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 - 24
Practice problems

Good morning everyone, welcome to Part 2 of Lecture 3 under the same module. So, in this module will practice few numerical examples, if you recall our discussion in the previous lecture.

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Module	Module name	Lecture	Content
07	Biomass conversion routes	03 (Part II)	Practice problems

So, in the previous lecture as well, we practice few numerical examples about sizing of digester that is volume of the digester. So, in this lecture as well, we will practice few examples in the similar line, but with slight different approach. So, if you see the statement of first example here.

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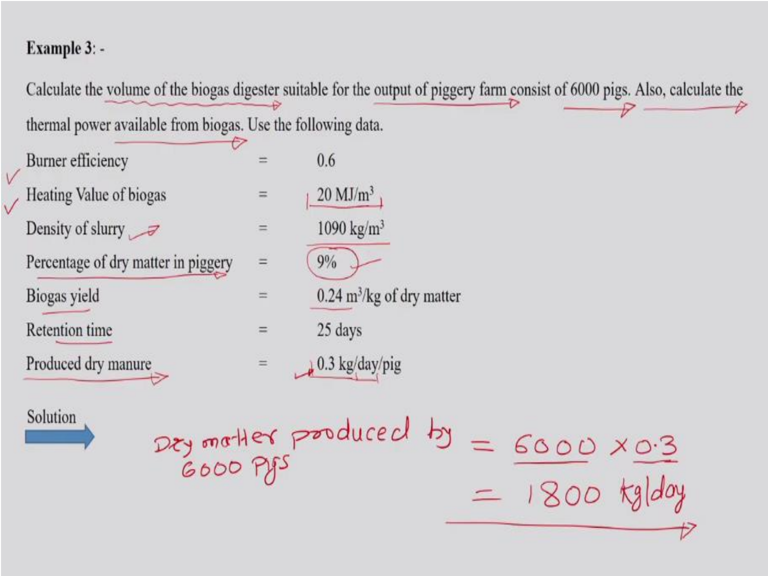

In this, we need to calculate the volume of biogas digester which is suitable for the output of one piggery farm. So, there is one piggery farm. So, the output of that particular piggery farm is utilized to produce a biogas. So, if you see the number of the pigs in that particular farm is given here. So, this gas which is produced based on that, we need to also calculate the thermal power which is available from this particular gas.

So, the example is very clear that we need to design one biogas plant first. And from that particular biogas plant some thermal energy is being produced for some application purpose. So, now, that particular thermal power which is available from that produced biogas is also need to be calculated in this example. If you see the content, the given data here is burner efficiency.

So, the burner efficiency is given here because we need to calculate the thermal power. So, the gas produced is getting burned. So, as a result, the burning efficiency of that particular burner is 0.6. The heating value of that biogas is mentioned here is 20 megajoule per meter cube. Now, if you see here, the value is slightly different than the value range which we have discussed in the module.

And it all depends on the feedstock as well as the biogas composition as well. So, that is why here, the calorific value which is mostly here, the parameter of the composition of the biogas. As a result, here the composition is such that its value is coming to be around 20 megajoule per meter cube. Now, the density of the slurry is given as this much. So, this is like change here, because here we are trying to find out the volume based on the slurry density.

And the percentage of dry matter content is 9%. So, as we know, for any digester the solid content in the slurry should be around 9 to 10%. So, whereas it is mentioned, the 9% is the dry matter content in the waste. And the biogas yield, if you see here it is 0.24 meter cube per kg of dry matter. So, this value is also depends on the feedstock which is being used and based on that the yield also changes.

So, this entirely is a parameter of the feedstock which is being used for the bio digestion purpose. The retention time given here is 25 days. And the produced dry manure is 0.3 kg per day per head. So, now, with this given data, we need to estimate the volume of the digester. And based on that particular volume, the gas which is getting produced is being used for the thermal power. So, based on that, we need to calculate the thermal power.

Let us try to solve this example in a stepwise manner. So, first as we know, we have the dry matter produced by. So, it is very easy to calculate because we know the numbers. And then we know the dry matter in the manure which is around 0.3. So, we know this many numbers, so, I just multiplying it by the produced dry manure per day per head. So, that is around this much. So, it is coming around 1800 kg per day.

So, now, this is the dry matter produced from the particular farm. So, now, with the help of this dry matter which is produced from the farm, we can calculate further the volume which is required for the digestion purpose.

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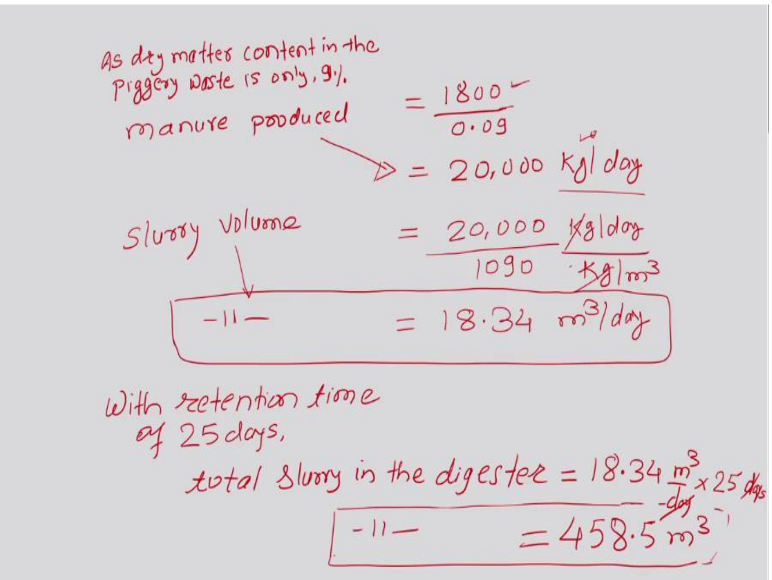

As dry matter content in the piggery waste is given here, which is only 9%. So, we can calculate the manure produced. So, simply what we are to do in this case is like, you just divide the dry matter which you have calculated in the previous stage by the dry matter content in the waste. So, it gives the values equivalent to 20,000 kg per day. So, this is the manure produced.

This value is nothing but the dry manure which is produced from the specific farm. And as it is given the dry matter content in the piggery waste is around 9%. So, to get the total manure which is produced in the farm, what we need to do in that case is like you have to just divide it by the that percentage of dry matter content to that particular quantity. So, once you do that, we will get the total manure which is produced from the farm on daily basis.

So, once we know the total manure produced so what we can do that case is like because as we know the density of this particular slurry, so, what you can do is like you can just divide it by the density of the slurry. Because if you see these particular value is in the kilogram, and since we need to calculate the volume in the meter cube, so, simply we are just dividing this particular value of manure produced by the slurry density.

So, if you see here this is in the kg per day and this value is kg per meter cube because this is a density. So, if you see here after dividing this the value comes out to be around 18.34 meter cube per day. So, this is the slurry volume we can say, which is getting generated per day. So, this is the total slurry which is getting produced on a daily basis.

So, now, with the help of this particular slurry, we can easily calculate the volume of the digester which is required for the given feed material and then based on that we can fix the sizing of the digester. So, now, let us see how to calculate the remaining steps. So, based on this 18.34 because as it is mentioned in the example with retention time of say 25 days is given in the example, so, based on this 25 days retention time, so total slurry in the digester can be calculated very easily.

So, the total slurry in the digester is, for example, this is the slurry which is getting fed inside the digester on daily basis per day suppose, you just multiplied by the 25 days. So, what happened in that case? So, we will get the total volume in the form of. So, this is what is the total slurry in the digester for 25 days.

So, now, if you remember our discussion in this particular module, so, we assume that the volume of the slurry is nothing but equivalent to the volume of the digester, so, in this case, since the volume is 458.5 meter cube.

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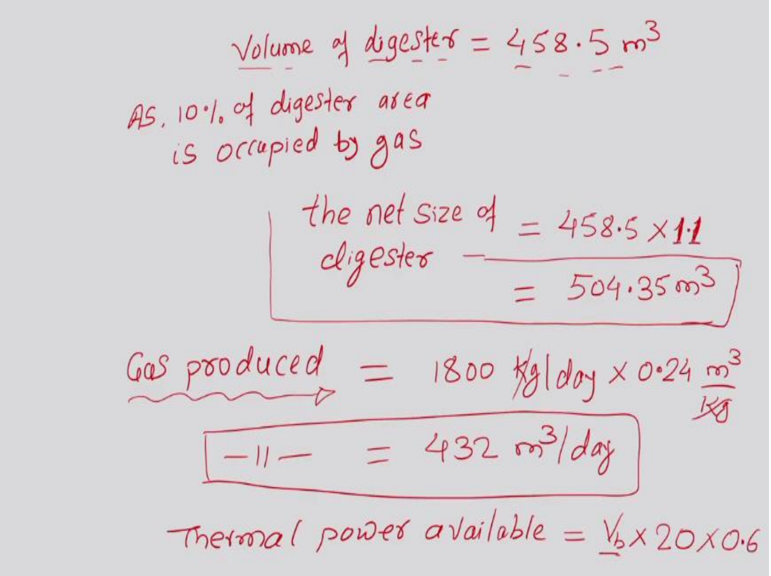

So, now, you can assume that this is the volume of the digester. So, the volume of the digester we are considering it as is equal to 458.5 meter cube. So, this is because the slurry volume is considered as equivalent to the volume of the digester. So, we can refer this as or we can assume that this is the volume of the digester. So, now, another assumption which you have made in the module while discussing about the biogas plant or sizing of the biogas plant.

As 10% of digester area is occupied by gas. So, based on this particular assumption, the net size of digester if you need to calculate, so the net size of digester equal to because simply what you have to do here is 458.5 into just we are increasing the area by 10% that is multiplied by 1.1. So, we will get the value equivalent to 504.35 meter cube.

So, now, this value is equal to the net size of the digester considering the 10% of the area which is occupied by the gas even. So, this is volume of the digester which is equivalent to the volume of the slurry, but as we are assuming the particular model that 10% area is always occupied by the gas in the digester. So, we have to adjust that particular volume while designing accordingly.

So, that is the reason we have just multiplied by the 10% excess area here so that if you see the change in the volume is by this much amount. So, this is you can say the net size of the digester for the given feed. So, now, once you know this is the net size of the digester which is required to produce the given amount of gas. So, now, based on this now, we can calculate the thermal power which is available.

So, if you remember the given data in this example, it is mentioned that the biogas yield in this case is given as 0.24 meter cube per kg of dry matter. So, now, based on that, we can calculate the gas produced in the digester. So, if you see the data which we have calculated in the previous slide, so, we have in this example around 1800 kg per day is the available dry matter for the digestion purpose in the digester.

So, the given gas yield for this case is around 0.24 meter cube per kg of dry matter. So, now, if you multiply this term, we get the value equivalent to 432 meter cube per day. So, this is nothing but gas produced per day. Now, if you see the gas produced and the size of the digester, you can easily distinguish between the values. Because obviously, it is higher the net side of the digester is higher than the gas produced here.

Because it is occupying some amount of gas in the digester itself and it is continuously being used, we assume that the gas produced is being utilized continuously for the thermal power. So, accordingly this particular volume is sufficient enough for the digester to produce the gas. So, now, based on this gas produced, if you calculate the thermal power available, then we need to do few more calculation.

For example, thermal power available can be calculated using this equation. Simply because this is the volume of the biogas because in this case, the biogas is used to produce the thermal power, so, once we know the volume of the biogas which is getting produced per day. So, we consider that same amount of gas is getting utilized for the production of the thermal power, so, based on that we are just calculating the thermal power which will be available from this particular output of gas.

So, if you multiply this volume of the gas into its calorific value, which is given 20 megajoule per meter cube into the efficiency of the burner. Now, here the efficiency plays a significant role, because the efficiency of the burner is 60%. So, if the input of the gas is mentioned at around like 432 meter cube per day, but how much gas is really getting utilized to produce the thermal power. It is based on the efficiency of the burner.

So, efficiency of the burner is about 60%. So, we are just multiplying the entire value by 0.6 and then based on that, if you see the calculation.

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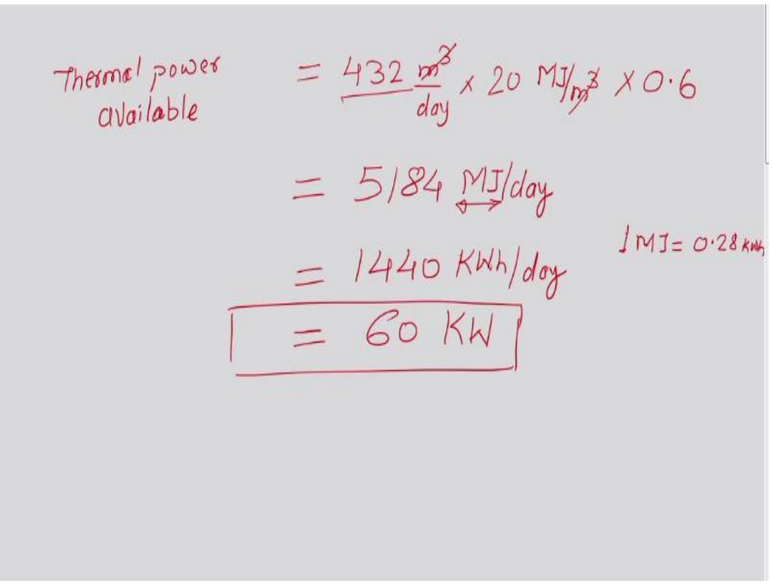

So, I would say here again, the thermal power available equal to so volume of the gas, we will just replace the number here, which is 432 meter cube per day, which we have calculated in the previous step multiplied by the calorific value, which is 20 megajoule per meter cube because it is in the meter cube and then the burner efficiency which is around 0.6. So, now, if you multiply these quantities, so in this case, this value will go.

So, now we will have the thermal power, we just multiply this quantities here, and then will get the thermal power available is 5184 megajoule per day. So, now, if you convert this value into kilowatt hour, so, for that, we are into convert the megajoule into the kilowatt hour. So, what we will do in this case is like, we will just convert this value into kilowatt hour. So, 1 megajoule equal to 0.28 kilowatt hour.

So, now, accordingly, if you convert this value here, we get the value in the form of 1440 kilowatt hour per day. So, this is per day basis. Now, if we just convert this value into a kilowatt, so what you have to do in this case is like just you have to convert this value into the hour basis. So, you just simply divide it by the 24 hour basis, and then we will get the value in the kilowatt that is 60 kilowatt.

So, the thermal power which is available from the produced gas is around 60 kilowatt amount of the thermal power which will be available from the specific biogas plant with volume of the biogas if you consider or you can say the volume of biogas which is getting produced from the digester is suppose this much. So, based on that around 60 kilowatt amount of power can be extracted here.

By this way, we can practice few more examples in the similar line. If we just change the waste from suppose piggery waste to cattle manure in the form of like cow manure also. So, there will be a slight changes in the values which are given there. Because, as I shown the table in the previous lecture even in that table we gave the values of the specific feedstock and what is the biogas yield for the specific feedstock as well.

So, once you note down those values accordingly, we can calculate the volume of the digester for the specific feedstock. So, this is how is the volume of the digester we can estimate based on the given data as well as we can assume certain values, if it is not mentioned in the example, but the value should be in the range, which are discussed in this particular module. So, based on that, we can easily calculate the volume of the digester.

And if it is required to calculate the thermal power available, similarly, we can also calculate the thermal power available from the specific output of the gas.

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Example 4:

A engine generator system running a on biogas is installed to produce 5 kW of electric power. Estimate the volume of the digester of the biogas plant required, if cattle waste is used as the feed material?

Given data: -

	Calorific value of biogas	= 25000 kJ/ m^3
	Generator efficiency	= 85%
	Engine efficiency	= 28 %

The following are some approximate rules can be of use for sizing biogas plants.

(i) One kg of dry cattle waste produces approximately 0.9 m^3 of biogas

(ii) One Kg of fresh cattle waste contains 9% dry biodegradable mass

(iii) One kg of fresh cattle waste has a volume of about 0.75 liters.

(iv) One Kg of fresh cattle waste needs an equal amount/ volume of water for preparing slurry.

(v) Typical HRT of slurry is a biogas plant varies from 40-55 days. For this example HRT is considered as 40 days.

So, now, let us discuss one more example, which is slightly different than what we have discussed earlier. So, this will also give one more attempt to understand like, if the given data is not in the specific form, so, we can assume certain values. So, those assumption what we have done in this particular example, so, assumption will be given on the practice examples as well.

So, (()) (21:53) assumptions can be used to solve the example. And if you see this example, it is mostly based on the engine generator system and it is running on a biogas which is installed to produce around 5 kilowatt of electric power. So, it is producing 5 kilowatt amount of electric power. And based on this we need to estimate the volume of digester of the biogas plant, if the cattle waste is used as the feed material.

So, for this particular case, it is mentioned that the cattle waste. So, now, calorific value of this particular biogas mentioned here is now suppose this much, so which is slightly different (()) (22:43) which have discussed in the previous example. That is the reason I mentioned it is all based on the composition of the biogas. So, there is a slight variation in this particular values.

In this case, the generator efficiency is 85% and the engine efficiency is 28%. Because, here the engine is attached with the generator, so generator also has this efficiency as well as the engine also has some specific efficiency. So, we need to take into consideration both these efficiencies to calculate the size of the digester. Apart from this, there are certain approximate rules which we need to consider for sizing the biogas plant.

In this case, if you see here, it is mentioned that 1 kg of dry waste it produces approximately 0.9 meter cube of biogas. Similarly, second assumption 1 kg of fresh cattle waste it contains again 9% dry biodegradable mass. And third assumption 1 kg of fresh cattle waste has volume of about 0.75 liters. So, this is also mentioned here. And 1 kg of fresh cattle waste needs an equal amount volume of water for preparing the slurry.

So, this is one additional point which is mentioned or given in this example that even if the fresh cattle waste has a volume of 0.75 liter which is mentioned there. So, it is mentioned that to utilize this fresh cattle waste an equal amount of water still need to be added in this particular example, clear. So, that is the reason even the dry matter content is mentioned here is 9% but still because the fresh cattle waste has only volume of around like 0.75 liter.

So, that is the reason it is specifically mentioned here that to these wastes and equal amount of water need to be added to make it a slurry. And the last is the point about the HRT of slurry in a biogas plant. As we know it varies from 40 to 55 days, but for this example, the HRT is considered as the 40 days. So, now, with this given data, we need to calculate the volume of digester of a biogas plant.

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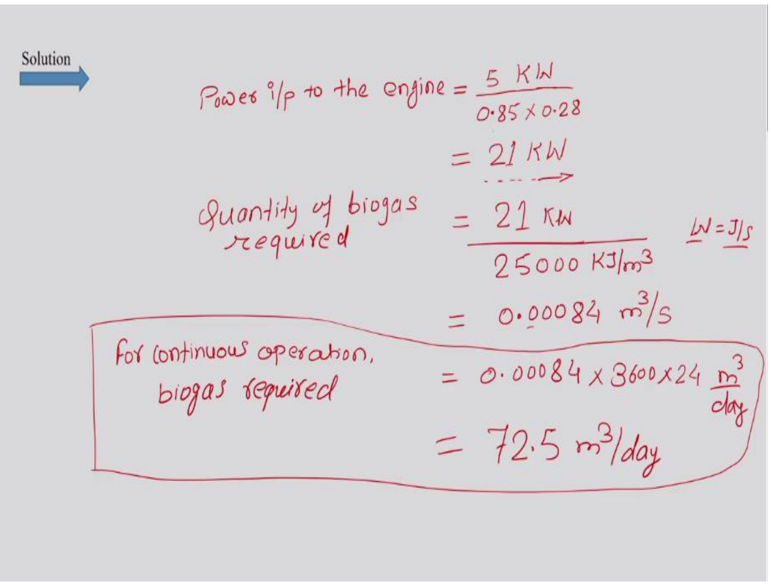

So, let us try to solve this example, again, if you see in this example, the power output is around like 5 kilowatt amount of power is the output from this particular engine generator system. So, to get 5 kilowatt amount of power, what is the power input which is required to the engines and generator system that need to calculate first.

So, based on that the power input to the engine is suppose 5 kilowatt amount of power divided by the efficiency of both the system that is generator and the engine, why it is so, because as I mentioned, this is the generator efficiency and this is the engine efficiency. So, now, based on this efficiency, we need to calculate the exact power input to the engine.

And if you see the value which comes out here is around 21 kilowatt because this is 5 kilowatt amount of power which is the output from the engine generator system. So, now, to this input power which is at 21 kilowatt, so, for this power we need to calculate the quantity of biogas which is required to input this much amount of power to the engine. So, now, quantity of biogas required how we calculate, so, we have 21 kilowatt amount of power.

So, based on 21 kilowatt amount of power which is a input to the engine, we can calculate the quantity of the gas which is required. So, now, for this we need to simply divide it by the calorific value of the gas which is 25,000. Now, here it is in kg per meter cube. So, here it is kilowatt. So, kilowatt is nothing but you can convert it into kilojoule per second.

And then once you convert it, and after dividing these values, we will get the value in the form of 84 meter cube because this kilowatt is nothing but is joule per second. So, this is the conversion. So, 1 watt is equal to 1 joule per second. So, using this conversion, you have just converted this particular value still got the value in the form of 0.00084 meter cube per second.

So, for continuous operation, we need to convert this value on the per day basis. So, for continuous operation, biogas required is nothing but equal to 0.0084 we have just converted the value on per day basis which is coming around. So, once we multiply these values, it comes out around 72.5 meter cube per. So, this is biogas which is required for continuous operation on a daily basis. So, this is the quantity of the biogas which is required.

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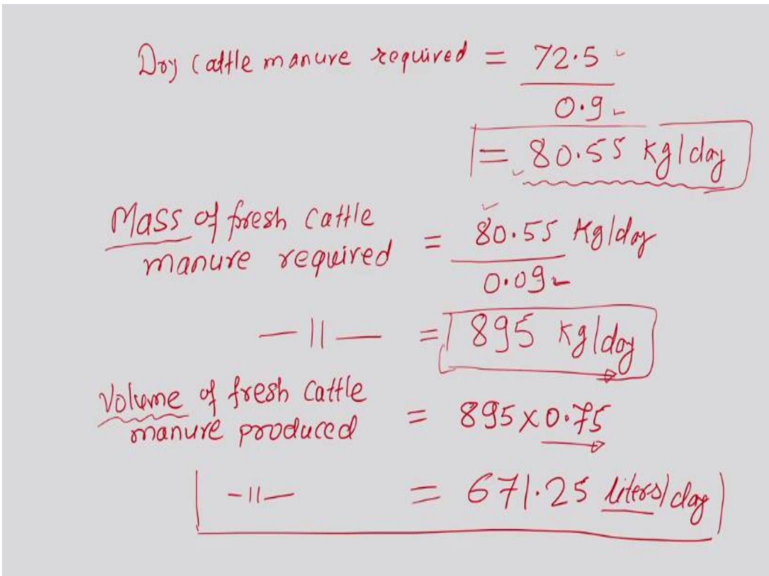

So, based on this now, we can calculate the dry cattle manure which is required. So, it is simply we can calculate because we know because this is the value of 72.5 is the biogas which is required. That is 72.5 meter cube per day. So, the dry cattle manure required is 72.5

divided by we are just simply dividing it by the 0.9. Because in this case if you see the first point in the example, which is mentioned there that 1 kg of dry cattle manure it almost produces around like 0.9 meter cube of a gas.

So, based on this because we know 72.5 is nothing but amount of the biogas which is required. And 1 kg of cattle dry manure it produces around 0.9 meter cube of a gas. So, you are simply using this conversion here so that we can get the value in the form of kilogram per day which is around 80 point. So, this conversion, if you are not clear, so, I am just explaining again.

So, this is 72.5 is the biogas which is required for the continuous operation on daily basis. So, once we know this is the biogas which is required on a daily basis. So, the first rule which is given in this example is 1 kg of dry cattle manure it produces around 0.9 meter cube of gas. So, based on that we have just converted this into a dry cattle manure which is really required for the production of this much amount of the gas, so, which comes out around 80.55.

So, once you know that raw cattle manure which is required, so, you can simply calculate the mass of fresh cattle manure which is required for the given plant. So, in this case, it is very simple what we are doing is like in this case, so, this is the dry cattle manure amount which we know which is 80.55 kg per day. So, simply we are dividing it by 9% of the this is the dry matter.

So, simply we are dividing it by 9% which is 0.009 which is the dry matter content in the cattle manure. So, once you divide this we get the value in the form of 895 kg per day. Because this value is in the kg per day, similarly, once we are dividing it by the dry matter content in the cattle manure.

So, to calculate the fresh mass of cattle manure which is produced on daily basis, what we are done in this case is the dry cattle manure produced value is around this much. And in this particular manure, there is a 9% of dry matter content. So, simply we have just divide those values by the 0.09 here. So, once you divide this by 0.09, what happens is like they are getting converted into the fresh manure which is produced on a daily basis.

So, you have just simply divided by the 9%. So, this is the amount of fresh cattle manure which is produced on daily basis. So, if you see one more rule in this example, it is mentioned that although the cattle manure in this case, so 1 kg of cattle manure has a volume of around 0.75 liter and to make the slurry for this particular cattle manure, there is equal amount of water which need to be added so that we can convert it into the slurry.

So, if you convert this into the volume, so the volume of fresh cattle manure which is produced is equal to because this is the value which is given in the example. Simply it is getting multiplied here that 0.75 liters is nothing but the volume of the cattle manure. We have just simplifying it to convert into the volume. So, after multiplication of these quantities, it comes out around 671.25 liters per day.

So, this is the volume of fresh cattle manure, this is mass of the fresh cattle manure, we have just simply converted into the volume because then we can calculate the volume in the meter cube for the digester as well. So, once this is the volume of the fresh cattle manure, which is produced, which is 0.75 liter, which is mentioned there. For 1 kg of cattle manure, which is mentioned as, it has a volume of around 0.75 liter.

So, we have around this much amount of cattle manure. So, this much amount of cattle manure, which is in kilogram per day it has been converted into (()) (36:03) liters per day by this conversion. So, now, let us calculate the volume of the slurry.

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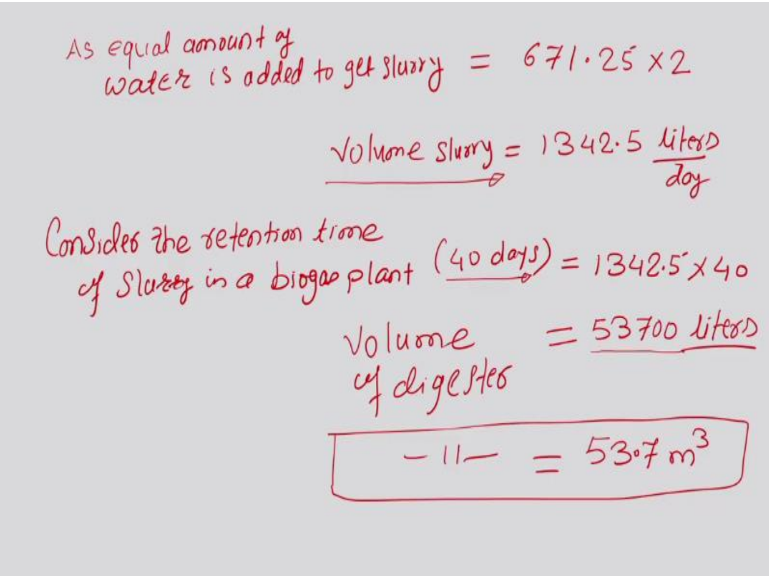

So, to calculate the volume of slurry now, as it is mentioned equal amount of water is added to get slurry. So, amount is nothing but suppose here 671. So, to get the volume of the slurry, what you have to do? You have to simply multiply it by the 2 so that equal amount of water we are adding into this slurry. So, the volume of slurry comes out is equal to 1342 point liters per day. So, this is the volume of slurry which is required for the specific plant.

Now consider the retention time of the slurry retention time of in a biogas gas plant has 40 days. So, as it is given as 40 days simply what we are doing is in this case is 1342.5 multiplied by 40. So, simply multiplying this quantity, get the answer as 53700 which is in liters. So, this is considered as the volume of digester. Because if you know this is the volume of the slurry which is required on the daily basis.

So, as the retention time of the slurry, which is mentioned here is a 40 days. So, simply we are multiplying it by the 40 days. So, that will get the total volume of the slurry. If this is the total volume of the slurry, so, the total volume of the slurry is equivalent to the volume of the digester. If you convert this value into the meter cube, so we will get it as 53.7 meter cube.

And then as this is the volume of the digester, so to calculate the net size of the digester so you can again multiply it by the 1.1 so that you can get the net size of the digester as well. So, whenever it is mentioned that to calculate the net size of the digester as well. So, you can just simply multiply it by the 1.1 to get the net size of the digester.

Because, as we mentioned already in the previous example, as well, because the 10% of the volume is occupied by the gas. So, this is the volume of the digester. So, to calculate the volume of the gas which will get occupied in the digester, so, for that reason, we are considering the 10% (()) (39:52) volume of the digester. So, in that case, here once you multiply it by the 1.1, again, you can get the net size of the digester so that you can do as well, while solving the example.

So, you can calculate that so that we already done in the previous example. So, I am just not repeating here, so that you can do that particular calculation. So, in this lecture, if you see here, we have seen 2 different approaches to calculate the volume of the digester. Similarly, based on the volume of the digester and the gas produced from the digester, if it is need to calculate the thermal power available, so, we can also calculate the thermal power which is available from the specific output of the gas from the given digester.

So, like this, there will be a similar kind of examples will be given in the assignment to solve. So, you can easily solve this kind of example, I guess. So, with this, we will stop here.

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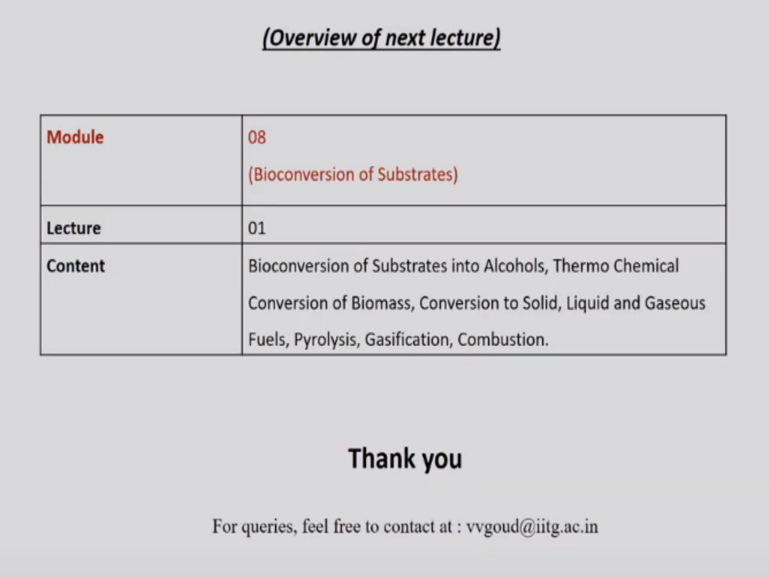

In the next lecture, we will start our new module that is the bioconversion of the substrate that is the Module number 8. So, the content of that module is bioconversion of substrate into alcohols, thermochemical conversion of biomass and then conversion into solid, liquid and the gaseous fuels. So, this particular topic will discuss in this particular module.

This is very important to know like what are the solid fuel, liquid fuel and the gaseous fuels can be obtained from the thermochemical conversion system. And then will study the pyrolysis, gasification and combustion technique. So, in the pyrolysis, we will touch upon some different types of pyrolyzer, different types of gasifier. And then we will discuss in slight detail about the combustion process as well.

So, this is all about today's lecture. In this lecture, if you have any doubt you just feel free to contact me at vvgoud@iitg.ac.in. Thank you.