried at 105 degrees centigrade until the mass remains constant. So I am just trying to explain the procedure to characterize the substrates. Mainly water will be lost but also some substances such as alcohols, aldehydes, ketones, carboxylic acid, etc., all organic components, having low vapour pressure they will be disappear.

Now, this residue is called total solids or dry matter. So, you can write either TS which is more appropriate or many times people write dry matter also. Now, after ashing for 6 hours at 550 degrees centigrade, only the minerals will remain. It is assumed that the difference between the mass of the total solid and the mass of the ash, so as to speak, the loss of ignition is the mass of the organic dry matter that was decomposed thermally or was burned down.

Sometimes, this organic dry matter is also called the volatile substances (VS) or volatile dry matter. In most of the cases, the biogas yield or the methane yield refers to the mass unit of organic dry matter such as meter cube per kg of oDM, oDM is organic dry matter. Further differentiation of the biodegradability requires either the *van Soest* test for the more detailed characterization of the substrate or the so called standard fermentation test, which delivers the biogas yield directly.

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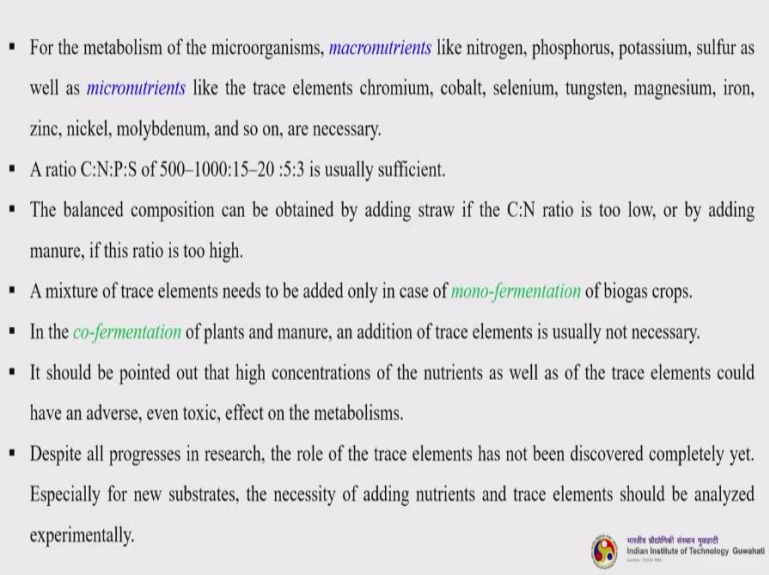

So, for the metabolism of the microorganisms, macronutrients like nitrogen, phosphorus, potassium, sulfur as well as certain micronutrients such as trace elements of chromium, cobalt, selenium, tungsten, magnesium, iron, zinc, nickel, molybdenum and so on are utmost necessary. A ratio of C:N:P:S of 500-1000:50-20:5:3 is usually sufficient. Now, the balanced composition can be obtained by adding raw straw if the C by N ratio is too low or by adding manure if this ratio is too high.

So, we are learning actually how do you prepare the feedstock material and charge the fermenter so that the anaerobic digestion can proceed. A mixture of trace elements needs to be added only in the case of mono-fermentation of biogas crops. While in the case of co-fermentation of plants and manure, an addition of trace elements is usually not necessary.

It should be pointed out that high concentrations of the nutrient as well as that of the trace elements could have an adverse, even toxic effect on the metabolism of the microorganisms those are responsible for producing biogas. Now, despite all progresses in research, the role of the trace element has not been discovered completely yet. Especially for the new substrates, the necessity of adding nutrients and trace elements should be analyzed experimentally.

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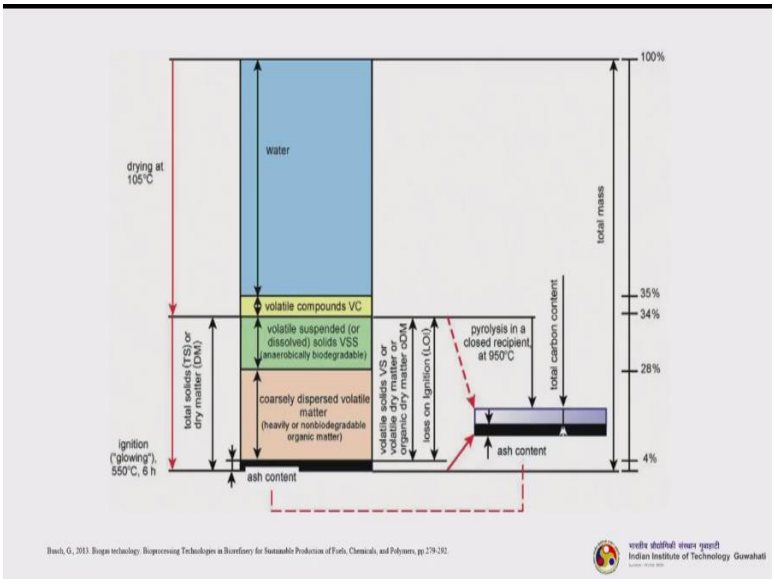

Now, this is a very interesting slide in which the authors, actually I have given reference here. You can see this, you can download and read later on of course. This is very interesting, in a single schematic representation, the authors have tried to make us understand that what are the different types of characterization processes and what temperature it will be carried out.

So, if you see this, the temperature is increasing in this direction and there the total mass is 100% and the mass is getting decreased in this direction or you can say that unit. So, if you see, most of the percent is almost 34 to 35%**.** So, this is entirely actually if you see it is 35%**,** so rest 65% is the water loss or the moisture loss or loss due to bound and unbound moisture you can say. Then small portion, this yellowish portion almost 2 to 3% that is due to the volatile compounds.

And volatile suspended or dissolved solids (VSS) again another 15 to 20% in that range. Then while we come down, so almost 24% here this is coarsely dispersed volatile matter, heavily or non biodegradable organic matter. So, this takes into account some lignocellulose and basically your lignin is also there. Then ash content which is usually 0 to 4%, depending upon the biomass feedstock again.

So, ash content can be carried out using this pyrolysis in a closed recipient at 950 degrees centigrade. So, you can understand that in a single slide that what are the different characterization techniques can be done with respect to the thermal decomposition basically.

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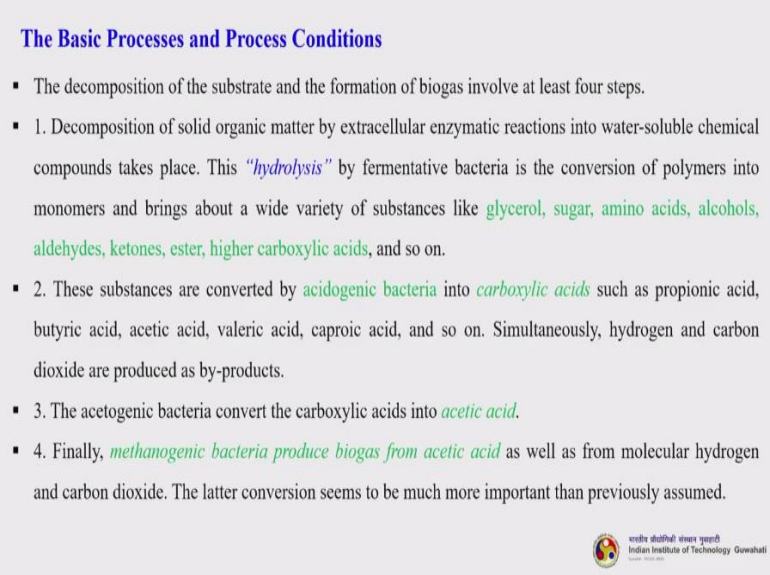

So, now we will try to understand the basic processes and the process conditions that are essential for the biogas fermentation. The decomposition of the substrate and the formation of biogas involves at least 4 distinct steps. So, we will see one by one. The first is the decomposition of the solid organic matter by extracellular enzymatic reactions into water-soluble chemical compounds takes place. This is called hydrolysis - the most important step of the biogas process. Now this hydrolysis by fermentative bacteria is the conversion of polymers into monomers and brings about a wide variety of substances like glycerol, sugar, amino acids, alcohol, aldehydes, ketones, ester, higher carboxylic acids, and so on.

Now in the second step, these substances are converted by the acidogenic bacteria into carboxylic acids, such as propionic acid, butyric acid, acetic acid, valeric acid, caproic acid and so on. Simultaneously, hydrogen and carbon dioxide are produced as byproducts but at a very low amount. Third step is that here the acetogenic bacteria convert the carboxylic acid into acetic acid. In the fourth and final step, it is a methanogenesis step when methanogenic bacteria produce biogas from acetic acid as well as from the molecular hydrogen and carbon dioxide. The latter conversion seems to be much more important than previously assumed.

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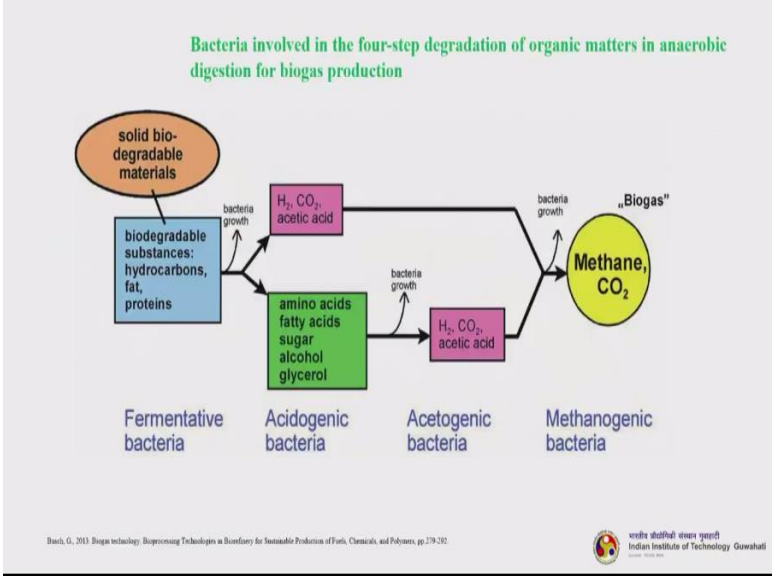

So, this is a slide where you can understand what are the different types of bacteria those are involved in the 4 distinct steps. So we will just quickly go through. The first is the fermentative bacteria. Here actually solid biodegradable materials such as hydrocarbons, fat, proteins they are getting converted to monomers. So, hydrolysis step. Now, then you go ahead. These steps are happening in sequence, but once they start these are all happening simultaneously.

Then we have acidogenic bacteria, which are carrying out the a acidogensis. Here amino acids, fatty acids, sugar, alcohol, glycerol all these things will be converted into different types of acids like carboxylic acids. Then when we move ahead and you can see from here also little amount of molecular hydrogen, carbon dioxide and little amount of acetic acid also formed during this hydrolysis process.

Now, we go for acetogensis process where acetogenic bacteria are converting the acetic acid and molecular hydrogen, carbon dioxide formally into methane and carbon dioxide. So, that is the getting converted using the methanogenic bacteria. So, you can understand the 4 distinct classes of bacteria that are responsible for carrying out 4 distinct and necessary steps inside the biogas fermenter.

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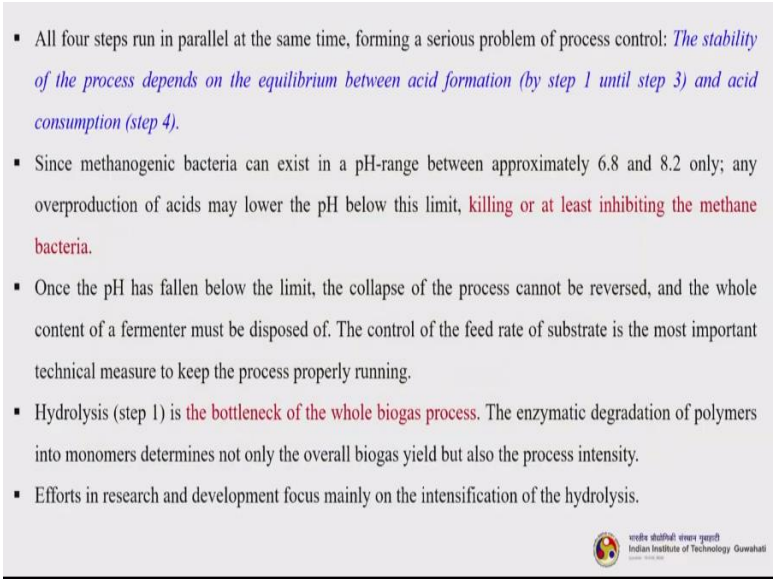

All the four steps run in parallel at the same time forming a serious problem of process control. Now, the stability of the process depends on the equilibrium between the acid formation (that is by step 1 to until step 3) and acid consumption (that is step 4). So, there should be a balance between these 3 steps where the acids are getting produced and this is the final step where the acid is being consumed and they are getting converted into methane and carbon dioxide.

So, since methanogenic bacteria can exist in a pH range between approximately 6.8 and 8.2 only, any overproduction of acids may lower the pH below this limit, thereby killing or at least inhibiting the methanogenesis bacteria - which is not good. Now, once the pH has fallen below the limit, the collapse of the process cannot be reversed and the whole content of a fermenter must be disposed of.

The control of the feed rate of substrate is the most important technical measure to keep the process properly running. Hydrolysis, that is step 1, is the bottleneck of the entire biogas production process. Now, the enzymatic degradation of polymers into monomers determines not only the overall biogas yield but also the process intensity. Having said that, the meaning why that is the bottleneck, because hydrolysis is the step where the polymers are getting degraded into monomers.

So, more efficiently the polymers are degraded into monomers, more amount of methane will be produced. It is as simple as that, more amount of monomers so more amount of methane.

Efforts in research and development focus mainly on the intensification of this particular hydrolysis step.

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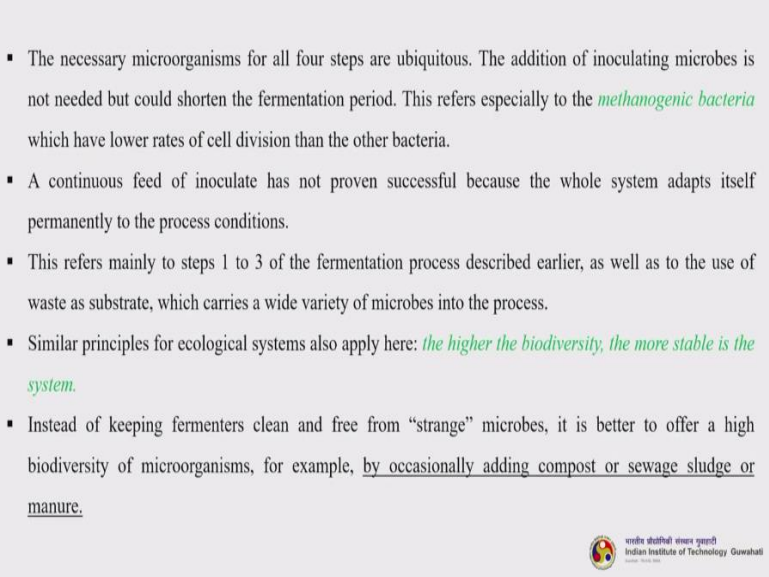

The necessary microorganisms for all four steps are ubiquitous. Now, the addition of inoculating microbes is not needed but could shorten the fermentation period. This refers especially to the methanogenic bacteria, which have lower rates of cell division than other bacteria. Other bacteria means**,** other acidogenic bacteria. Now, a continuous feed of inoculate has not proven successful because the whole system adapts itself permanently to the process conditions.

This refers mainly to step 1 to 3 of the fermentation process described earlier as well as to the use of waste as substrate which carries a wide variety of microbes into the process. Similar principles for ecological system also apply here: that is the higher the biodiversity, the more stable is the system. It is again understood. So, instead of keeping fermenters clean and free from strange microbes, it is better to offer a high biodiversity of microorganisms. For example, by occasionally adding compost or sewage sludge or manure.

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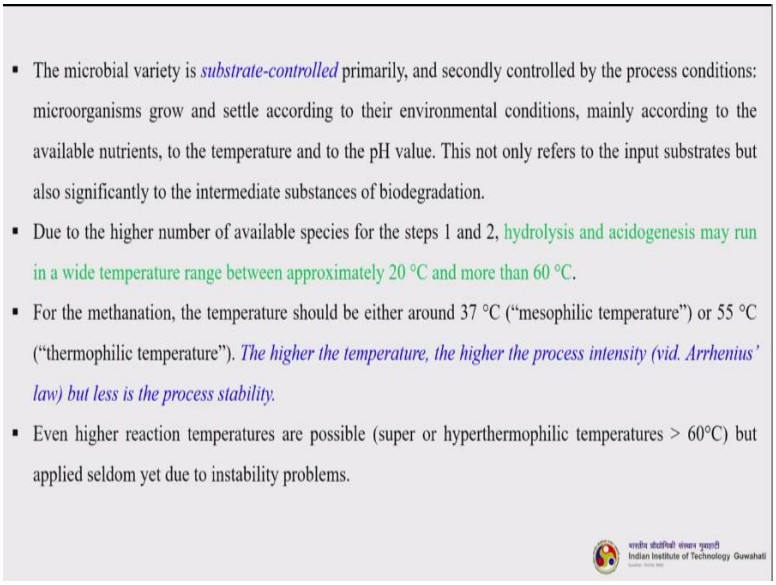

The microbial variety is substrate controlled primarily and secondly controlled by the process conditions. Microorganisms grow and settle according to the environmental conditions, mainly according to the available nutrients to the temperature and to the pH value. This not only refers to the input substrates, but also significantly to the intermediate substances of the biodegradation process.

Now, due to the higher number of available species for the step 1 and step 2, hydrolysis and acidogenesis, these two steps, they may run in a wide temperature range between approximately 20 degrees centigrade to more than 60 degrees centigrade. Now for the methanation, the temperatures should be either around 37 degrees centigrade it is the mesophilic temperature or 55 degrees centigrade which is thermophilic temperature depending upon what type of microorganisms are present in your biogas plant. The higher the temperature, the higher the process intensity (vid. Arrhenius' law), but less is the process stability. Even higher reaction temperatures are possible. So, you can talk about a super or hyperthermophilic temperatures which are usually greater than 60 degrees centigrade, but applied seldom yet due to the instability problems. Maintaining temperature is always an issue.

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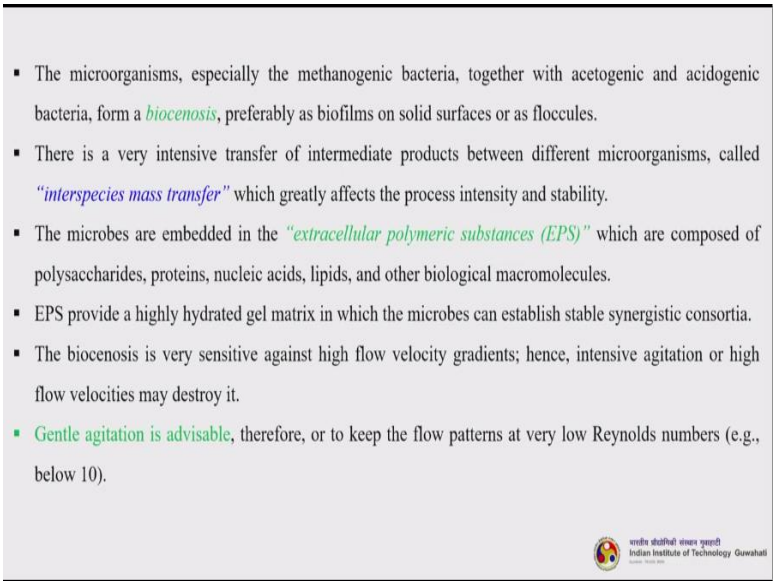

The microorganisms, especially the methanogenic bacteria together with acetogenic and acidogenic bacteria form a biocenosis (Biocenosis means a consortia of bacteria), preferably as biofilms on solid surface or as floccules. So, there is a very intensive transport of intermediate products between the different microorganisms called the interspecies mass transfer that greatly affect the process intensity and stability.

The microbes are embedded in the extracellular polymeric substances which are popularly known as the EPS. They are composed of polysaccharides, proteins, nucleic acids, lipids and other biological macromolecules. Now, EPS provide a highly hydrated gel matrix in which the microbes can establish stable synergistic consortia. So, the biocenosis is very sensitive against high flow velocity gradients.

Hence intensive agitation or high flow velocities may destroy it and must be avoided also. Gentle agitation is advisable because some form of agitation enhances the rate of mass transfer, therefore to keep the flow patterns at very low Reynolds number, almost below 10.

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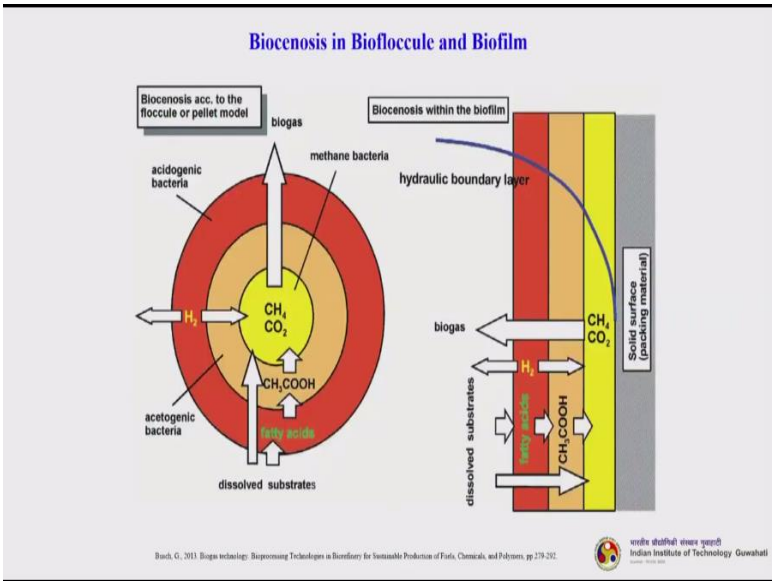

This is another interesting slide which is taken from this particular reference, you can refer to it later on. So, this is what I was just mentioning that how the biocenosis actually keeps itself in two forms. First is this film; as a film over some solid surface. They are getting attached. So, this is a schematic representation, otherwise in the form of floccules. So, let us see two. So, you can see that, please do not think that exactly it looks like that or it appears like that, some sort of floccules you can imagine.

So, this is an imaginary representation. So, the first red one is composed of acidogenic bacteria, microorganisms. The middle one consists of a acetogenic bacteria and the yellow one the core one that consists of the methanogenic bacteria. So, similarly, it is the same thing, the representation is the same way. You can see that when we are talking about a film attachment, film type of growth over a solid surface.

You can see that here we have methanogenic bacteria which is present immediately on the surface of the host or you can say the solid surface. Above that acetogenic bacteria and above finally acidogenic bacteria which is exposed to the bulk or you can say that to the feed. More or less, the film getting represented whatever it is here represented, more or less it is being seen in the similar way distinct, but there is no clear distinct. You cannot cut and get them, taking them separately that I will remove this part of acetogenic bacteria, only methanogenesis and you cannot do like that. So, this is a schematic representation as I told you that they exist in a very beautiful way either in floccules or in film development in an entirely synergistic way. They have a very good synergism between all of them and the intermediate products, let us look at what about the fatty acids that is being consumed here?

This is the step where the polymers are getting converted to monomers. Now, apart from that please understand that small amount of acetic acid, small amount of molecular hydrogen and carbon dioxide are also formed. Now, all these are getting transported in this direction you can understand. So, that here the acetogenic bacterias will convert all these monomers into different acids. Now, these acids are the source for the methanogenic bacteria which will eventually pass through this.

Mass transfer is happening in this direction and mass transfer is happening in this direction. So, what is happening is this as I was telling that the acids, now these acids are the source or the substrates for the methanogenic bacteria which eventually convert them into methane and carbon dioxide that is happening in the final core one. And then methane and carbondioxide will come out.

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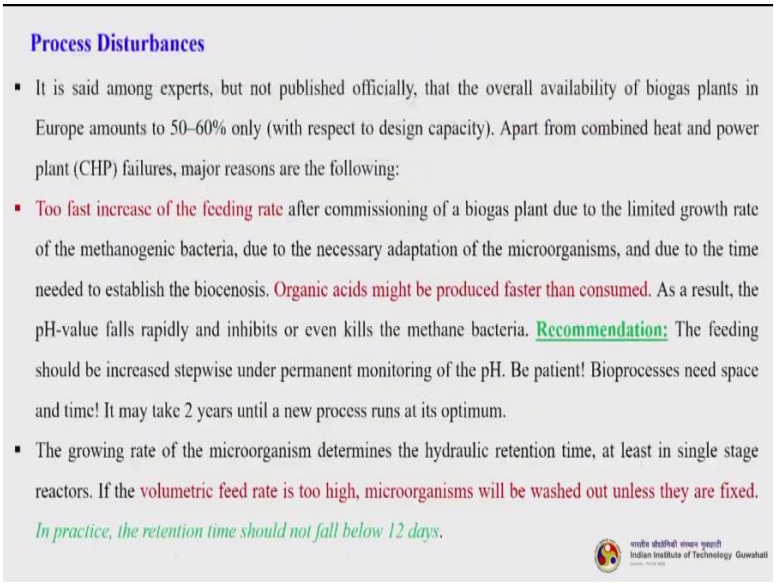

So, we will try to understand the process disturbances. It is very important because operating the plant though looks simple, but it is not so simple we need to take care of many things. We will try to understand what are the things that create disturbances and how to address them. So, it is said among experts, but not published officially, that the overall availability of biogas plants in Europe amount of 50 to 60% only with respect to the design capacity.

Apart from combined heat and power plant failures, major reasons are the following. The first is too fast increase of the feeding rate. So, if you do that after commissioning of a biogas plant due to the limited growth rate of methanogenic bacteria due to the necessary adaptation

of the microorganisms and due to the time needed to establish the biocenosis too fast increase of the feeding rates are not going to serve any purpose. Now, why?

Organic acids might be produced faster than it is consumed, this is what we do not want because it will inhibit the entire process. As a result pH value falls rapidly and inhibits or even kills the methanogenic bacteria those are very sensitive. Now, what should you do? The recommendation says that the feedings should be increased stepwise under permanent monitoring of the pH. So a fed batch system is always a better system. So be patient.

Bioprocesses need space and time, do not be in a hurry. It may take 2 years until a new process runs at its optimum. So, you need to be very patient. The growing rate of the microorganism determines the hydraulic retention time at least in single stage reactors. So, if the volumetric feed rate is too high, microorganisms will be washed out unless they are fixed. In practice, the retention time should not fall below 12 days, minimum retention time.

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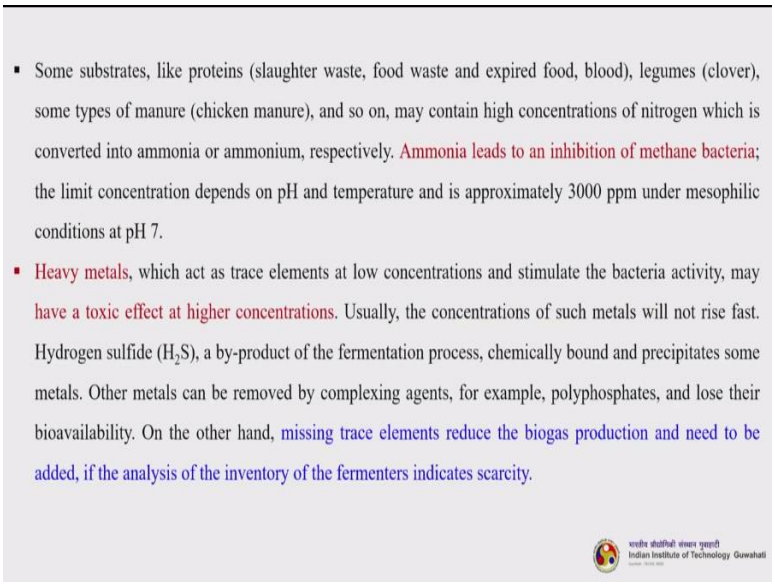

Then some substrates like proteins especially when coming from the slaughter waste, food waste, expired food, blood, etc., then legumes, some types of manure like chicken manure and all these things may contain high concentrations of nitrogen which is converted into ammonia or ammonium depending upon the process conditions. Now ammonia leads to an inhibition of methane bacteria.

So, again, I am telling you please understand that methanogenesis bacterias are extremely sensitive to environmental conditions. So, you have to be very careful. So, the limit

concentration depends on pH and temperature and is approximately 3000 ppm under mesophilic conditions at pH 7. Now, heavy metals which act as trace elements at lower concentrations and stimulate the bacterial activity may have a toxic effect at higher concentrations.

So, any such metals beyond certain limit always they are toxic. It is same for us also, human beings also. So, usually, the concentrations of such metals will not rise fast. Hydrogen sulfide a byproduct of the fermentation process chemically bound and precipitate some metals. Other metals can be removed by complexing agents for example polyphosphates and lose their bioavailability.

On the other hand, missing trace elements reduce the biogas production that is also an issue and need to be added if the analysis of the inventory of the fermenter indicates scarcity. You need to keep on monitoring every day, even certain hours basis so as to find out the heavy metal concentrations. Then you will find out whether you need to supply them or they are already present in sufficient amount.

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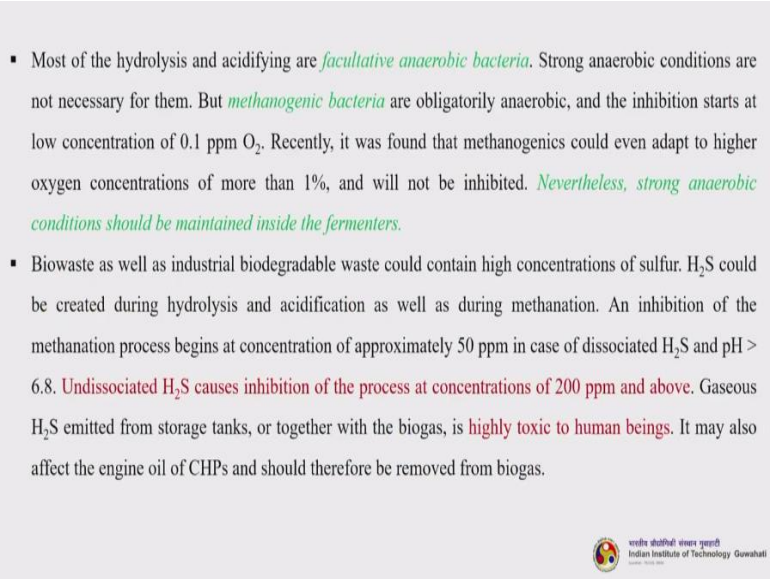

So most of the hydrolysis and acidifying are facultative anaerobic bacteria. Strong anaerobic conditions are not necessary for them. But methanogenic bacteria are obligatorily anaerobic or anaerobes. The inhibition starts at low concentration of 0.1 ppm oxygen. So it is very low, you can understand then how sensitive this methanogenic bacterias are. Recently, it was found that methanogenics could even adapt to higher oxygen concentration of more than 1% and will not be inhibited.

Nevertheless, strong anaerobic conditions should be maintained inside the fermenters at any conditions. Then biowaste as well as industrial biodegradable waste could contain high concentrations of sulfur. Hydrogen sulfide could be created during hydrolysis and acidification as well as during methanation. An inhibition of methanation process begins at concentration of approximately 50 ppm in case of dissociated hydrogen sulfide and a pH greater than 6.8.

Now undissociated hydrogen sulfide causes inhibition of the process at concentrations of 200 ppm and above. Gaseous hydrogen sulfide emitted from storage tanks or together with the biogas is highly toxic to human beings that is another problem. So it may also affect the engine oil of the CHPs and should therefore be removed from the biogas process plants.

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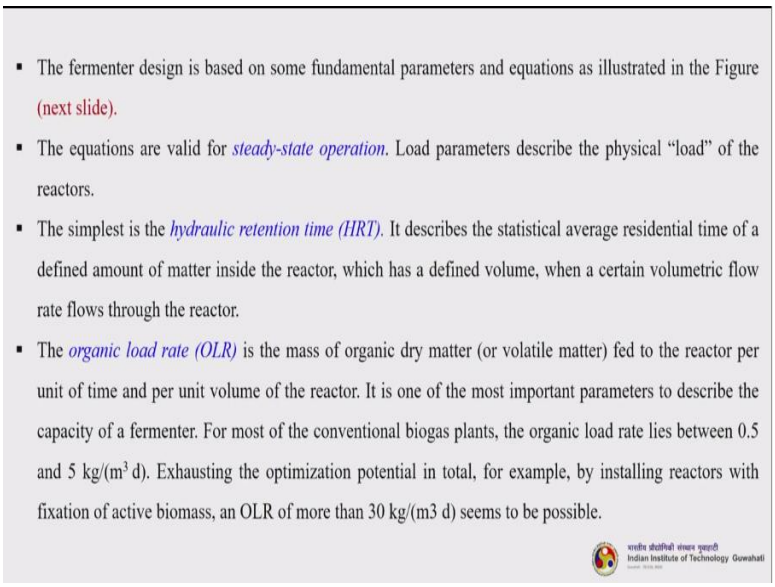

So now we will talk about different types of fermenter designs for the biogas production. The fermenter design is based on some fundamental parameters and equations as illustrated in the figure. So I will just show the figure and then we will come back again.

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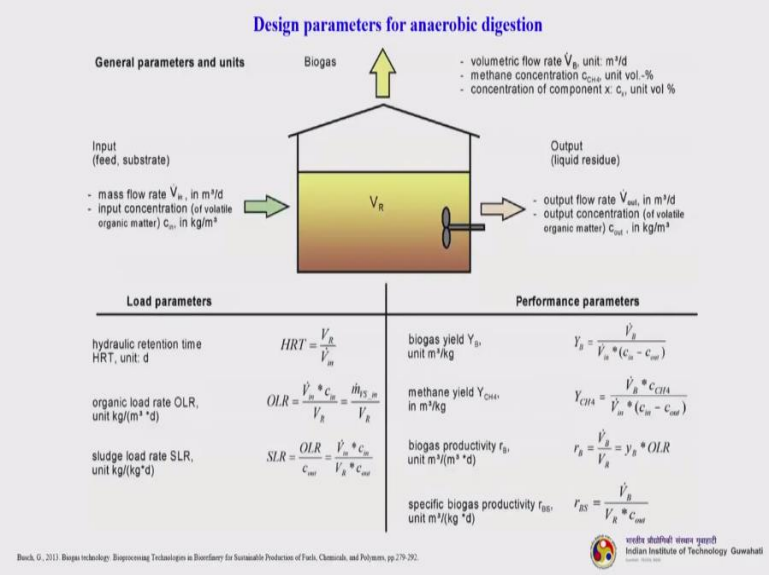

So this is the design parameters for anaerobic digestion. So, I will just try to explain quickly. So 3 things. First is this is the input, feed substrate whatever it is. This is the output, liquid residue and then this is the biogas that is the final product output. So, you can see that the load parameters are given here. The performance parameters are given here. So, the load parameters like hydraulic retention time HRT in terms of days.

So, V R by V in. So, V in is your input of mass flow rate and V R is your output mass flow rate. So, organic load OLR, then sludge load rate SLR. Sludge is also required but it is in a very minute quantity depending upon the capacity also and the condition. So, performance parameters are biogas yield, methane yield, biogas productivity and specific gas productivity unit in meter cube per kg day. So, the equations are valid only for steady state operation.

Load parameters describe the physical load of the reactors. The simplest is the hydraulic retention time. It describes the statistical average residential time of a defined amount of matter inside the reactor, which has a defined volume when a certain volumetric flow rate flows through the reactor. Then, the next is the OLR organic load rate. It is the mass of the dry organic matter or we can say the volatile matter fed to the reactor per unit of time and per unit volume of the reactor.

It is one of the most important parameters to describe the capacity of a fermenter. For most of the conventional biogas plants, the organic load rate lies between 0.5 and 5 kilograms per meter cube day. Exhausting the optimization potential in total for example by installing

reactors with fixation of active biomass and OLR of more than 30 kg per meter cube day seems to be possible. It is recommended actually.

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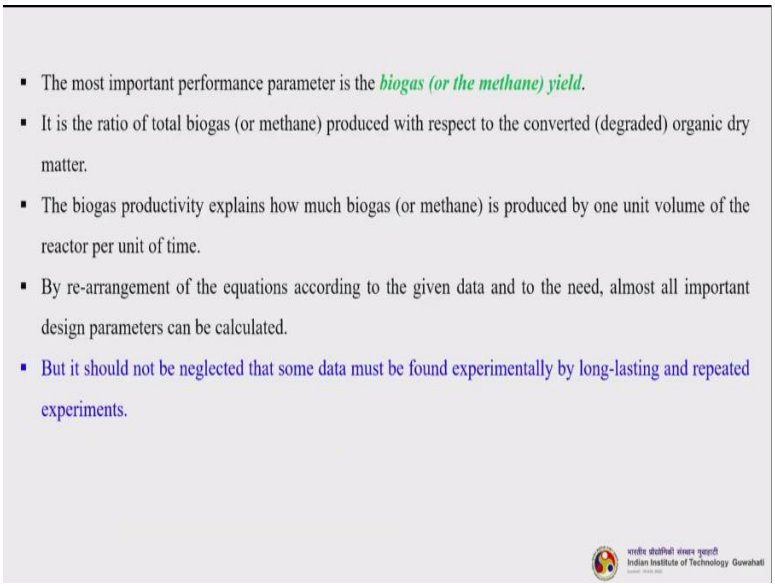

The most important performance parameter is of course the biogas or the methane yield. It is the ratio of the total biogas produced with respect to the converted organic dry matter. The biogas productivity explains how much biogas is produced by unit volume of the reactor per unit amount of time. By rearrangement of the equations according to the given data and to the need, almost all important design parameters can be calculated.

But it should not be neglected that some data must be found experimentally by long lasting and repeated experiments. So, they become more reliable data then.

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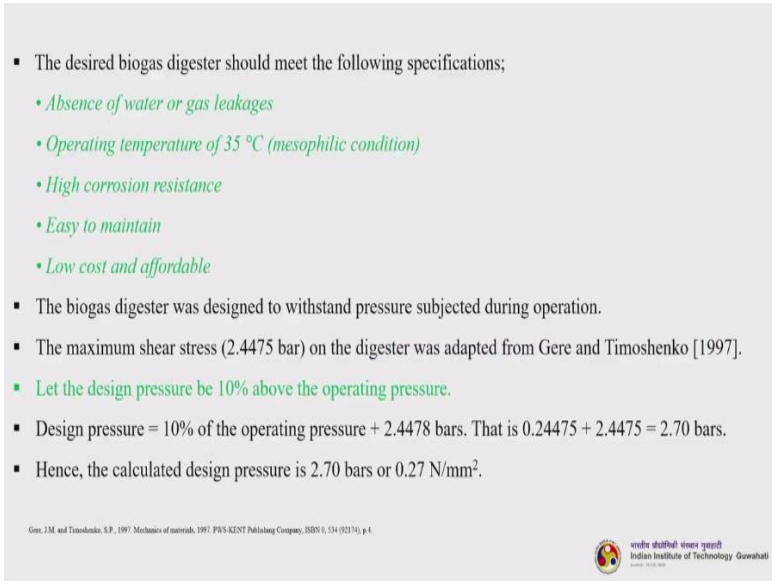

So, the desired biogas digesters should meet the following specifications. Absence of water or gas leakages, operating temperature of 35 degrees centigrade which is the mesophilic condition for the methanogenesis bacteria, high corrosion resistance, easy to maintain, low cost and affordable. The biogas digester was designed to withstand pressures subjected during the operation. The maximum shear stress on the digester was adapted from a classic work by Gere and Timoshenko.

The reference is given below. Let the design pressure be 10% above the operating pressure that is what is basically recommended by the designers. So, design pressure equals to 10% of the operating pressure plus 2.4478 bars. So, that 2.4478 is the maximum shear stress, so that is 2.7 bars. Hence, the calculated design pressure is 2.7 bars, so 0.27 Newton per mm square.

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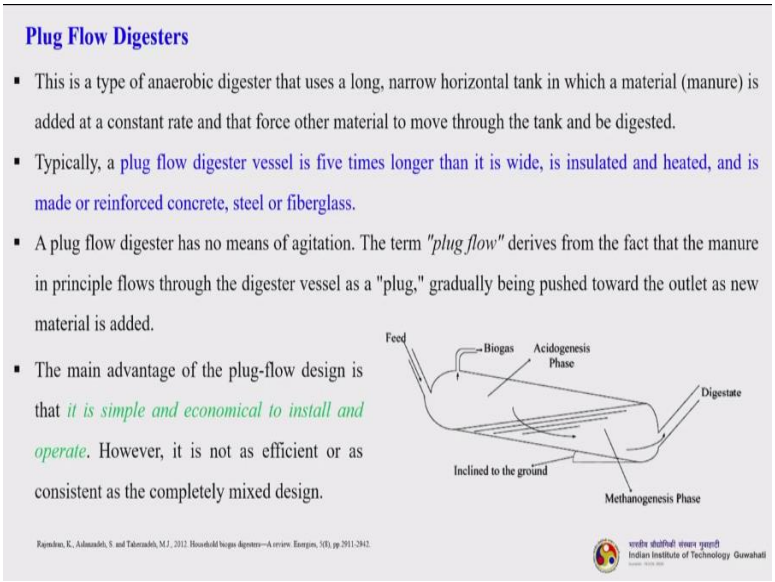

Now, we will quickly discuss few of the digesters which are commercially being adopted and used and installed in many places. So, first is the Plug Flow Digester. Now, this is a type of anaerobic digester that uses a long narrow horizontal tank in which a material or manure is added at a constant rate and that force other material to move through the tank and be digested. No mechanical or any form of agitation inside.

Typically, a plug flow digester vessel is five times longer than it is wide. It is insulated and heated and is made of reinforced concrete, steel or fiberglass. A plug flow digester has no means of agitation. The term plug flow means that the manure in principle flows through the

digester vessel literally as a plug, so gradually being pushed out to the outlet as the new material is being added.

So, the main advantage of the plug flow design is that it is simple and economical to install and operate. However, it is not as efficient or as consistent as the completely mixed fermenters.

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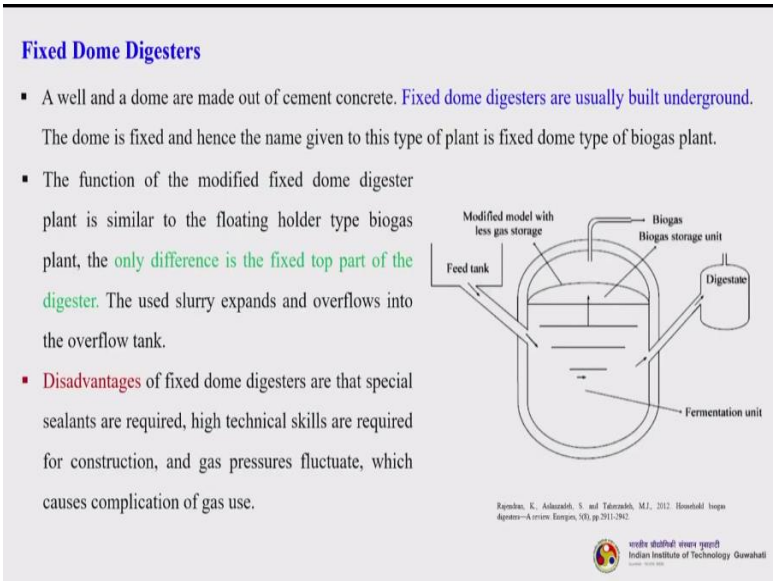

The next one is fixed dome digesters. So a well and a dome are made out of cement concrete basically. Fixed dome digesters are usually built underground. The dome is fixed and hence the name is given to this type of plant is fixed dome type of biogas plant. The function of the modified fixed dome digester plant is similar to that of the floating holder type biogas plant. The only difference is the fixed top part of the digester. You can see here, this portion, it is fixed, it is not floating.

I will show you floating one in the next slide. So, the used slurry expands and overflows into the overflow tank. Now disadvantage is that special sealants are required for this type of fixed dome digesters, high technical skill are required for construction and gas pressure fluctuate which causes complication of the gases; because the gas is continuously getting generated. And in case of the fixed dome here what is happening, when the gases are continuously getting generated, you should have a proper headspace to hold the gas. Now, even if you have a proper headspace also, when the gas is continuously formed and getting concentrated here it will create too much pressure inside the tank. And if they are not continuously getting removed at a particular flow rate, thereby maintaining the pressure inside the fermenter that

the fermenter may also get cracked or burst. So, these are the disadvantage of the fixed dome process.

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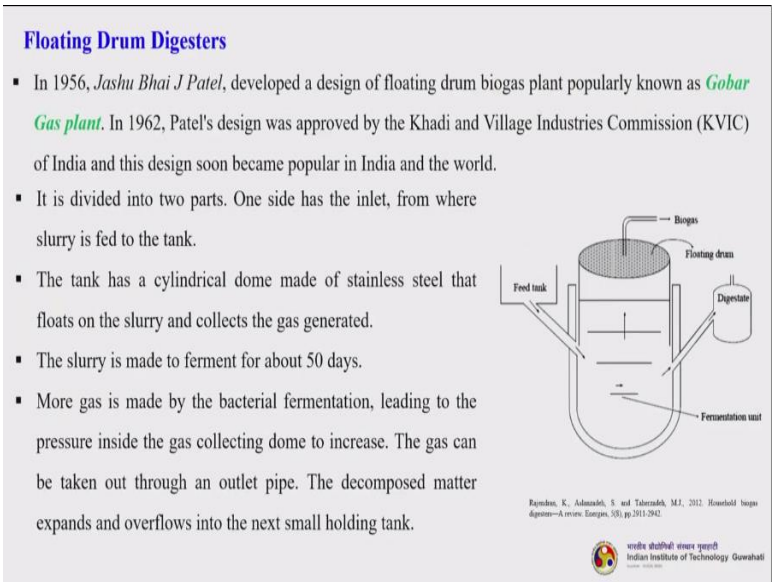

Now to overcome that we have floating drum digester. So, this is a classic design. It was done by Jashu Bhai J Patel in India in 1956. So, he has designed a floating drum biogas plant popularly known as the Gobar gas plant in India. In 1962, Patel's design was approved by the Khadi and Village Industries Commission of Government of India popularly known as the Khadi Commission. And this design soon became popular in India and the entire world.

It is divided into two parts. One side has the inlet from where the slurry is fed to the tank. The tank has a cylindrical dome made up of stainless steel that floats on the slurry and collects the gas that is generated. So, this is a beautiful design. What is happening here is that the top portion is floating. So, as and when the gas is getting formed and the gas is becoming more the amount of gas that is generated, so the dome that top portion which is floating will move upward.

So, depending upon the amount of gas that is getting generated as well as the pressure that is getting developed, the head will float. It will move up and down like this. It is a beautiful design. So, the slurry is made to ferment for about 50 days. More gas is made by bacterial fermentation leading to the pressure inside the gas collecting dome to increase. Now the gas can be taken out through an outlet pipe. The decomposed matter expands and overflows into the next small holding tank.

So, now we will talk about the biogas purification. As I told you in the beginning of the class that once we produce biogas as we have understood that biogas consists of so many different types of components starting from the major component of methane to carbon dioxide, carbon monoxide, nitrogen, hydrogen, hydrogen sulfide and other compounds.

Now, you need to purify them for a particular application. Suppose I am talking about preparing biomethane then I have to scrap all carbon dioxide and everything else so that at least I have 98% enriched biogas, then I can call it a biomethane which can be directly used in the vehicles. Let us try to understand how it can be done.

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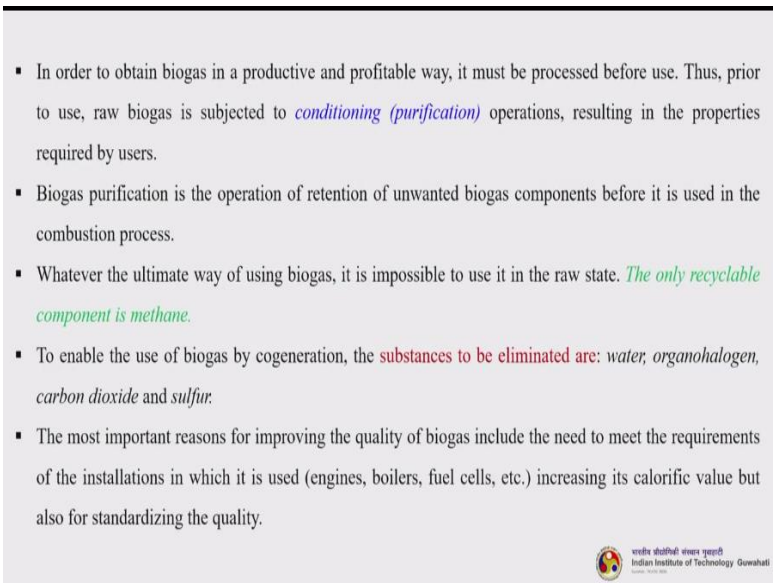

So, in order to obtain biogas in a productive and profitable way, it must be processed before use. Thus prior to use, raw biogas is subjected to conditioning or we can call it as purification operations resulting in the properties required by the users. Biogas purification is the operation of retention of unwanted biogas component before it is used in the combustion process. Whatever the ultimate way of using biogas, it is impossible to use it in the raw state.

The only recyclable component is the methane. To enable the use of biogas by cogeneration the substances to be eliminated are water, organohalogens, carbon dioxide and sulfur. The most important reasons for improving the quality of biogas include the need to meet the requirements of the installations in which it is used as for example engines, boilers, fuel cells increasing its calorific value, but also for standardizing the quality.

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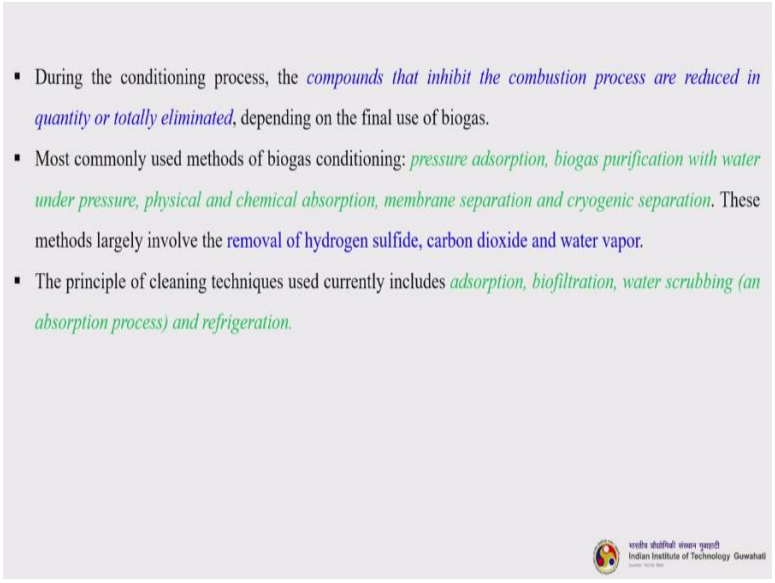

During the conditioning process, the compounds that inhibit the combustion process are reduced in quantity or totally eliminated depending on the final use of biogas. Most commonly used methods of biogas, conditioning pressure adsorption, biogas purification with water under pressure, physical and chemical absorption, membrane separation and cryogenic separation.

So one or two specific and most widely used applications we will discuss just now. Now these methods largely involve the removal of hydrogen sulfide, carbon dioxide and water vapor. The principle of cleaning techniques used currently includes adsorption, biofiltration, water scrubbing which is an absorption process and refrigeration. So, these will discuss.

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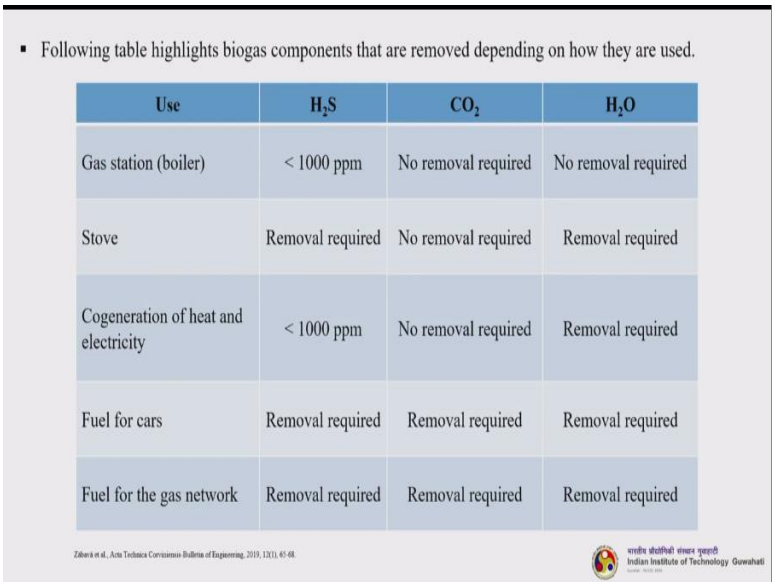

So following table highlights the biogas components that are removed depending on how they are being used. So what are the components? The major components being listed here. Hydrogen sulfide, carbon dioxide and water. So, if you talk about the biogas use in gas station, so, hydrogen sulfide must be less than 1000 ppm, carbon dioxide removal not required, water removal not required.

Let us talk about the stove, so cooking gas. So, hydrogen sulfide removal has to be, complete removal is required and carbon dioxide removal is not essential, water has to be removed otherwise ignition will not proceed. Then if it is being used in cogeneration of heat and electricity in the CHP plants, so hydrogen sulfide must be less than 1000 ppm, carbon dioxide no need to remove whereas water has to be removed.

Again, it will create problem of combustion. If you are going to use it for fuel for cars, you can see that everything needs to be removed whether it is hydrogen sulfide, carbon dioxide or water. And if you talk about a biogas used in the fuel for the gas network, then you can see that everything else needs to be removed whether it is hydrogen sulfide, carbon dioxide or water.

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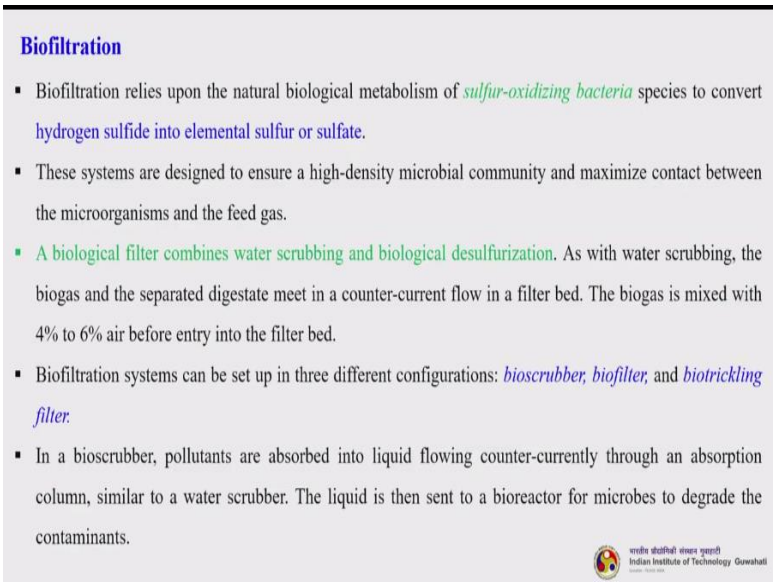

So we will quickly discuss few cleaning process. First is the biofiltration. Now, biofiltration relies upon the natural biological metabolism of sulfur oxidizing bacteria species to convert hydrogen sulfide into elemental sulfur or sulfate. So these systems are designed to ensure a high-density microbial community and maximize contact between the microorganisms and the feed gas. A biological filter combines water scrubbing and biological desulfurization.

As with water scrubbing, the biogas and the separated digestate meet in a counter current flow in a filter bed. The biogas is mixed with 4 to 6% air before entry into the filter bed. Biofiltration systems can be set up in three different configurations. Bioscrubber, biofilter and biotrickling filter. In a bioscrubber, pollutants are absorbed into liquid flowing counter-currently through an absorption column similar to that of a water scrubber. The liquid is then sent to a bioreactor for the microbes to degrade the contaminants.

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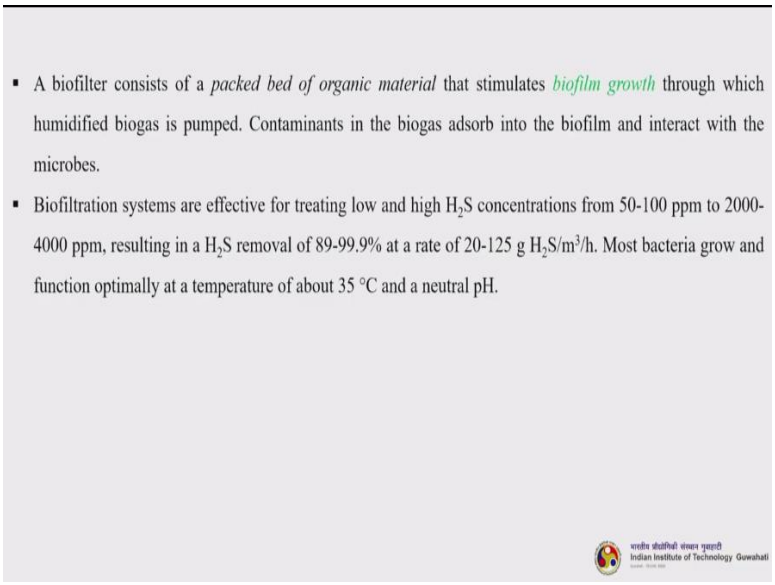

A biofilter consists of a packed bed of organic material that stimulates biofilm growth through which humidified biogas is pumped. Contaminants in the biogas adsorb into the film and interact with the microbes and then eventually they are degraded. Biofiltration systems are effective for treating low and high hydrogen sulfide concentrations from almost 50 to 100 ppm to 2000 to 4000 ppm, resulting in a hydrogen sulfide removal of 89 to 99.9% at a rate of 20 to 125 gram hydrogen sulfide per meter cube per hour, which is excellent actually. Now, most bacteria grow and function optimally at a temperature about 35 degrees centigrade and neutral pH. So this process conditions you need to maintain.

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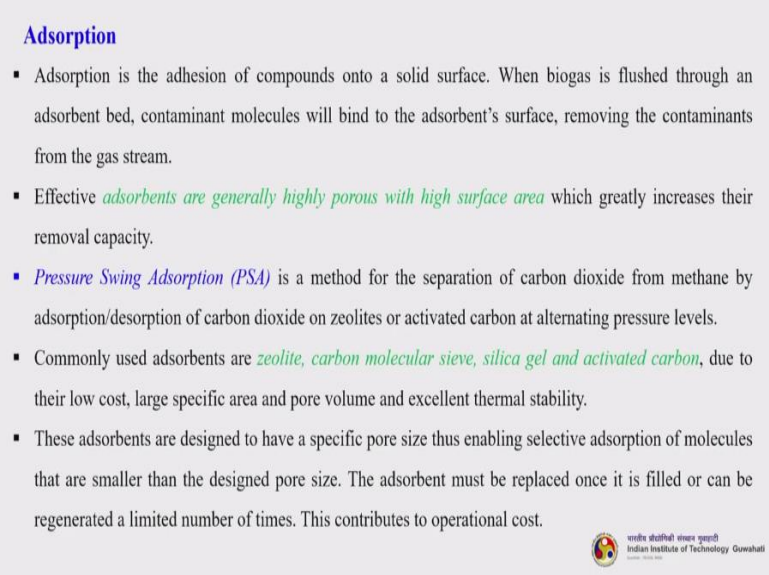

Next is adsorption. Now adsorption is the adhesion of compounds onto the solid surface. When biogas is flushed through an adsorbent bed, contaminant molecules will bind to the adsorbent's surface removing the contaminants from the gas stream. Effective adsorbents are generally high porous with a high surface area which greatly increases their removal capacity.

Pressure swing adsorption is a method for the separation of carbon dioxide from methane by adsorption/desorption of carbon dioxide on zeolites or activated carbon at alternating pressure levels. Commonly used adsorbents are zeolite, carbon molecular sieve, silica gel and activated carbon due to their low cost, large specific area and pore volume and excellent thermal stability.

These adsorbents are designed to have a specific pore size thus enabling selective adsorption of molecules that are smaller than the design pore size. The adsorbent must be replaced once it is filled or can be regenerated a limited number of times. This however contributes to extra operational cost.

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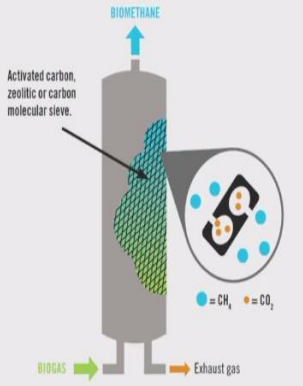
- In PSA processes, biogas is compressed to a pressure between 4-10 bar and is fed to a vessel (column) where it is put in contact with a material (adsorbent) that will selectively retain CO_2.
- The adsorbent is a porous solid, normally with high surface area.
- Recent research and experimental demonstrations have shown that adsorption technology paves the way for scaling up the biogas upgrading process with high energy efficiencies.
- Moreover, PSA systems can be deployed in any part of the world since they do not depend on the availability of cold or hot sources.



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In a PSA System, pressure swing adsorption process, biogas is compressed to a pressure between 4 to 10 bar and is fed to a vessel where it is put in contact with the material that is the adsorbent you can see there, activated carbon, zeolite or active carbon molecule sieve (the etched portion), a representation, that will selectively retain the carbon dioxide. The adsorbent a porous solid normally with high surface area.

Recent research and experimental demonstrations have shown that adsorption technology paves the way for scaling up the biogas upgrading process with high energy efficiency. Moreover, PSA systems can be deployed in any part of the world since they do not depend on the availability of cold or hot sources.

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Pressurized Water Scrubbing

- Purification of biogas by *pressure water* is one of the most widely used biogas treatment methods.
- Pollutant compounds can be physically adsorbed (or dissolved) in a liquid solution.
- To enhance the absorption of CO_2 and H_2S, biogas is usually compressed to 900–1200 kPa and a high surface area packing media is used.
- Inside the scrubber, biogas flows counter currently to water that is sprayed from the top of scrubber and the absorption primarily occurs on the surface of the packing media.
- The raw biogas is introduced at the bottom of the column and flows upward, while fresh water is introduced at the top of the column, flowing downward over a packed bed.
- The packed bed (typically a high-surface-area plastic media) allows for efficient contact between the water and gas phases in a countercurrent absorption regime.

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Next is pressurized water scrubbing. Purification of biogas by pressure water is one of the most widely used biogas treatment methods. Pollutant compounds can be physically adsorbed or dissolved in a liquid solution. To enhance the absorption of carbon dioxide and hydrogen sulfide, biogas is usually compressed to 900 to 1200 kilo Pascal, and the high surface area packing media is usually used.

Inside the scrubber, biogas flows counter currently to water that is sprayed from the top of the scrubber and the absorption primarily occurs on the surface of the packing media. The raw biogas is introduced at the bottom of the column and flows upward while fresh water is introduced at the top of the column flowing downward over a packed bed. The packed bed which is typically a high surface area plastic media allows for efficient contact between the water and gas phases in a countercurrent absorption regime.

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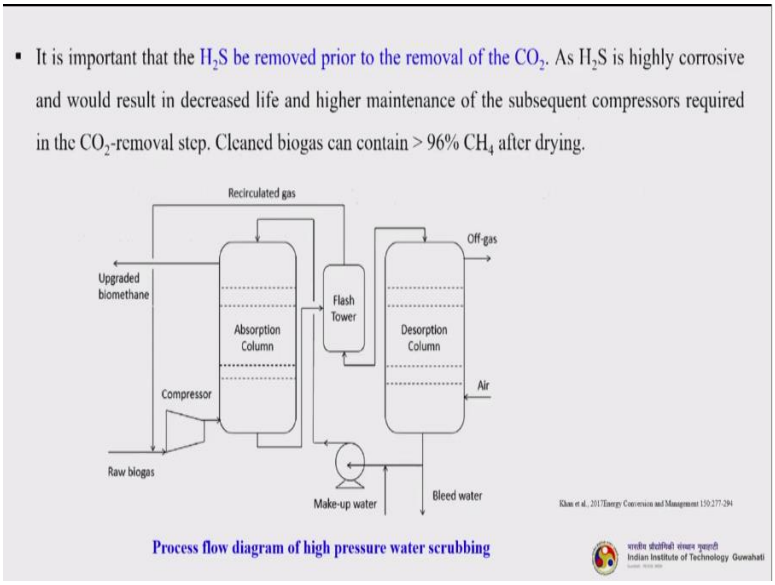

So, this is the process flow diagram of a high pressure water scrubbing. You can see two columns. One is the absorption column, one is the desorption column. So, here the raw biogas compressed and fed to the absorption column. In between there is a flash tower. So, upgraded biomethane you will get here. When you go for the desorption column, air will be utilized to do the desorption.

And whatever is coming, the bleed water and make-up water is being added and it is basically pressurized and fed to the absorption tower. Now, it is important that hydrogen sulfide be removed prior to the removal of the carbon dioxide. As hydrogen sulfide is highly corrosive and would result in decreased life and higher maintenance of the subsequent compressors, it

is required that before the carbon dioxide is removed, hydrogen sulfide must be removed. Cleaned biogas can contain almost greater than 96% of methane after drying.

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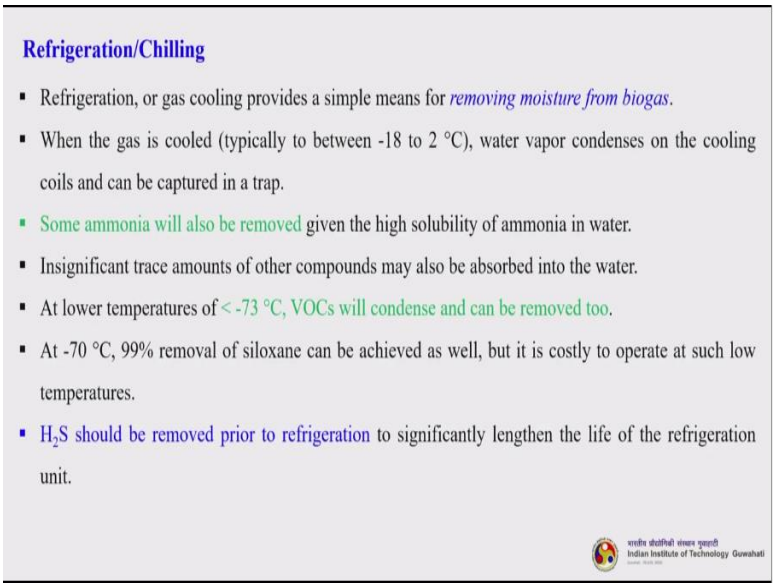

So, the next one is refrigeration and chilling. Now refrigeration or gas cooling provides a simple means for removing moisture from the gas. When the gas is cooled, so typically to between -18 to 2 degrees centigrade, water vapor condenses on the cooling coils and can be captured in a trap. Some ammonia will also be removed given the high solubility of ammonia in water.

Insignificant trace amounts of other compounds may also be absorbed into the water. At low temperature of less than –73 degrees centigrade, volatile organic components will condense and can be removed too. At –70 degrees centigrade, 99% removal of siloxane can be achieved as well, but it is costly to operate at such a low temperature. Hydrogen sulfide should be removed prior to refrigeration to significantly lengthen the life of the refrigeration unit.

So you must understand that every cleaning step you go, the final polishing step, hydrogen sulfide must be removed before that. It is the most notorious component present in the biogas.

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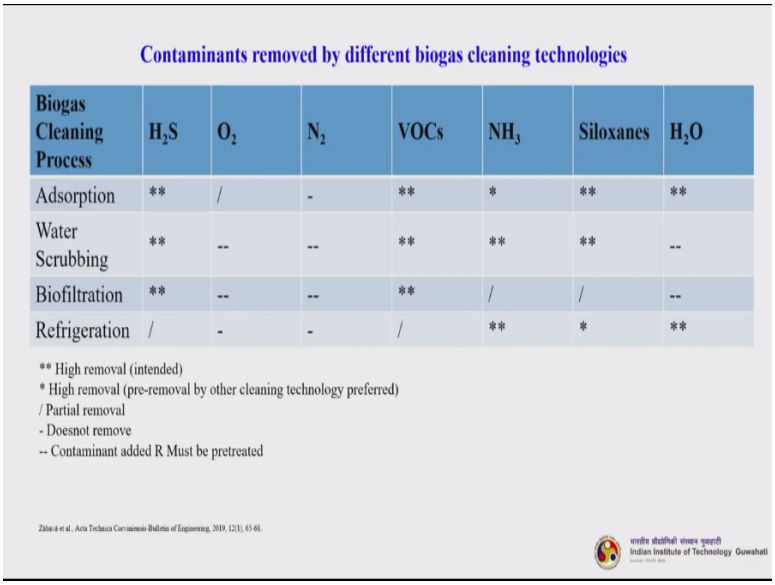

So, these are the contaminants that is removed by different biogas cleaning technologies. So, it is just a comparative understanding. So, look at adsorption. Hydrogen sulfide will be removed. VOCs, ammonia, siloxanes, and water all will be removed. So high removal. So, if you talk about water scrubbing again hydrogen sulfide, VOCs, ammonia, siloxanes will be highly removed.

And if you talk about biofiltration the same thing. And in refrigeration also ammonia and siloxane and water will be removed completely apart with other components will be removed partially.

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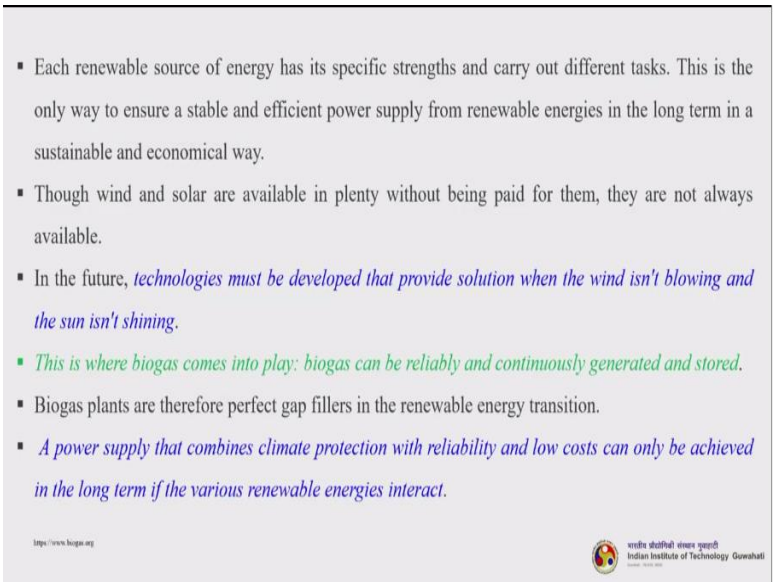

So, before I wind up I will just like to mention that, each renewable source of energy whether it is wind, biomass, whether it is solar or any such thing has its specific strength and carry out

different tasks. Now, this is the only way to ensure a stable and efficient power supply from renewable energies in the long term in a sustainable and also in an economical way. Though wind and solar are available in plenty without being paid for them, they are not always available.

In the future, technologies thus must be developed that provides solution when wind is not blowing and the sun is not shining, we have to take care of all these things. Now, this is where biogas comes into picture. Biogas can be reliably and continuously generated and stored. Biogas plants are therefore perfect gap fillers in the renewable energy transition system.

A power supply that combines climatic protection with reliability and low costs can only be achieved in the long term if the various renewable energies interact. Having said that, I just wish to mention that we have discussed about different types of renewable sources though our focus is on biomass in the beginning lectures. You must understand that a single source of renewable energy is not sufficient.

So, we should have multiple sources of energies. Wherever it is possible solar plus biomass, wind plus biomass, solar plus wind, something like that. There are other sources also. I am just telling the major three sources. So they need to be integrated in such a way that generation of power, electricity, everything that is possible from different multiple sources without any hindrance so that there is no shortage of power supply.

And this is now being practiced in many European countries, slowly other developing countries have also adopted this model and things are moving in a right direction.

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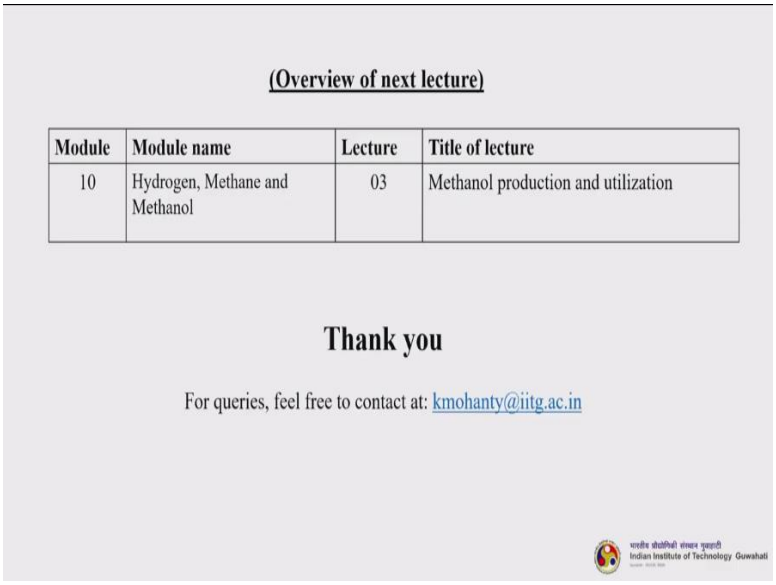

So, I conclude and in the next class under this module, we will be discussing about methanol production and utilization. So, if you have any query, please register it under the Swayam portal or you can always drop a mail to me at kmohanty@iitg.ac.in. So, thank you very much.