BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture 39

Lecture 39: Wind and Bio Energy

Welcome to the NPTEL lecture on Building Energy Systems and Auditing in the module number 8 Green Energy and Sustainability. In the lecture number 39 we will now discuss the Wind and Bioenergy. In this particular chapter in this lecture, we will be going to discuss the application of the wind energy and its different components and also the bioenergy and method of energy estimation. So, first of all let us go to the bioenergy. I have written down again these four important parameters of any kind of the Re.

The first one is the in case of the bioenergy the output is some gas particularly the methane as the will be the gas which can be having some kind of a calorific value and which can be act as a fuel. So, from the bioenergy directly I am not going to get any kind of electricity which I can get from the solar. Even I can also get from the wind, but from bio I have to go via a particular methane gas. The application, what is the application? We can generate electricity through generator, we can actually use that gas as a fuel also for our cooking purpose or some kind of the heating the water or something like that.

Suitable applications definitely the residential societies, the multifamily apartments and also the institutes and the hotels where the bio the waste bio waste is much more I mean can be there is a potential of the much higher amount of the generation of the bio waste. Specific requirement a continuous availability of the biomass. This is very important if you have a run a particular bio the energy digester or so a continuous flow from the design point of view at that particular flow is required. So, there are lot of the waste we can actually think of, we have written down something we can have some kind of agricultural waste, food waste, animal waste, human and the waste from some kind of animal excretors and all. So, those are all are come under the bio waste.

So, everything cannot be sometimes taken into a biodigester. So, you may have to segregate that one, sometimes you have to think of that in a residential community or maybe a hotel or maybe a kind of a community of the multifamily apartment, which type of waste is much more and from that point of view, we can have to we can design the particular biodigester. The bio waste can be converted into the biogas through the anaerobic digestion. So, and that will be actually the chemical decomposition of this bio organic waste through some kind of a bacteria involvement of the bacteria and so and that will be going to create some kind of the gases. Out of that the methane is the higher potential and that has to be taken into account for our generation of the fuel a generation as a fuel to generate electricity or the heat.

So, this is a tentative a chemical equation you may say specially a CH_4 which is the methane and carbon dioxide is also going to evolve through this particular digestion. So, first we can say it is $C_6H_{12}O_6$ which is a kind of equation for the glucose or may be the starch kind of a thing which is practically available in all the bio the waste and from there it can be generated. Thus, methane can be generated, but it is only this particular this chemical reaction So, this is maybe I can say it is a very prominent kind of equation or prominent kind of a generation, but there are other ways also the methane can be generated. Mostly if in a biogas if you see it has almost 50 to 75% of the methane and rest are other gases out of that the next important one is the carbon dioxide which is about 20, 25 to 50% or so and nitrogen oxygens those are very small in number in amount.

So, it has a high potential of the generation of the methane minimum 50% to 75%. So, that can be easily converted to a fuel. So, what is the system modeling? How can I model the particular system? Let us suppose in we need to know the how much is the daily production of the organic waste.

I may say it is a production, but it is actually through some kind of society that always produces some kind of organic waste. If you see any market after it is over, maybe in the If it is the morning market, maybe around 12 o'clock in the afternoon or so, you see there is a lot of waste generated, and the municipality or corporation takes away that waste to some landfill areas or whatever. So, any kind of social housing or any kind of social setup will definitely produce some kind of waste. So, I can say it is a daily production of organic waste, and those productions come under various conditions.

The subheads: one may be food waste, which may come from residential houses or some kind of hotels and all. Vegetable waste—yes, to prepare some kind of food, we have that vegetable waste. Animal excreta, animal waste, fruit waste—there are a lot of types of waste. So, what I intend to tell you is that. So, this particular system can be modeled with different types of waste and different configurations, and because the type of waste changes, their chemical behavior and digestion follow-up will change, and because of that, you need different types of digested volume and different amounts of biofuel generation.

So, we sometimes may think of only one or two types of these things for our community—suppose it is a hotel kind of thing. So, then we can think of vegetable waste, fruit waste, and food waste. The animal excreta and animal waste may not be taken into account. If I want to think of a dairy farm, then these two will be the main potential: animal excreta and animal waste. So, based on your building application, we need to know, and from there, we need to see how it is going to be generated.

The next is we have to add some water in it. Why we add to water? Because water will give you some kind of a slurry which will going to give you some kind of the favorable condition for some kind of the biological digestion. A dry kind of a waste cannot have that efficient kind of the biological digestion by bacteria. So, we have to create some kind of a slurry.

So, in that This WFS is the weight of the feedstock in kg that means, what are this organic waste, how much kg I am producing per day plus. Ww is the weight of the water per in kg we have to see. So, these two mixed together is the WSL which is the volume of the sorry the weight of the slurry that means, slurry is nothing but the water plus there is this feedstock. the organic waste and then this particular weight of the slurry is converted to the volume of the slurry by dividing weight by the density of the slurry which is tentatively around 1900 sorry 1090 kg/m^3 mostly normally you can take this particular value. So, we can now know the per day how much volume of the slurry is coming to my digestion tank or whatever.

So, from that we have to find out the digester volume. So, what should be the volume of the digester? So, if there is a per day if I going to collect Vsl kind of volume, I multiply that with R. What is R? R is the retention of the feedback. How much day I have to retain?

Is it for 1 month? Because then and there, you cannot expect to generate the biofuel or this kind of methane or so. The digestion will take some time. Digestion takes some time because it has to have some kind of favorable condition in there. It requires some kind of typical favorable temperature. It requires some kind of the other type of water mass and all those kinds of things. So, generate those bacteria, and they will multiply and then start generating those kinds of bios.

So, there are some days—maybe 30 days, 60 days. So, it is called the retention time. So, I have to prepare for those 30 days or 60 days, whatever may be the value of R, to multiply with the VSL to get that particular total volume of the I have multiplied by 1.1, which is another 10% extra because there may be some ups and downs. So, this capital V D is the volume of the digester I have to first find out, and this particular volume of the digester is, say, typically for 60 days.

So, if I want to have those kinds for a community, I may prepare three such digesters—maybe one is running for 60 days, then after 60 days, it will take some further days to generate electricity or the biofuel or whatever, and then next the bio digester I will now recharge. So, like that, 1 or 3 or 4 or maybe something like that—a multiple number of digesters can be thought of. Now, this is the first setup that we have to find out from, and we have to do the initial part of this bio-system energy modeling.

The next one is I need to know that how much bio fuel that means, the gas biogas is given to generate. So, how it will be going to generate? It generates based on this your slurry, the amount of slurry you have collected for last 60 days or the retention period last 50, 30 days whatever may be your retention period. We will come to that how to calculate the retention period or so. So, factors are one is temperature.

It is supposed it is freezing cold temperature. So, no the digester will not be going to work. So, digester will be going to very well work in this tropical climatic zone, tropical climatic area this kind of temperature is 18 to the 35° or so is the very favorable condition for this digester to the digest and all. Then, it is depended upon the volume of the digester yes, because the volume of the digester the total capacity of the digester will definitely allow much more type of much more amount of collections and much more amount of production of the biogas. The third one is the organic volatile matter concentration.

So, that is each bio waste we have talked about the animal waste, we talked about the vegetable waste or fruit waste. Each vegetable waste or the other type of waste animal waste has a conversion ratio of the biofuel. The amount of methane generated from the from a banana leaf banana this thing may not be the equal with a cauliflower or something like that. From meat how much is generated from fish it may not be the same.

So, there is different the conversion ratios or the concentration ratios of the organic volatile matter.

So, that also has to be understood. And from that point of view, we can use this equation: G is equal to Y into Vd into S divided by 1000. What is G? The biogas production, m^3/day. So, how many m^3/day is it generating?

The Y, what is Y? The yield factor based on the temperature and the feedstock retention time. So, that we have to take from a table. How much is the yield factor? And the S is the initial concentration of volatile solids, which we have called the initial concentration of the volatile solids present in the slurry, and that depends on the type of organic waste. Vd is the digester volume. So, I have to calculate that one, and then I can find out the G. There are some conversion ratios.

So, conversion ratios are: 1 m^3 of the biogas is almost about 0.65 m^3 of methane. So, the conversion is almost 65% or so. What we have discussed in the very first slide is that the methane is about 50 to 75%. So, 1 m^3 of methane is almost about 34 megajoules of energy. 1 m^3 of biogas is almost about 22 megajoules of energy, or 1 m^3/day of biogas is almost about 0.8, 0.6, 0 megajoules per year or so.

So, those are some of the conversion factors. I have actually designed this particular lecture based on this particular source or material, which is available inside from the International Renewable Energy Agency (IRENA). They have a document published in 2016. I have written down the link to that below. You can download it, or we can provide it to you in our forum.

So, let us take a small problem: a biogas plant is in a market complex, and it is producing daily waste like vegetable waste of 25 kg, animal waste of about 40 kg, and food waste of about 10 kg per day. They are generating this waste and thinking of creating a biogas plant. And the feedstock-to-water ratio is almost 1:1.5. They are thinking of a retention period of 60 days, and the density of the slurry can be taken as 1100 kg per cubic meter. And the average temperature is almost 30°, we can say. So, let us see how I can use these equations to find out how much potential this particular market has to produce some biogas energy per day. So, first, I find out the total feedstock weight, which is 25 plus 40 plus 10, totaling 75 kg. Then I add 1.5 times 75 as water because the ratio is 1:1.5.

So, the total weight of the slurry becomes almost 187.5 kg, which is the addition of 75 kg and 112.5 kg. And as I know, it is given that the density of the slurry is almost about

1100 kg per cubic meter. So, I can say that per day, this market will produce almost about 0.17 cubic meters of the volume of slurry per day. So, that is the first thing I can calculate from the first step of our model equation. Then I have to think of the total volume of the digester. I have assumed that it is 60 days, but you can assume something else also.

So, based on that your total capacity and all this thing will going to change we will see that one. So, let us suppose it is for 60 days. So, I have found out the total volume of the digester which is 11.22 m^3 and so this is the digester volume. So, now I have to find out this yielding Y value because I have to know that these three things S, the Y and this VD, VD is with me this 11.22 m^3. Now you see the

So, I have to find out the yield factor this is yield factor table as I have cropped it from that particular the international renewable energy that particular document. And this yield factor is based on temperature in the x axis you see temperature and the feedstock retention time my feedstock retention time is 60 days. and the temperature of that area is I have assumed as 30°. So, the Y factor the Y yield factor is 4.75. Now, if you if you say that yes, my I will have the retention time may be 30 days or something like the 30 days one month and the temperature is remained same suppose 30° centigrade.

So, your yield factor will be around the 0.8, 8.2 or So, this way we can actually see that what will be the yield factor and that particular thing. So, if the temperature is dropping suppose the temperature is average temperature is 16° or 18° it is drop from 8.2 to 3.44. So, as and when the retention period is increasing your yield factor is almost going to be the decrease. And the temperature decrease means your yield factor is also going to decrease, but there is a catch.

The catch is this particular decrease in the yield factor when we increase the retention time or in other ways. When the retention time is decreased, the yield factor is increased based on the type of feedstock you are considering, and you need to have some other interventions or some kind of biological interventions there. So, that is not within our scope of discussion. So, we will go with this particular recommendation, and then we can find out the

Now, next is the S. So, we have also noted down or given the initial volatile solid percentage in all three types of stocks: 70, 50, and 80%. So, based on that, I have calculated the weighted average, which comes out to be 60.67% as the initial concentration of the volatile solids. And now I use these three values: the y value is 4.75, which comes from the last previous slide. The Vd is the volume of the digester, which is

11.22 m^3, and the concentration we obtained here is 60.67%. So, these three are given there, and we have obtained from the equation 3.23 cubic meters per day of biogas.

Please remember, this is the amount of biogas, not the amount of methane. Only 50 to 75% of this biogas may be methane. So, we need to find out how much energy is generated. So, I know that 1 cubic meter of biogas is almost equivalent to 22 megajoules. So, for a day, I can actually think of generating 71.06 megajoules as an absolute value, but you know there will be some losses due to other factors.

So, around 50 I am definitely going to get 50 mega joule or so and I have divided that by 3.6 which is giving me almost about 19.7 kWh or so which is not very high. And maybe if you increase the feedstock volumes or so, it may be a little bit high. You may say that I will decrease the retention period, I will have a high yield capacity yes. Then also it will be going high just to change the retention period you may save some amount of the volume of the digester, but the thing is that you have to actually check further with the digestion time the satisfactory digestion time or the effective digestion time for all those types of the organics matter.

Suppose the fruits waste has digestion time 45 days or so. So, if you can keep it 60 days it is fine, but if you can keep it for 30 days even though the yield factor looks like to be it is the average it is the average for more than that but effectively the all components of the fruits cannot be digested because it required 45 days, you have kept retention period 30 days. So, there will be some kind of the mismatch of your assumptions and the productions capacity or the estimation. So, we have to look into that.

Next, let us go to the next type of clean energy which is a Wind Energy Wind has enormous potential from the mega scale also from the micro scale point of view. So, and it is the production of the wind is increasing like heavily in last 30 years or so. In 1997 the worldwide 7.5 gigawatt of energy was generated whereas, 2018 it was it was worldwide generation I am talking about it is 564 times. So, it is 75 times increment.

So, it is increasing by leaps and bounds in the areas where there is no cultivation potential, such as desert areas or places where the soil is not suitable for cultivation. Those areas, which are neither green jungles nor forests, can actually be used for installing wind tunnels or turbines. And those are not wind tunnels—sorry, I mean wind turbines. Wind tunnels are equipment used to test high-rise buildings under wind loads. I am talking about wind turbines for electricity generation. For example, in the Thar Desert of Rajasthan, the third-largest desert, the Government of India has installed many wind turbines and wind towers to generate electricity. The working mechanism of that.

What happens is that when the wind blows, it passes through the blades, turning the shaft inside. This rotation of the shaft generates energy because it is connected to a generator. The shaft turns the generator, which converts kinetic energy into electrical energy. This electrical energy can then be transferred to a grid or used locally. But note that this is alternating current. So, this is AC, not DC current. We cannot store it directly in a battery.

You would need an inverter to convert it for battery storage if you want to use it when there is no wind velocity. Another advantage is that it can also work at night, unlike solar power. However, its efficiency depends on the location. Coastal areas are ideal because wind velocities are higher, and higher wind velocity means more torque. This increases the possibility of converting more mechanical energy into electrical energy. But in coastal areas, solar installations face other issues. Wind turbines must be placed in open atmospheres, and coastal areas have high salinity and moisture, which can reduce efficiency due to rusting and other maintenance challenges.

So, that is why sometimes it is better to place in the inland locations where the salinity is less. And also, there is a considerable amount of the chance of high velocity of wind which probably lead to the insulation of the lot of the wind towers in the desert of Rajasthan where salinity is almost 0, the moisture content in the air is almost negligible and there is a considerable amount of wind velocity and that can go to the electricity grid. So, there are depending upon the turbines how the turbines are dependent with different type of turbines. There are two type of turbines one is called the horizontal axis wind turbine or HAWT, another one is called the vertical axis turbine which is the VAWT.

So, it is one is the this if it is rotate like this, this is the axis is horizontal. So, like our stand fan, stand fan is the horizontal axis. So, this is something like this. So, it is the kind of a like this.

So, this HAWT has horizontal rotor and has 2 to 3 blades. It is suitable for both the small scale and the residential scale and the large scale the application and for the wind farms the typical HAWT can generate almost about electricity ranging from 1 kW to almost 10 megawatt. It has a potential it is a at present the globally it has been almost like almost like power is generated by this horizontal axis wind turbines. How the vertical axis wind turbine?

So, vertical axis means this will rotate about this vertical axis. So, it has this kind of a rotation small applications VAWT's have vertical rotor. And VAWTs are small and capture wind from any direction that is another very important thing. If you see the horizontal axis, it has only if the wind comes from this side it will going to rotate. So, it has a direction the I mean say it is a negativity.

But if the wind comes from this side the horizontal axis will not going to rotate or may be rotate, but not that way it is the highest rotation is possible if the wind is perpendicular but in a vertical rotation wherever wind comes this way, this way or may be the other way may be in the angular way it will be going to rotate. So, it is going to rotate something like that. So, if you have a typical direction is the wind direction the is almost fixed for a particular location then probably, we can think of the horizontal. For building applications, it is better to go with the vertical, it is smaller in size, it can have typical circular motions for different angles.

There may be changes in the direction of the wind in the cityscape because there are lot of other buildings also there are sometimes there may be some kind of a obstructions to flow the winds also. So, it is ranges from few hundreds watt to few megawatt depend which is lower side it is a kind of a lower side and it is only 5% application in the global wind power generation. So, from the types we have the building mounted wind turbines which is mounted on the building. So, that means, it is mounted at the top of the building or in a tower at the rooftop or something like that. So, these are the some of the buildings where it is mounted things are in the top.

So, these three US buildings are I have found out from the Wikipedia these three buildings are having one football stadium is all not football stadium it is may be a rugby stadium they call that is a football, but our football is soccer they call that is a soccer. So, this is a rugby stadium where they have installed in the one part of the stadium the building mounted wind turbines. The next one is the building integrated; it is not the mounted at the top, it is integrated inside or in some part. So, that is there in the Satara SE 1 London, they have three such you see three such the wind turbines at the top, but it is not you may call it is mounted, but it is integrated with the building, it is infused with the design. So, turbines are integrated with the building architecture.

So, yes this is the ASE 1 is London is look like this particular 3 holes and the that is 3 turbines are the integral part of the architectural design itself. Whereas, in this particular discover has discovered tower Houston if you see in the top the top frame there are some kinds of a vertical kind of the shaft rotations which actually concentrate over here you can actually See that particular, I think there are some on YouTube videos are available on this particular building and it is a kind of a zoom view when these particular things are rotating or so. The third one is the building augmented the wind turbines.

What is augmented? The building design and the turbine placement are augmented to deliver the optimum wind energy. So, something like the Bahrain the WTC the World Trade Center Bahrain augmented. They have designed the two triangular slices of the building in some inclined way and in between in a small slit like locations three turbines such a way that the wind flow comes from one side and when it is passes through this particular narrow area it's the velocity is increased because of the small aperture with respect to the front side and it's kind of the generation is there.

And this is the Pearl River Tower from the other side. If you see the front side, there are two such turbines there. That is in between those two, the middle slit areas. So, this is augmented with the particular building, and they designed the building in a similar manner. So, now, how am I going to model the wind energy? What I mentioned earlier is that it is a conversion of the kinetic energy. Because of the speed of the wind, wind has mass, and wind has speed or velocity.

So, mass and velocity of an object can be translated to kinetic energy: half into m into v squared, and that is going to be replaced on the other side as electricity, the energy generation with some kind of factors or losses. So, I am thinking of a particular wind turbine which has a blade diameter of d, so that means the sweep area is pi d squared by 4, and then the kinetic energy I can find out by the mass of the wind into the velocity of the wind squared, mv squared. So, this is actually half mv squared, and so mass I am going to calculate with the flow. Flow rate of the wind into density, and flow rate of the wind is nothing but the velocity of the wind in the rotor sweep area. So, how much mass is passing through this total sweep area is the total amount of the mass, the volume of the things going on, the density of the air.

So, that is going to be the mass. And now the velocity. So, finally, this has to come like this: the potential amount of power P generated by the wind is 0.5, which is half A into V, where A is your area of the rotor sweep area, and V is the velocity of the wind, rho is the density. And the Cp and Cv's are the two coefficients of performance: one from the total performance point of view, and Cg, where p is the total performance coefficient, and Cg is the generation efficiency. So, let us do a small problem finally.

So, we propose a generation of the annual energy of 50 mWh. Please remember this is the annual energy I am talking about for a wind form. The average wind velocity is estimated 6 meter per second for a estimated period of 3500 hours annually. and other some month and some period of 4000 hours is of your 4.5 meter per second. The density of air is 1.2 kg/m³ if I assume and coefficient of performance and the generator efficiency is your 0.75 and 0.9 respectively.

I have to find out that what should be the radius of the rotor, size of the rotor if I want to install 5 such the wind turbines. in these locations to generate 50 mWh electricity. So, things are look like complicated, but it is very simple. Let us go back to the equation this P equal to half into A V rho V square. So, finally, it is V cube and C P and C G. So, I have used the same over here see half A I do not know A is the area 1.2 is what 1.2 is the density of the air.

Now, 0.75 and the 0.9 is the this is your C p and this is your C g, this is the density, this is the area and this is the velocity square velocity 1 cube and this is the velocity 2. There are two velocities are for two different period or two different monthly or the hour the annual hour. So, this is the first annual hour or 3500 and this is the 4000. So, as I multiply this with the hour, so finally, I am what I am going to get is the watt hour watt hour because

The energy is coming down to be in the particular the in the J, and as this particular velocity is the m/s or so, that is in the watt because joule per second is the watt, and I am multiplying with the hour watt hour. So, that means this much mWh because I have divided that by 10 to the power 6 and now equating this. 0.45388 with 10. Why 10? Because I want to harvest 50 mWh, but I have 5 such.

So, 1 will take care of 10; there are 5 such towers that have to be installed. So, the area is 22.4, and the radius of the rotor should be from area to circular area. I can find out the value of D by virtue of the equation, so 2.65 meter. So, 2.65 meter huge radius. Maybe 3 such rotor blade areas are that particular sweep area is 22.04, and the radius of the rotor is 2.65 meter. The diameter is almost like 5 meter or so, more than 5 meter, 5.2 meter, 5.3 meter. So, that is all for this particular thing, but yes, there are two more things we let us discuss: geothermal energy and the fluid cell.

Geothermal energy we have discussed already. It is the earth core; there is heat, and from that heat, we can generate electricity or we can actually create some kind of hot air or maybe sometimes cooling also, and this is going to be the use of the. This kind of membranes and all, we can actually fuel cell also going to be used. The fuel cell is the electrochemical device that converts the chemical energy of the fuel directly to the electricity, and it is actually nowadays coming up very sharply in application in the building and the renewable energy. So, there are two very common types of fuel cell: the solid oxide fuel cell and the polymeric kind of a thing. So, we will not discuss in details of that.

So, what we discussed here is the discussion of the two types of energy, like wind and bio, and from that particular point of view, it can be applied to buildings also. So, thank you very much.