Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
Prof. Vaibhav V. Goud and Dr. R. Anandalakshmi
Department of Chemical Engineering
Indian Institute of Technology – Guwahati

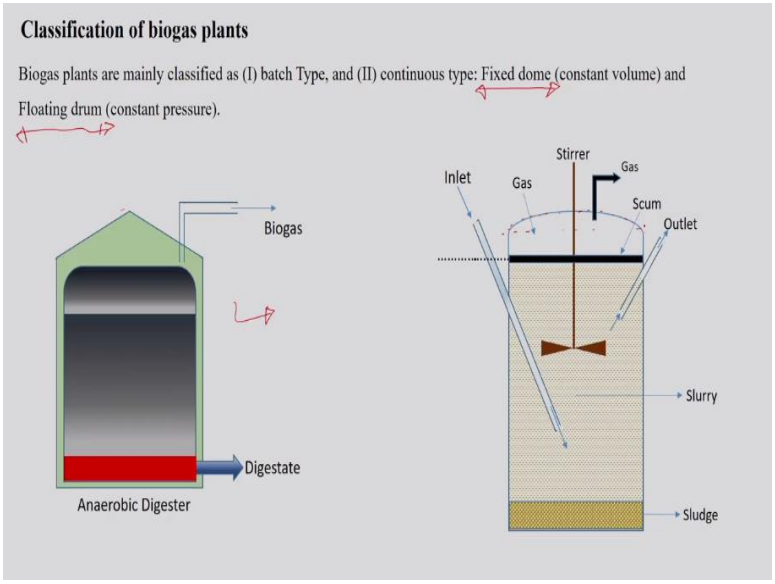
Lecture - 22
Classification of biogas plants

Good morning everyone and welcome to Part 2 of Lecture 2 under Module 7. So, in this particular lecture, we will discuss about the classification of biogas plants and factors which affects the biogas yield.

(Refer Slide Time: 00:38)

Module	Module name	Lecture	Content
07	Biomass conversion routes	02 (Part II)	Classification of biogas plants Factors affecting biogas yield

(Refer Slide Time: 00:44)

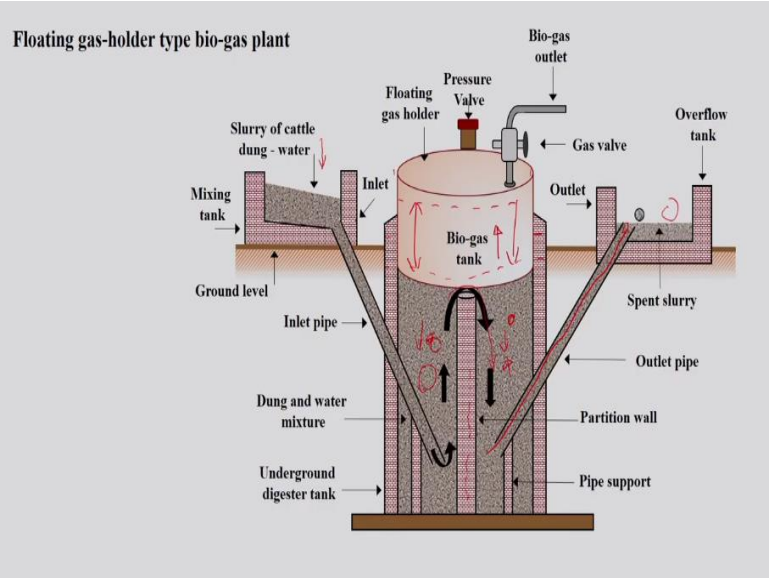


So, if you recall our discussion in the previous lecture, so, we ended our previous lecture with the classification of the biogas plant. So, the biogas plants are mainly classified as batch type

and the continuous type biogas plant. So, continuous type biogas plants are further classified as fixed dome and floating drum type biogas plant. So, the representative schematic of floating drum as well as the fixed dome type biogas plant is shown here.

So, this particular plant it indicates the batch type of biogas plant, where this structure it represents the floating drum on the slurry inside the digester. Similarly, this particular part it represents the fixed dome of the digester in the biogas plant.

(Refer Slide Time: 01:40)



So, this particular schematic it represents the floating drum type biogas plant. And this particular part, it represents the floating drum in the digester. So, numerous designs of this kind of plants are developed in various countries, but a family size KVIC model which is developed in India, which is shown here. So, this is a family type KVIC model, which is developed in India for the bio digestion purpose.

If you see the operation of this particular plant, in this case, this part is mainly made of the steel and this also works as a gas holder inside the digester. The remaining construction is nothing but the machinery construction. And part of this particular construction is underground. So, if you see this particular part of the machinery construction, it is bifurcated by a partition wall.

So, this represents the partition wall in the digester. And this partition wall it helps to maintain the proper condition inside the digester for the growth of the acid former and

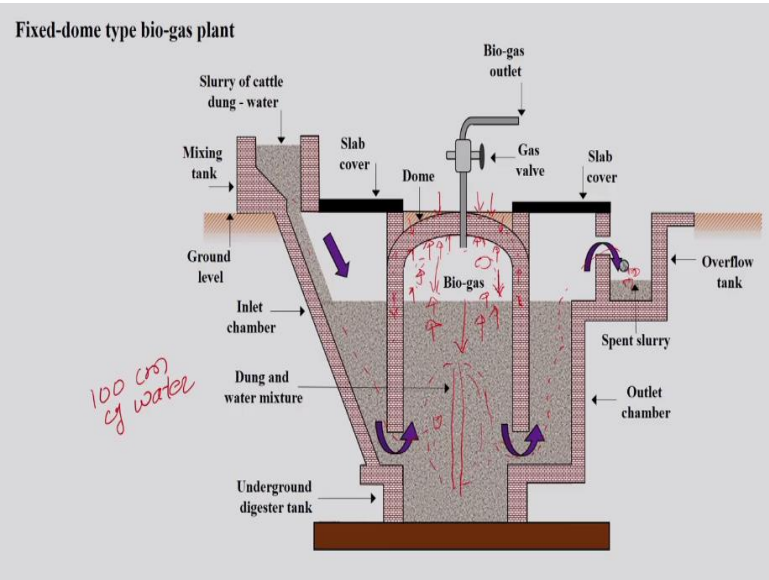
methane former bacteria here. So, this partition wall it also helps to provide a specific retention time or residence time inside the digester for the digestion of the organic matter.

And as a result, what happens is like this particular plant, it operates very well with good gas yield, because we are providing a specific environment which is required for the digester here because of this partitioning wall. So, what happened in this case, if you just try to see the operation of this particular plant, just take a look at the slide, so what happens is like the slurry, which either in the form of organic matter or the animal manure is fed inside the digester like this.

It goes inside the digester, its spend some time here, you can say in this particular part where mainly the acid former bacterias act upon the organic matter. And then it enters into the second chamber of the same digester where mainly the methanogenical bacteria acts upon this digested material or you can say the some acid which are formed during the this particular stage here in the digester.

And then it releases the gas during this methanogenic activity. And the gas produced get accumulated inside this particular drum. And then, it floats according to the pressure which is generated on the particular drum. That is why it is called as a floating drum type biogas plant. And then the digested slurry will come out from this particular output and will get ejected into the overflow tank. So, this is how the operation of this particular plant takes place.

(Refer Slide Time: 04:24)



So, if you just try to compare the operation of the now fixed dome type biogas plant, if you (()) (04:30) these kind of plants are more economical because of the complete machinery construction. As the gas pressure inside this particular dome, it varies depending on the consumption and the production of the gas. By construction of a dome structure, if you see here, this is a dome structure.

So, because of this what happens is like it provide a very strong structure for the outside pressure. But for the inside pressure, it is very weak and the gas exerts the pressure from inside out on this particular dome. The construction of this particular dome in the fixed dome type biogas plant is very crucial. And as a result, a skilled machinery workmanship is required for the construction of this particular dome in this plant.

If certain cracks or leakage happens in this particular dome, so, then what happens is like the oxygen or the air, it may penetrate from these leaks inside the gas and then it may not be able to maintain the anaerobic condition inside the digester. As a result, it will inhibit the anaerobic fermentation process and it will stop the entire digestion process inside the digester.

So, that is the reason as I mentioned, the construction of this kind of dome is very crucial in a fixed dome type biogas plant. So, if you try to see the operation also here of this particular plant, just try to have a look at the slide. So, here also the slurry either in the form of organic waste or the animal manure, it can be fed inside this particular digester like this. So, what happened in this case is now, if you see here, there is no bifurcation wall.

So, as a result as there is no bifurcation wall, so the gas yield which is obtained in this particular digester is relatively less compared to the floating drum type biogas plant. Because of the bifurcation in the digestion chamber there, it provides a proper environmental condition for the growth of the acid former bacteria as well as for the methane former bacteria, where it is not possible in this particular case, because there is no bifurcation here.

The gas yield which is obtained in case of fixed dome type biogas plant is relatively less compared to the floating drum type biogas plant. Moreover, many variations of the basic designs of this kind of plants are developed just to reduce the cost of the material. So, this is done by making use of different types of material, which are you can say the local materials

which are also being used into the construction of this kind of plant, just to reduce the cost of this particular plant.

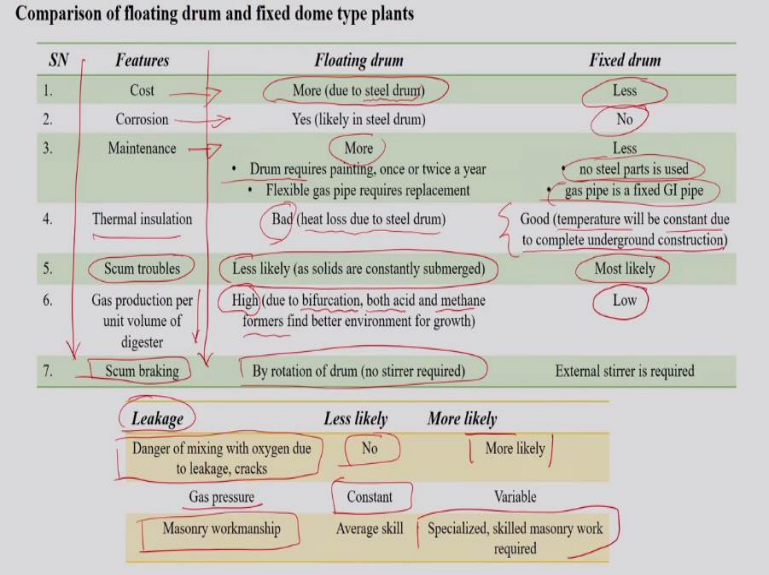
The slurry once which enters inside this digester, the digestion process will happen in this particular chamber. And then, the digested slurry will be displaced through this particular into the displacement tank. When this digestion process is taking place, so the gas which exerts the pressure on the particular drum, so, it will accumulate the gas inside this particular dome here which is called as a gas holder also.

And it accounts for around 10% of the volume of the digester as well, the pressure which gets buildup in this particular digester. It also displaces the inlet and outlet slurry in this particular digester. And also helps to maintain the pressure inside the reactor. But then in this case, the pressure appears to be in the range of around like as high as 100 centimeter of water.

So, as I mentioned earlier, as it maintains the pressure inside the reactor, so because of that high pressure, it may happen so that there may be some cracks or the leakages in this particular dome structure of the plant. The most of the gas is getting accumulated in this particular zone. So, it is exerting pressure inside out. As a result, it may create some cracks or leakages on this particular dome.

Since the entire construction of this particular plant is underground, hence, it is very easy to maintain the constant temperature inside this particular digester. So, this is one of the advantage of this particular digester as well. And some time it will happen that the temperature inside the digester is considerably higher than the ambient temperature mostly in the winter.

(Refer Slide Time: 08:52)



Comparison of floating drum and fixed dome type plants

SN	Features	Floating drum	Fixed drum
1.	Cost	More (due to steel drum)	Less
2.	Corrosion	Yes (likely in steel drum)	No
3.	Maintenance	More • Drum requires painting, once or twice a year • Flexible gas pipe requires replacement	Less • no steel parts is used • gas pipe is a fixed GI pipe
4.	Thermal insulation	Bad (heat loss due to steel drum)	Good (temperature will be constant due to complete underground construction)
5.	Scum troubles	Less likely (as solids are constantly submerged)	Most likely
6.	Gas production per unit volume of digester	High (due to bifurcation, both acid and methane formers find better environment for growth)	Low
7.	Scum braking	By rotation of drum (no stirrer required)	External stirrer is required

Leakage	Less likely	More likely
Danger of mixing with oxygen due to leakage, cracks	No	More likely
Gas pressure	Constant	Variable
Masonry workmanship	Average skill	Specialized, skilled masonry work required

So, if you just now try to compare the floating drum and the fixed dome type biogas plant, so there are different features are listed here, by which we can compare the operation of these 2 particular plants. So, if we just talk about the cost at the beginning, so, cost involved in the construction of floating drum type of biogas plant is more and in the fixed drum, it is less. Why? Because in this particular construction, the steel drum is required.

As a result, it is one of the most expensive material. And hence, the cost of construction of this kind of plant is more. Similarly, if you talk about the corrosion, it is more likely that the steel drum may get corrode here. But in this case, the corrosion is no because the entire construction is a machinery construction and which is made of the brick. So, corrosion is not an issue in case of the fixed drum type biogas plant.

Maintenance, obviously, it is more in case of floating drum. Why? Because the drum it requires painting once or twice in a year. And flexible gas pipe requires the replacement as well. In this case, no steel part is used as well as the gas pipe is a fixed GI pipe. So, as a result, the maintenance is relatively less in case of fixed dome type biogas plant. Thermal insulation, as it is a bad in this particular case, because heat is lost due to the steel drum.

Whereas, in this case is a very good insulator, as I mentioned, because the temperature will be constant due to the complete underground construction of the plant. Scum troubles, if you try to see this scum troubles, the scum formation is less as the solids are completely submerged in this particular case whereas here the slurry is not as like this. As the result, it form a scum on the top of the slurry as well.

The gas production in this particular case is relatively high, because of this part that is a bifurcation of the digester in the same unit, because both the acid and the methane formers find a better environment for their growth inside this particular digester whereas in this particular case, it is less because there is no bifurcation here. So, the scum braking, it can be done just by rotation of the drum here.

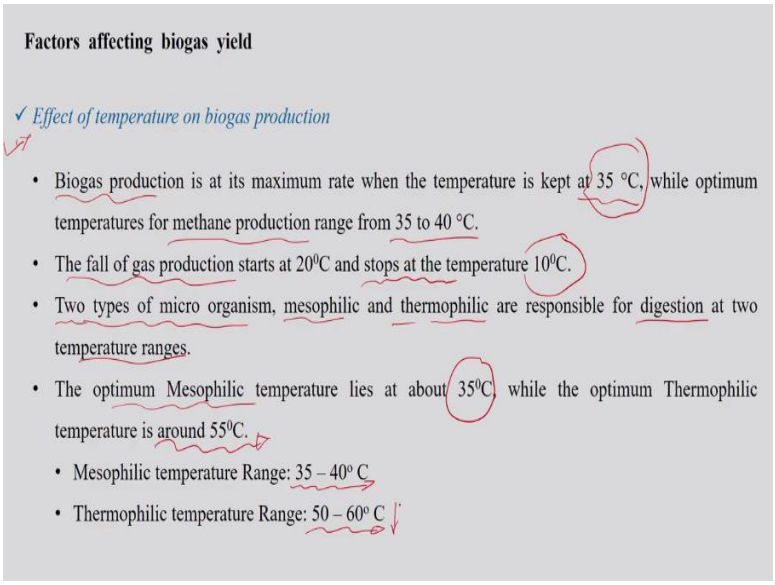
So, no stirrer is required, whereas in case of the fixed dome type biogas plant, the external stirrer is required to brake the scum in the digester. So, now, if we just talk about the leakage and safety aspect of this particular plant, so, compared to this the danger of mixing with oxygen due to leakage and the cracks, it is negligible here. But if you just try to see in this case, it is more likely.

Because, if you recall our discussion in the previous slide as I mentioned, so, the dome which is made of the construction of brick, so, it may happen that because of the excess pressure, there might be a some leakage inside that particular digester. And hence, the mixing of oxygen or the external air inside the digester is more likely to happen in this particular case. So, the gas pressure, it is constant here.

But in this case, it is a variable because the dome is fixed. And the masonry construction workmanship, as I mentioned, these are average skill here, whereas, in this particular case specialized, skilled masonry workmanship is required for the effective construction of the dome of this particular plant. So, this is how is the difference between these 2 particular plants.

So, after learning these 2 types of plant, let us see and discuss in details about the factors which affect the biogas yield in the digester. So, there are number of factors which affect the bio digestion process in the digester. And this particular factors need to be optimized to achieve a better gas yield. So, we will discuss these factors one by one.

(Refer Slide Time: 13:05)



So, now, if we just talk about the effect of temperature first, temperature is a very important factor for the efficient bio digestion of the organic matter. Because, when we talk about the temperature, so, the gas production is reaches to its maximum value, when the temperature is maintained at around like 35 degree C in the digester. While the optimum temperature for the methane production, it is in the range of like 35 to 40 degree C.

So, this is how this particular plant and the gas yield it varies if we are varying the temperature inside the digester. So, the digestion process it proceeds very rapidly at higher temperature. And it reduces the rate of digestion, if the temperature is below this particular range. Because what happens is like when the temperature is high, the digestion process get accelerated.

Similarly, if we just start to compare the digestion process in the cold climate region, what happened in that case is like the external drum, it needs to be heated, so, that we can maintain the temperature of around like 35 degree C for the digestion purpose. And if it is not done so, then the fall of the gas production will start once the temperature reaches to 20 degree C, and it completely ceases the production of gas at this particular temperature.

So, how to maintain this particular temperature of 35 degree C in the cold climate condition is like the gas is supplied from the produced gas in the same unit. The operation of such kind of plant is not economical. So, the methanogenic bacteria, they works better in the temperature range of around like 20 to 55 degree C. It has already been discussed that there

are 2 types of microorganism like mesophilic and the thermophilics are responsible for the digestion at 2 different temperature ranges.

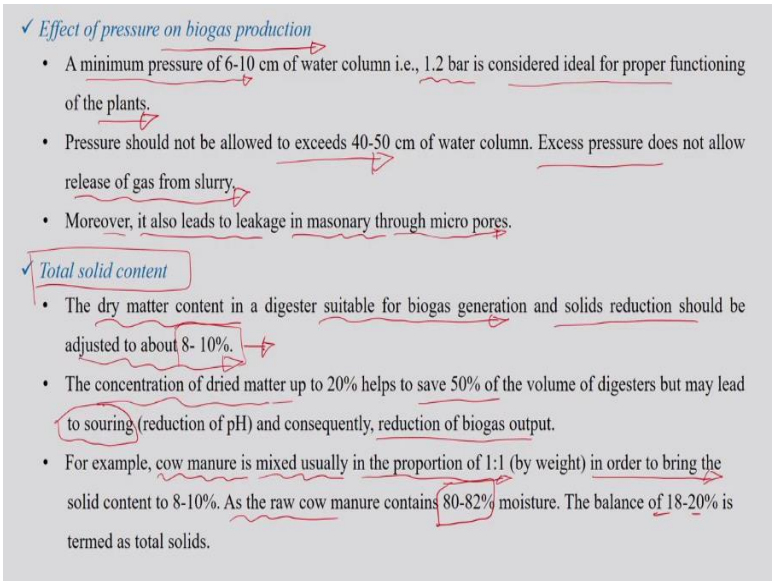
The optimum mesophilic temperature it lies at about 35 degree C, while the thermophilic optimum temperature range is around 55 degree C. Now, if we just try to compare the range of the mesophilic temperature range and the thermophilic temperature range here, so, it is 35 to 40 degree C and here it is 50 to 60 degree C. So, the range is very narrow.

And if the temperature goes beyond 60 degrees C, then what happens is like the production of the gas it gets stopped because of excessive temperature inside the digester. And it inhibits the growth of the bacteria, which are very essential for the bio digestion purpose. Hence, the proper or we can say the optimum temperature is required for the bio digestion purpose and which need to be maintained inside the digester for the efficient digestion of the organic matter as well as production of the good amount of gas from the digester.

It is also to be noted that, just by raising the temperature, it increases the gas production no doubt. But it also decreases the content of methane inside the gas. So, as a result, the optimum temperature is very crucial for the efficient operation of this particular plant. And any gross variation in the operating temperature in the digester it may lead to the unsatisfactory performance of the digester as well.

And hence I am just emphasizing on this particular point here that the temperature is very important factor in the bio digestion process. So, likewise, if we just try to see the another factor pressure on the biogas production.

(Refer Slide Time: 16:40)



✓ *Effect of pressure on biogas production*

- A minimum pressure of 6-10 cm of water column i.e., 1.2 bar is considered ideal for proper functioning of the plants.
- Pressure should not be allowed to exceeds 40-50 cm of water column. Excess pressure does not allow release of gas from slurry.
- Moreover, it also leads to leakage in masonary through micro pores.

✓ *Total solid content*

- The dry matter content in a digester suitable for biogas generation and solids reduction should be adjusted to about 8- 10%.
- The concentration of dried matter up to 20% helps to save 50% of the volume of digesters but may lead to souring (reduction of pH) and consequently, reduction of biogas output.
- For example, cow manure is mixed usually in the proportion of 1:1 (by weight) in order to bring the solid content to 8-10%. As the raw cow manure contains 80-82% moisture. The balance of 18-20% is termed as total solids.

Minimum pressure of around like 6 to 10 centimeter of water column is essential in the digester. So, that means, like around this much bar 1.2 bar is considered as ideal for the proper functioning of a plant. And pressure should not be allowed to exceeds 40 to 50 centimeter of water column. Why?

Because, the excess pressure does not allow the gas to release from the slurry, so, what happens is like, because of the excess pressure, the gas will get accumulated inside the slurry itself and hence it is not allowing the gas to release from the slurry and reach to the gas holder. This is one of the disadvantage of the excess pressure inside the digester. As a result, it also leads to the leakage in the machinery through the micro pores.

Apart from that, it may also leaks the pipeline as well as the joints in the pipeline. And then it also not safe in terms of the bio digestion process because it may form some explosive mixture also. So, that is the reason, maintaining a proper pressure or the ideal pressure inside the digester also is very important. So, now, if we talk about the total solid content, the water is very important for the survival and for the activity of the microorganism in the digester.

As well as it also helps in the hydrolysis of this organic matter inside the digester. As well as it also maintains the activity of the extracellular enzyme which are formed inside the digester. And this also helps to maintain a uniform mixture of the organic matter and its constituents (()) (18:21) inside the digester. Apart from that, it also helps for the movements of the bacteria inside the digester.

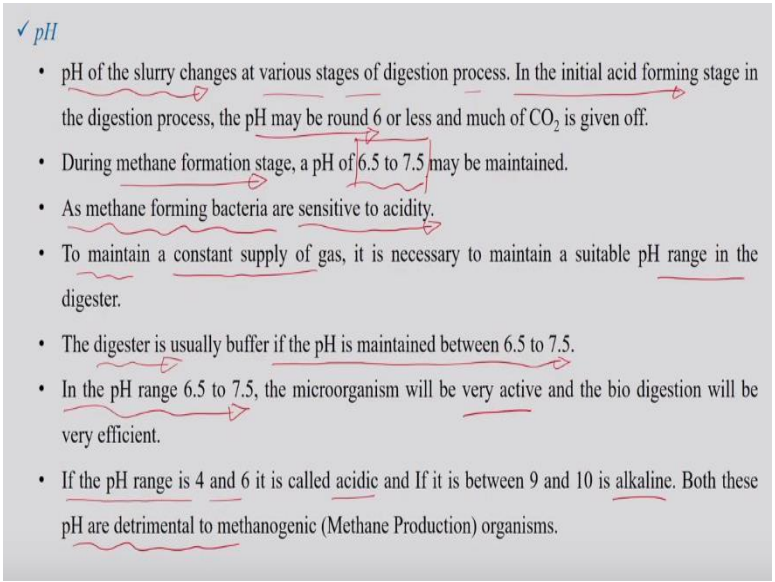
Because of the movement of this particular bacteria inside the digester, the digestion of the organic matter will occur in a faster rate. So, that is the reason the presence of water is very much important in the digester for the effective digestion process. So, what happened in this case is like if the dry matter contained in the digester suitable for the biogas generation, and solid reduction should be adjusted to around like 8 to 10%.

The concentration of the dried matter up to 20% it may save 50% of the volume of the digester. But then what happens is like it may lead to souring of the slurry solution and consequently what happens is like, it reduce the biogas output. And that is the reason, the dry matter in the range of like 8 to 10% is considered as the optimum solid content inside the digester.

For example, if you see here, the cow manure is mixed usually in the proportion of 1 is to 1 in order to bring the solid content in the cow manure to 8 to 10%. Why? Because, the raw cow manure contains about 80 to 82% of moisture, so, the balance is nothing but 18 to 20% is a dry matter. So, now bring down this particular solid content or dry matter to 8 to 10%. So, equal amount of water need to be added to this particular cow manure so that solid content can come down to 8 to 10%.

So, that way, the solid content need to be optimized inside the digester. Now, if we just try to see another parameter, which is a pH.

(Refer Slide Time: 20:10)



Because pH of the solution is very important in the digester, as I mentioned, the acid formers and the methanogenic former bacteria, their pH requirements are different. So, as a result, dynamic equilibrium between the pH need to be maintained so that the activity of this kind of bacteria is not getting affected inside the digester. pH of the slurry, it always changes at various stages of digestion process.

And this we already discussed in our previous lecture regarding the stages of anaerobic digestion process where the we discussed about also the mechanism of anaerobic digestion process. So, we have observed that the pH it varies according to these stages in the anaerobic digester. So, in the initial acid forming stage, it observed that the pH may be around 6 or less. And in this particular case, what happens is like much of the CO 2 is given off.

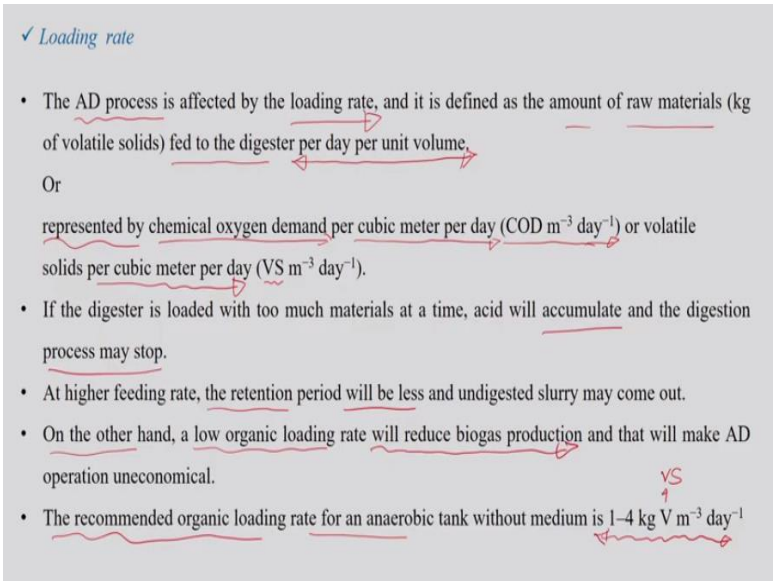
While during the methane formation stage the pH 6.5 to 7.5, it need to be maintained inside the digester for the better activity of this particular microorganism inside the digester. As methane forming bacteria are sensitive to the acidity, hence its pH need to be maintained in this particular range. Apart from that to maintain the constant supply of gas, it is also necessary to maintain a suitable pH range inside the digester.

If it is not done so, the digester is usually buffered if the pH is maintained between the 6.5 to 7.5. Obviously, it need to be done so that we can maintain this particular pH inside the digester. In the pH range of 6.5 to 7.5, what happens is like the microorganism will be very active and the bio digestion process will act faster rate. If the pH range is 4 to 6, then this is called as a acidic. Why? If the pH range is between 9 to 10, then it is called as a alkaline.

And too much deviation in this particular pH value may result into the detrimental effect on the methanogenic bacteria inside the digester. And eventually, it may result into the unsatisfactory performance of the digestion inside the digester. Thus, the pH is a very important and the crucial factor which need to be taken into consideration while operating the digester.

So, loading rate is also is one of the crucial and the important factor in the anaerobic digestion process.

(Refer Slide Time: 22:52)



Because, anaerobic digestion process is greatly affected by the loading rate and it is defined as the amount of raw material which is fed to the digester per day per unit volume. So, just take a note of all these units here. Because this will be helpful to us when we are designing a digester for the specific application or it is represented by chemical oxygen demands per cubic meter per day.

That is in the form of COD per meter cube per day or volatile solid matter per cubic meter per day that is nothing but represented as a VS here. So, if the digester is loaded with too much of the material at a time, what happens is like that, in that case, the acid will accumulated inside the slurry and the digestion process may stop.

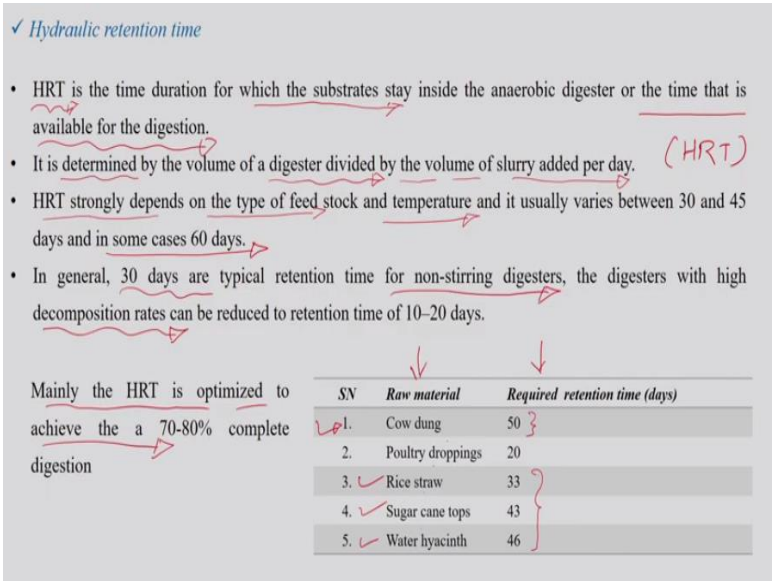
And if you recall our discussion in the stages of anaerobic digestion, so, in the third stage, if too much acid is getting accumulated, then what happens is like, the further stages will not happen in the digester and it will stop the digestion process inside the digester itself. So, that is the reason the loading rate need to be optimized. And it should be a very effective loading rate for maintaining the proper condition inside the digester.

If the loading rate is relatively high, then in that case, the retention period of that particular organic matter inside the slurry will be very less. And then as a result, the undigested slurry will come out from the digester. As a result, it will be a underperformer digester and then the gas yield which is produced during this particular operation at higher loading rate will be very less.

If you see on the other hand, a low organic loading rate, which you can say very low organic loading rate also will not be effective, because it will reduce the gas production. And then in that case, that the anaerobic digestion process will not be a economical. So, we need to optimize the loading rate accordingly. It should not be too much high. It should not be too much low also. It should be in between.

So, for that case, the recommended organic loading rate for anaerobic digestion process without medium is recommended as 1 to 4 kilogram of volatile solid. This is a volatile solid matter basically. It is VS, volatile solid matter per meter cube per day. So, if the operation is carried out in this particular loading rate, then the performance of the digester will be good. And it will also yield good amount of gas during the operation.

(Refer Slide Time: 25:36)



Now, the another important point is nothing but the hydraulic retention time. So, it is also related with the loading rate also. Because hydraulic retention time is the time duration for which the substrates stays inside the digester or you can say the time that is available for the digestion process inside the digester. It is determined by volume of digester divided by volume of slurry which is added per day inside the digester.

So, based on this, we can easily calculate the HRT of a specific digester. HRT is strongly depends on the type of feedstock and temperature. And it usually varies between 30 to 45 days. And in some cases, it may go up to 60 days also, because it all depends on the type of feedstock as well as the temperature which is maintained inside the digester.

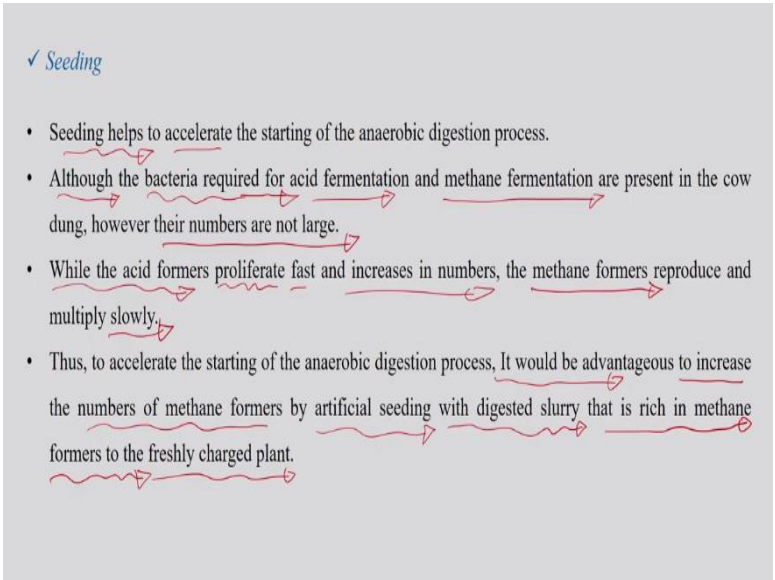
As we already discussed the effect of temperature, there also I mentioned the temperature is a very crucial factor in the bio digestion process. In general, 30 days is considered as a typical retention time for non stirring digester. The digester with high decomposition rates can be reduced to a retention time of even 10 to 20 days. But it all again depends on the types of the feedstock as I mentioned.

So, if you see here mainly the HRT is optimized to achieve the 70 to 80% of the complete digestion. So, based on this particular optimum value only the HRT is need to be calculated inside the digester so that at least 70 to 80% of the material should get digested inside the digester to achieve a good yield of the gas. So, similarly, different kind of raw materials and the retention time is shown here in this particular tabulated format in the slides.

If you see here, the cow manure, the retention time required is relatively high, which is around 50 days. And then if you try to discuss about the other component here, like rice straw, sugarcane tops and water hyacinth, the retention time is slightly different. And this also justifies our discussion that it depends on the quality of the material and the feedstock which is being used for the digestion purpose.

Apart from that also the temperature which is a crucial factor in the digestion process. So, this altogether helps to provide a proper retention type for the particular material inside the reactor.

(Refer Slide Time: 28:19)



Apart from that, this is also a very important factor which is called as a seeding inside the digester. Why it is essential, because seeding, it helps to accelerate the starting of the anaerobic digestion process. Because what happens is like, if we consider the raw material as a cow manure, so what happened in that case is like the bacteria which is required for the digestion that is nothing but the acid fermentation and the methane fermentation bacteria, these are present in the cow manure.

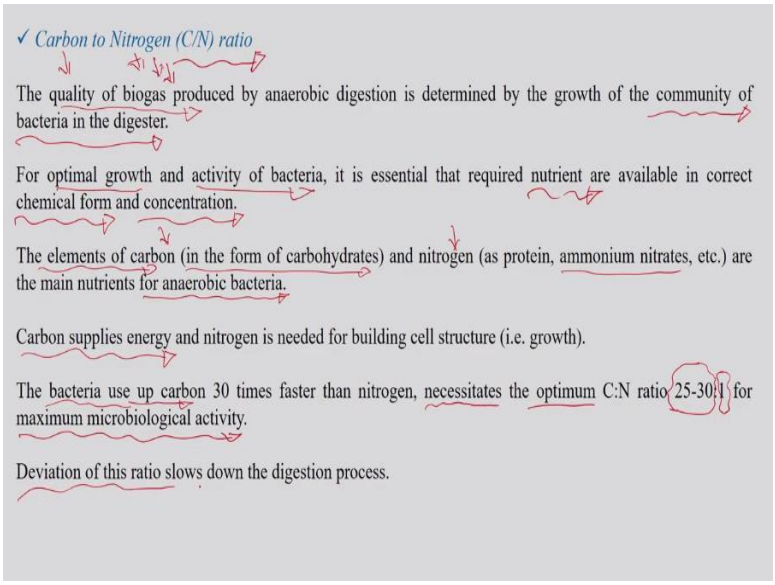
However, their numbers are relatively low in the cow manure. Then, what will happen in that case? If the number of bacterias are less, so accordingly, the slurry has to spend more time inside the digester for the complete digestion or you can say around like 70 to 80% of this digestion and then only it can release a specific amount of gas from the digester.

So, if you have to reduce that particular time of retention of the slurry inside the digester, then in that case, some amount of seeding need to be done along with the freshly charged plant inside the digester. Why it is so, because, the acid formers it may proliferate fast and increases in number at a faster rate. But the methane formation bacterias they reproduce and multiply very slow.

Therefore, to accelerate this particular process of digestion, it is advantageous to increase the number of methane formers by artificial seeding. That is nothing but by adding some seeding material inside the digester with the digested slurry (()) (30:00). So, the digested slurry of the previous batch can also be charged along with the fresh material inside the digester.

But only point which need to be considered here is like that the digested slurry and its solid content should not be more than (()) (30:14) 5 to 10% when you are feeding the seeding or you can say the digested slurry inside the digester. And this rich, because the digested slurry it is rich in the methane formers. So, it can be added to the freshly charged plant for the effective digestion of the material and to have the (()) (30:34) in the digestion chamber.

(Refer Slide Time: 30:37)



Apart from that, the carbon to nitrogen ratio is also is one of the important factor which need to be considered during the anaerobic digestion process. This carbon and nitrogen it plays a different role inside the digester. As I mentioned, a digester is a culture of bacteria, which is feeding upon this organic waste. So, this organic waste is nothing but the composition of the carbon and the nitrogen.

So, these are nothing but the nutrients which are available for the bacteria for their growth as well as for their survival inside the digester. If these particular nutrients are not maintained in the proper proportion inside the digester, then it may lead to the unsatisfactory performance inside the digester as well as it will have some harmful effect also on the anaerobic bacteria, which are inside this particular digester.

Why? Because, the quality of the biogas produced by this anaerobic digestion is determined by the growth of the community of bacteria inside this particular digester. If their growth is not happening under proper rate, so obviously, the gas yield will not happen in the proper rate as well as the good amount of gas will not come out from that particular digester.

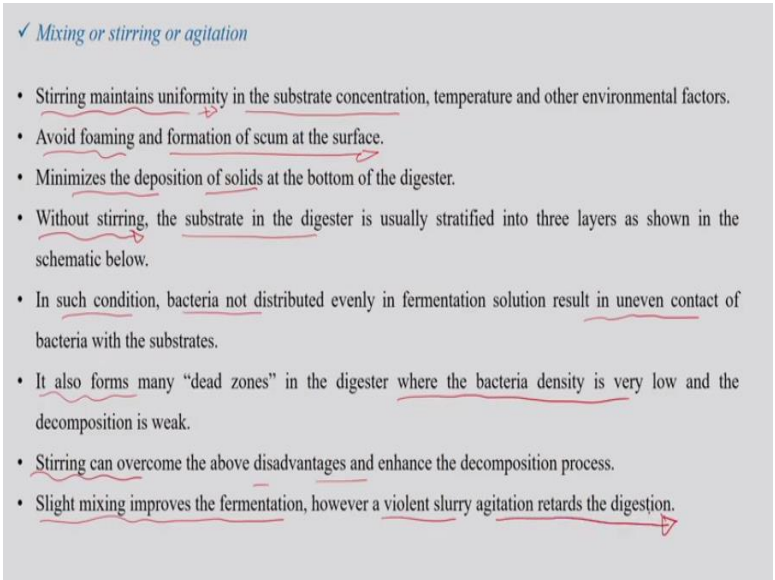
Similarly, for the optimal growth and the activity of the bacteria, it is very much essential to maintain the required nutrient in a correct proportion inside the reactor or you can see in the proper chemical form and in the proper concentration as well. The limit of carbon which are say in the form of carbohydrates and nitrogen such as proteins and ammonium nitrates are the main nutrients for anaerobic bacteria.

As I mentioned, so this carbon and nitrogen, this need to be maintained in proper proportion inside the digester. Why? Because, carbon supplies energy and nitrogen is needed for building the cell structure in the digestion chamber. And the bacteria as is very well known that it use up around carbon 30 times faster than the nitrogen. And hence it necessitates the optimum C by N ratio inside the digester.

And it is considered as around like 25 to 30 is to 1 C by N ratio for the maximum microbiological activity inside the digester. So, this is considered as a optimum C by N ratio for the efficient production of the gas inside the digester. Any deviation of this particular ratio it slows down the bio digestion process. Because the biodegradability of this all material it all depends on this particular C by N ratio.

For example, if this C by N ratio is not properly maintained, so, if it is low for example, in that case, what will happen is like more amount of ammonia will get generated inside the digester and then again it will inhibit the microbial growth inside the digester. It will again leads to a low gas yield inside the digester. So, that is the reason, the proper proportion of this C by N is very much important inside the digester.

(Refer Slide Time: 33:43)



Mixing or stirring inside the digester. As I mentioned, in the fixed dome, and the floating drum type biogas plant, the scum will form on the top layer of the slurry. And if the thickness of this particular scum is goes on increasing, then it will not allow gas to release from this particular slurry. And then, as a result, the pressure will get buildup inside this particular digester.

And then there might be a leakage or the breakage on this particular dome which again, allows the oxygen and the air to come inside this particular digester. And again, it will inhibit the entire microbial (()) (34:22) inside the digester. And the biogas production will stop. So, as a result, the mixing or the stirring or the agitation of the particular slurry is important inside the digester.

It helps to maintain the uniformity in the substrate concentration, temperature and other environmental factors, which are responsible for the efficient digestion of the slurry inside the digester. It also avoid forming and formation of scum at the surface. As I mentioned, because, it will also avoid the formation of scum at the surface if the particular slurry is stirred intermittently just to avoid the formation of scum on the surface.

So, it minimizes the deposition of solids at the bottom of the digester as well. So, without stirring, what happens is like the substrate in the digester is usually stratified into a 3 different layer as shown in the schematic below. So, in the next slide, I will show you like, if the stirring is not done inside the digester, how it is stratified into a 3 different layer inside the digester.

The bacteria are not distributed evenly inside the fermentation solution, and then it results in a uneven contact of that bacteria with the substrate. If there is a uneven contact of bacteria with the substrate, then what will happen is like, the digestion process will not happen effectively and then the gas yield also will not be good in that particular condition. So, apart from that, it also forms many dead zones inside the digester, where bacterial density is very low.

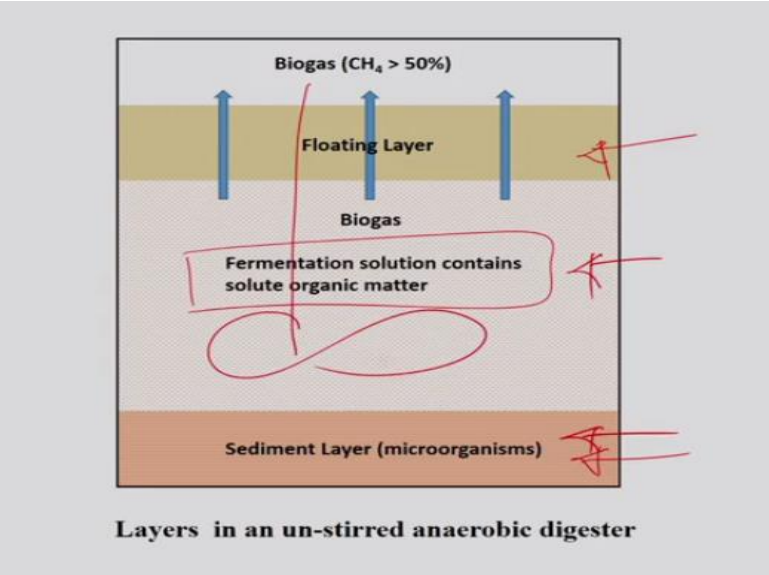
As a result, the decomposition is also very low. That is what I mentioned. Because, if the bacterias are not having even contact with the substrate, so obviously, the bacterial population in that particular area is very less. As a result, the decomposition is also very less and then relatively the gas yield is also very less. The stirring can overcome all these disadvantages and also enhance the decomposition process inside the digester.

But, one has to also make sure that slight mixing, it improves the fermentation. However, violent agitation inside this particular digester, it may retard the digestion process as well.

Because the stirring is also should not be very violent, otherwise, what will happen is like the bacteria will not have even contact with the substrate. So, as a result again, it will decrease the gas production.

So, it should be a very optimal stirring with the minimal rotation so that only it can be stirred once or twice so that the uniform contact of the bacteria with the substrate may happen inside the digester. And then the decomposition will start accordingly inside the digester. If this stirring is not done inside the digester, then it will form this 3 kinds of layer inside the digester.

(Refer Slide Time: 37:15)

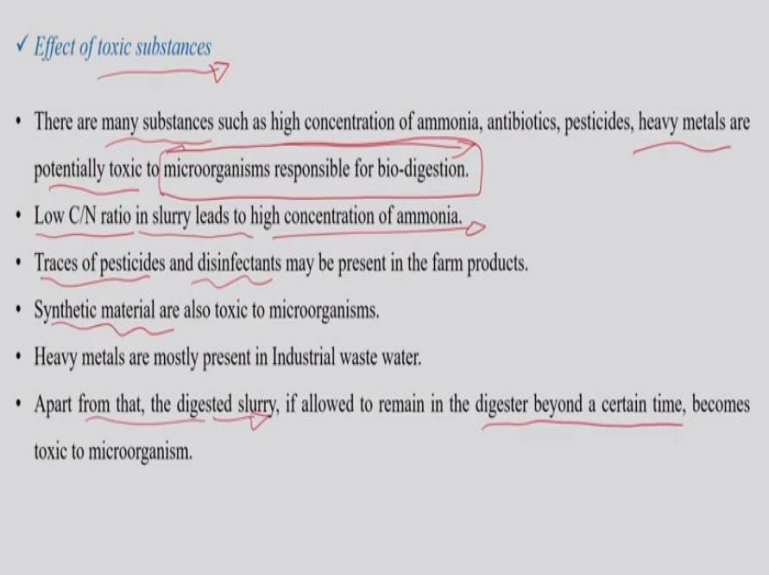


Layers in an un-stirred anaerobic digester

So, top one is nothing but the floating layer, as I mentioned, because, the light materials will float on this particular slurry. And then the fermentation solution which contains the organic solution also here and then the microorganism which is the sediment slurry. Now, if the stirring is not done, then there will be a stratification of this kind of 3 layers inside the digester.

So, to have the uniform mixture of all these 3, these need to be stirred inside the digester so that these 3 layers can be break and then it can form a uniform condition inside the digester for the better digestion of the organic matter by microbial activity inside the digester.

(Refer Slide Time: 37:58)



This is one of the important factor in the bio digestion process which is called as a effect of toxic substances. Why it is important, I am saying. Because, the source of these toxic substances is mainly depends on the type of organic material which is being used for the bio digestion purpose. And there are many substances such as high concentration of ammonia, antibiotics, pesticides, and heavy metals, which are potentially toxic to microorganisms, which are responsible for the bio digestion process.

Because, these microorganisms which are very much responsible for the bio digestion process and if the concentration of this particular substance is relatively high, then these are toxic to this particular microorganism in the bio digestion process. Even the low C by N ratio even as I mentioned in the C by N ratio also the slurry leads to high concentration of ammonia.

And again this is also inhibits the microorganism and its growth inside the digester. And traces of pesticides and disinfectant, it may be present in the farm product are also responsible for this particular toxic elements. And then it will inhibit again the gas production inside the digester. Synthetic materials are also toxic to the microorganism. Apart from that heavy metals which are mostly originated from the wastewater sewage are also toxic to the microorganism.

Hence, their concentration should be maintained in a proper control or in a allowable limit inside the digester. Apart from that, the digested slurry, this is also one of the important factor. If after one cycle of operation, if the digested slurry is allowed to stay again inside the

digester, then what happens is beyond certain time, it also becomes toxic to the microorganism.

And hence, it inhibits the growth of the microorganism as well as the it results into the low gas yields inside the digester. So, likewise, these kind of toxic elements need to be controlled inside the digester in a specific manner. So, for that these 2 tables are shown here, which represents the allowable limit of this particular substances or concentration of this particular substances inside the digested slurry.

(Refer Slide Time: 40:12)

Maximum allowable concentrations of toxic materials

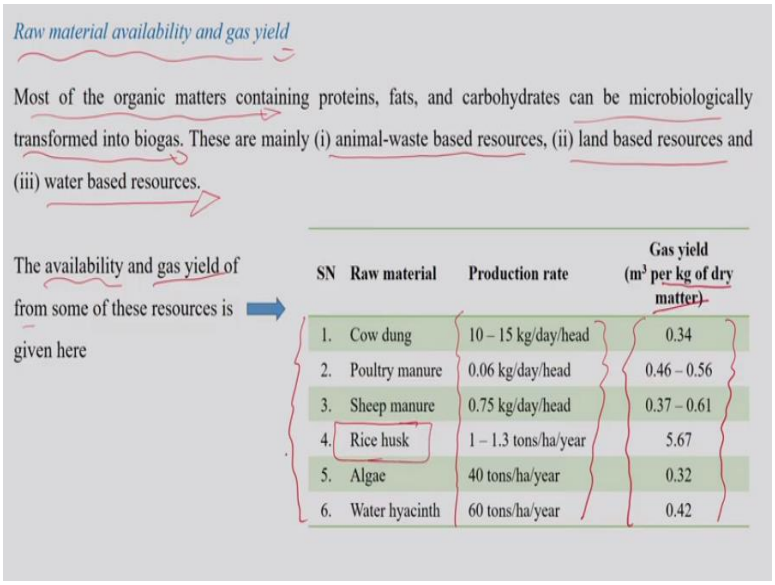
SN	Toxic material	Allowable concentration (mg/liter)
1.	Copper	100
2.	Chromium	200
3.	Nickel	200 – 500
4.	Sodium	5500
5.	Potassium	4500
6.	Calcium	4500

SN	Toxic material	Allowable concentration (mg/liter)
7.	Magnesium	1500
8.	Ammonia	3000
9.	Sulphate	5000
10.	Sodium Chloride	40000
11.	Cyanide	Below 25
12.	Detergent compd.	40 ppm

So, if you see that this particular table, it talks about this toxic material and it also talks about the different toxic material and this column gives the information about the allowable concentration of this particular material inside the slurry. It should be this much milligram per liter, and this is also this much milligram per liter. So, please take a note of these 2 tables. These are very useful if one has to design a proper digester.

And if certain feedstock consists of toxic elements, these need to be eliminated before feeding inside the digester.

(Refer Slide Time: 40:49)



Raw material availability and gas yield

Most of the organic matters containing proteins, fats, and carbohydrates can be microbiologically transformed into biogas. These are mainly (i) animal-waste based resources, (ii) land based resources and (iii) water based resources.

The availability and gas yield of from some of these resources is given here

SN	Raw material	Production rate	Gas yield (m^3 per kg of dry matter)
1.	Cow dung	10 – 15 kg/day/head	0.34
2.	Poultry manure	0.06 kg/day/head	0.46 – 0.56
3.	Sheep manure	0.75 kg/day/head	0.37 – 0.61
4.	Rice husk	1 – 1.3 tons/ha/year	5.67
5.	Algae	40 tons/ha/year	0.32
6.	Water hyacinth	60 tons/ha/year	0.42

So, this is one of the important point about the bio digestion process. Because, the raw material availability and the gas yield, this is one of the most important parameter which need to be discussed during this particular process. Most of the organic matters which are containing protein, fats and carbohydrates can be microbiologically digested or transformed into the gas in the digester.

And what are these particular matters? Mainly, animal waste, land based resources and water based resources. Water based resource in the sense is like sewage sludge which is coming from the wastewater or you can say the domestic sewage all those materials can also be used as a feedstock for that digestion purpose. The availability and the gas yield of this kind of materials is shown in this particular table here.

If you just try to see the raw material, there are ranges of materials which are shown here. And this is the production rate of this particular material. And relatively, this is the gas yield for this particular material. This is very much important, because the gas yield gives us the information about designing of the particular digester, how much amount of gas is getting generated per kg of dry matter.

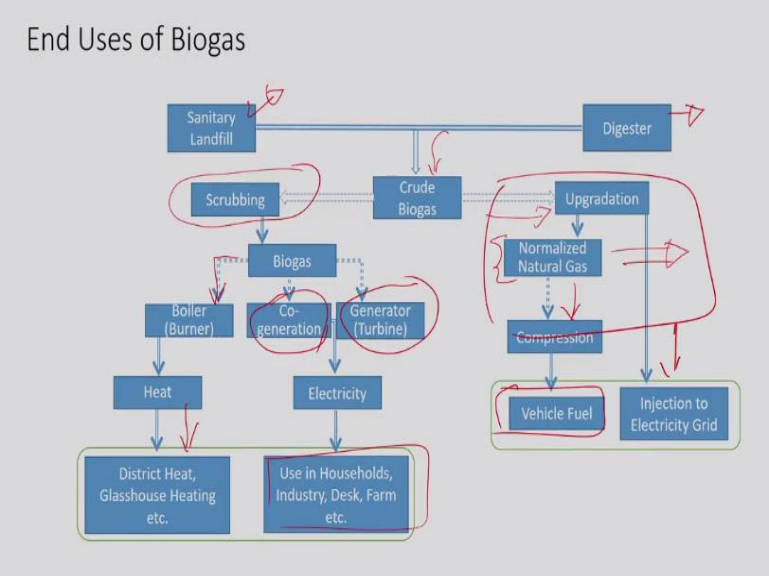
And based on that, one can design a very effective digester for the bio digestion purpose. Apart from that, if you see here, there are certain material which are nothing but the lignocellulosic material. So, for the effective position of this kind of material, this material needs to be pretreated first so that the (()) (42:21) cellulose can be broken down into a simple sugar.

And then the microorganisms can act upon these simple sugars for the effective digestion purpose. There are number of pretreatment techniques are widely being used nowadays for the anaerobic digestion process as well. So, by that way, it is nothing but a physical process, chemical process, biological process as well as a thermal process.

So, by doing so, we can pretreat the raw material before feeding inside the digester so that it is very convenient for the microorganisms which are present in the digester to act upon these simple sugars and get converted into a gas. As I mentioned earlier also in some cases, what happens is like, some amount of digested slurry is also fed inside this particular digester.

But solid content or dry matter content of this digested slurry it need to be maintained in the ratio of 5 to 10% so that it can also accelerate the bio digestion process inside the digester.

(Refer Slide Time: 43:20)



So, this slide it talks about the end uses of the biogas. So, now, the biogas which is produced from different kinds of raw material, so what to do with this particular biogas at the end? So, biogas, either it is produced from the sanitary landfills or maybe using the proper digester. So, this is called as a crude biogas.

So, the crude biogas once it is upgraded using a suitable upgradation technique, then, the methane content in this particular biogas can be increased to around like 70 to 90% even. And once the methane content reaches to around this particular range, then normalized natural gas composition can be reached. So, once this normalized natural gas composition can

be compressed then the compressed natural gas can be used as a fuel purpose inside the vehicle.

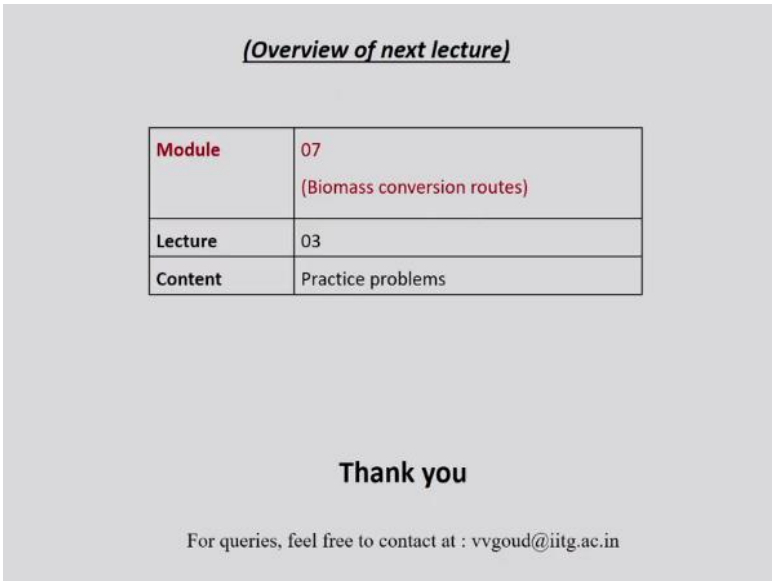
Along with that, the upgradation of this particular biogas can also be injected to a electricity grid for the electricity purpose. However, if this particular crude biogas is purified using a scrubber technique, so by that way, we can remove most of the unwanted gases from this particular crude biogas so that we can increase the percentage of the methane inside the biogas.

So, once the percentage of the methane is increased inside the biogas (()) (44:38) like 65 to 70% or even more than that, then in that case, the biogas can be used as a feed to the boiler so that the heat which is generated from this particular boiler can be used as a direct heat or the heat applications mainly for the heat applications. Similarly, the biogas can be co generated here or it can be also used in the generator.

So, it can be converted into the electricity and then the produced electricity can be used in the households or you can say in the commercial outlets, also in the desk or the farms. So, by that way the biogas has both the application it can be also used in the heating application, it can be also used to produce the electricity. Apart from that, it can be also used as a fuels in the vehicle just by this particular processing.

So, that way the biogas has a very wide application, as we have seen here in this particular slide. And hence, it is considered as a one of the most efficient renewable fuel which can be widely used for the specific application. So, with this, we will stop here. In the next lecture, which is Module 7, Lecture 3.

(Refer Slide Time: 45:53)



So, in that particular lecture, we will discuss about some practice problems about the design of the digester. In this particular lecture, if you have any doubt, just feel free to contact me at the email ID which is displayed on this particular slide. Thank you.