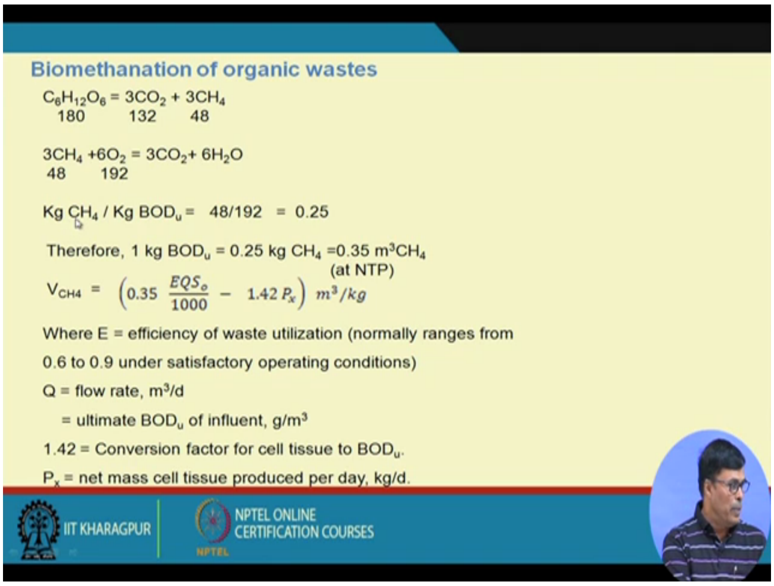
Course on Industrial Biotechnology
By Professor Debabrata Das
Department of Biotechnology
Indian Institute of Technology Kharagpur
Lecture No 58
Anaerobic Effluent Treatment Process
Biomethanation Process

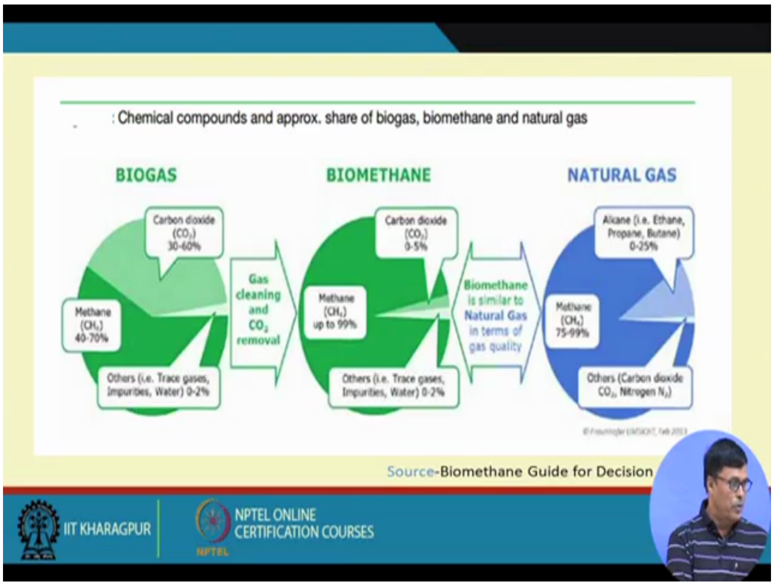
Welcome back to this course that is Industrial Biotechnology, in the last lecture I tried to concentrate on anaerobic digestion process and I told you how this anaerobic digestion process plays very important role for bring some revenue from the waste water treatment processes. So that you know and also I tried to discuss that why the two stage process plays very important role for this anaerobic digestion process because if you operate the process in two stages then you can run the process very comfortably and you will get lot of useful results.

(Refer slide time 1:20)



Now I shall give you some application of this process how different country they are using this process successfully. First let me tell you this European largest anaerobic digester plant that is in the northern Jutland, in Denmark. They are using 3000 cubic metre per hour, so biogas which they are producing is the huge amount of biogas, this is the plant they have and they are using about 2, 50,000 tonnes of manure, so you know there is a huge amount of manure they are using here. So you can see this plant has been successfully done and here I want to point out another thing there is an industry called Bakerdy that distillery plant they have the capacity of the bioreactors of 13,000 cubic metres which is consider as a largest anaerobic digester plant in the world, that has been in operation in that country.

(Refer slide time 2:11)



Now if you look at the chemical composition approximately and share biogas, biomethane and natural gas, how can it be comparatively comparable with each other? Now biogas usually contains 40 to 70 percent of methane and carbon-di-oxide 30 to 60 percent when it is passed through some kind of purification process what you call gas absorption, carbon-di-oxide absorption process then we can produce methane about 99 percent and carbon-di-oxide varies from 0 to 5 percent.

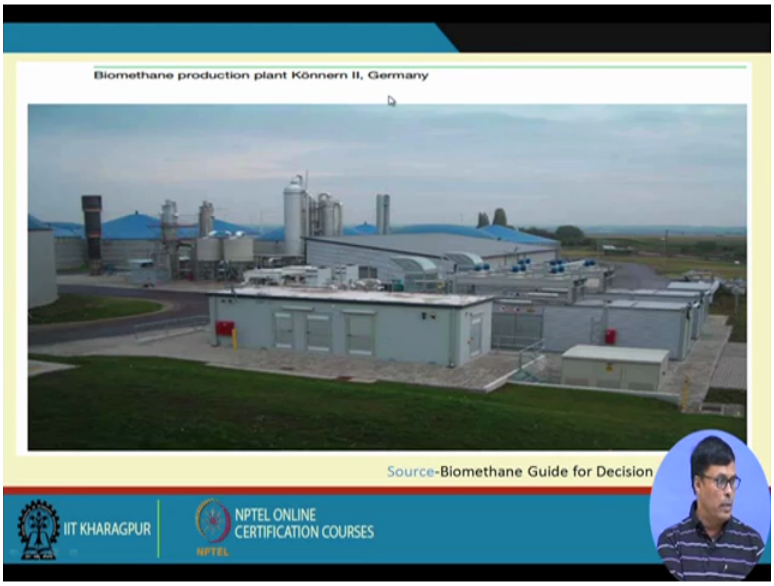
The natural gas if you compare with this with the natural gas, natural gas contains about 75 to 99 percent methane and alkane that is ethane, propane, butane, 0 to 25 percent. So it is quite comparable and this is I told you in our country CNG compressed natural gas we use for the running the vehicles that is largely used by the transportation sector and which contains mostly this methane.

(Refer slide time 3:19)

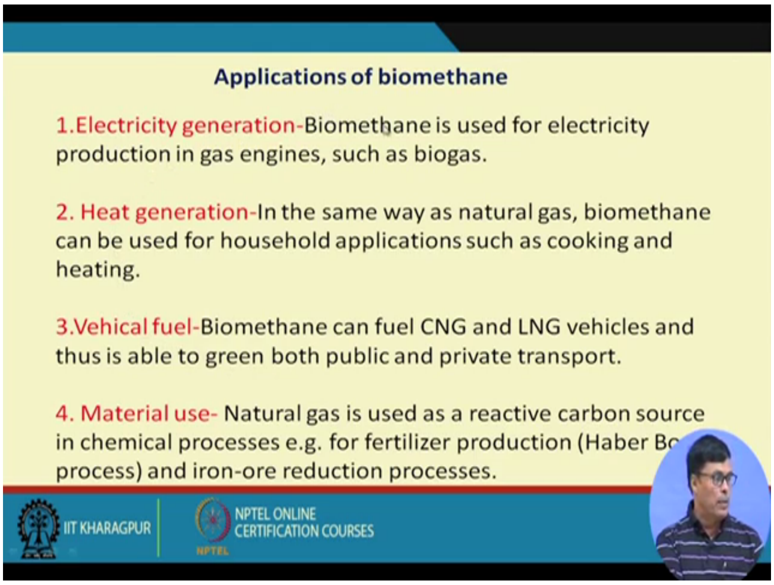
Now this biomethanation, biomethane satisfied all the three principles security of supply, sustainable and competitiveness. Security of energy supply a strong need exist to minimize the risk of exposure towards the fossil fuel price volatility ensured the security of energy supply by diversifying the existing energy production sources.

Sustainability because since we are using this process from the waste material so this waste will be available so this process can be sustainable for lower longer period of time. Competitiveness because promotion of localized production energy, and simulation technology innovative is the key for the development because here I want to point out that this biogas can have both the applicability for the small scale as well as in the larger scale, so applicability is there.

(Refer slide time 4:28)

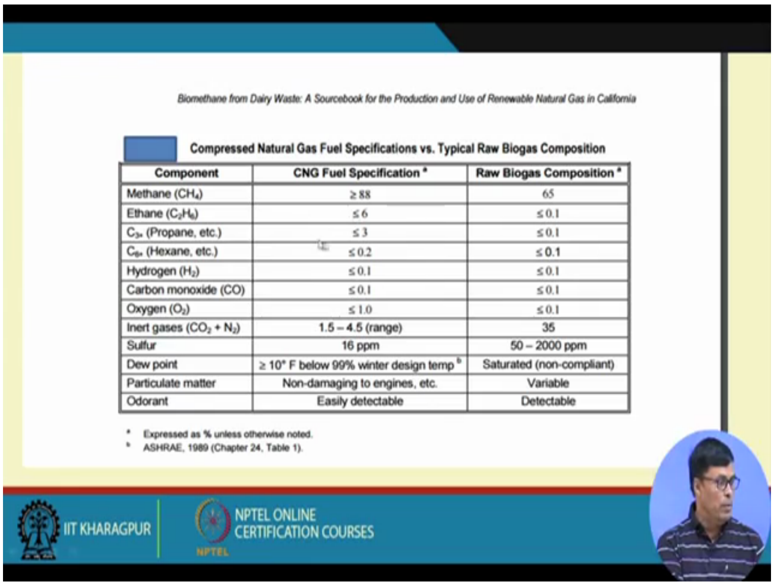


(Refer slide time 4:34)



And this is another biogas plant that is located in Germany this is largely in operation because and application I told you biomethanation process has several application. Electricity generation, heat generation, vehicle fuel and material use the natural gas is used as a reactive carbon source in the chemical process as for example fertilizer production and iron ore reduction process largely used. So not only the biomethane has tremendous potentiality in the market.

(Refer slide time 5:07)


Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California

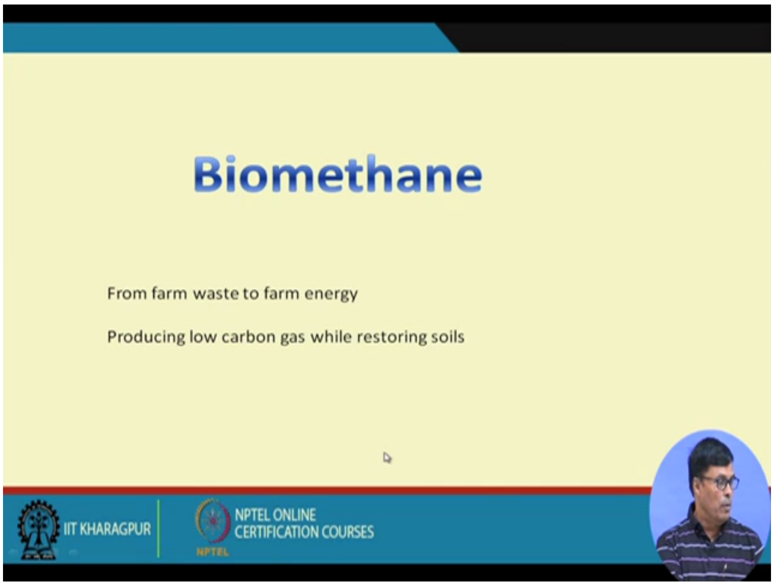
Compressed Natural Gas Fuel Specifications vs. Typical Raw Biogas Composition

Component	CNG Fuel Specification [a]	Raw Biogas Composition [a]
Methane (CH_4)	≥ 88	65
Ethane (C_2H_6)	≤ 6	≤ 0.1
C_{3+} (Propane, etc.)	≤ 3	≤ 0.1
C_{6+} (Hexane, etc.)	≤ 0.2	≤ 0.1
Hydrogen (H_2)	≤ 0.1	≤ 0.1
Carbon monoxide (CO)	≤ 0.1	≤ 0.1
Oxygen (O_2)	≤ 1.0	≤ 0.1
Inert gases (CO_2 + N_2)	1.5 – 4.5 (range)	35
Sulfur	16 ppm	50 – 2000 ppm
Dew point	≥ 10° F below 99% winter design temp [b]	Saturated (non-compliant)
Particulate matter	Non-damaging to engines, etc.	Variable
Odorant	Easily detectable	Detectable

[a] Expressed as % unless otherwise noted.
[b] ASHRAE, 1989 (Chapter 24, Table 1).

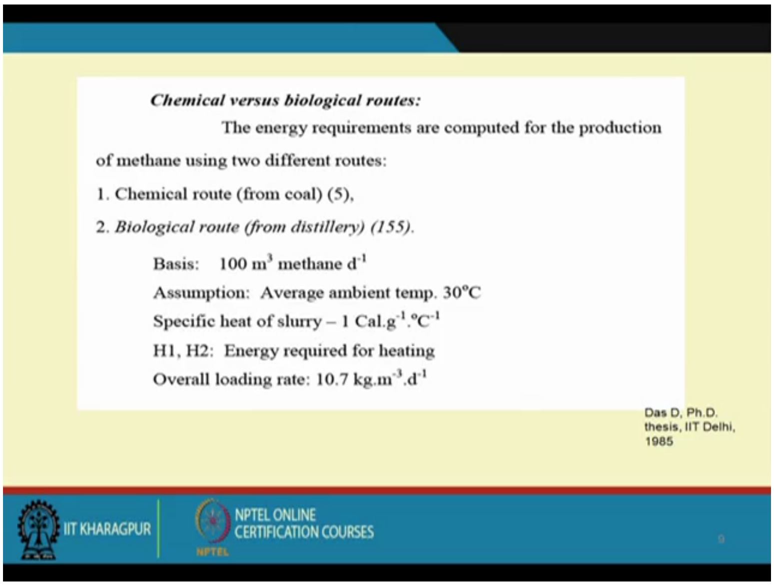
Now this is a table which compare CNG and the raw biogas you can find out how they can be comparable with each other, so that is how this biogas plays very important role in the world market.

(Refer slide time5:24)



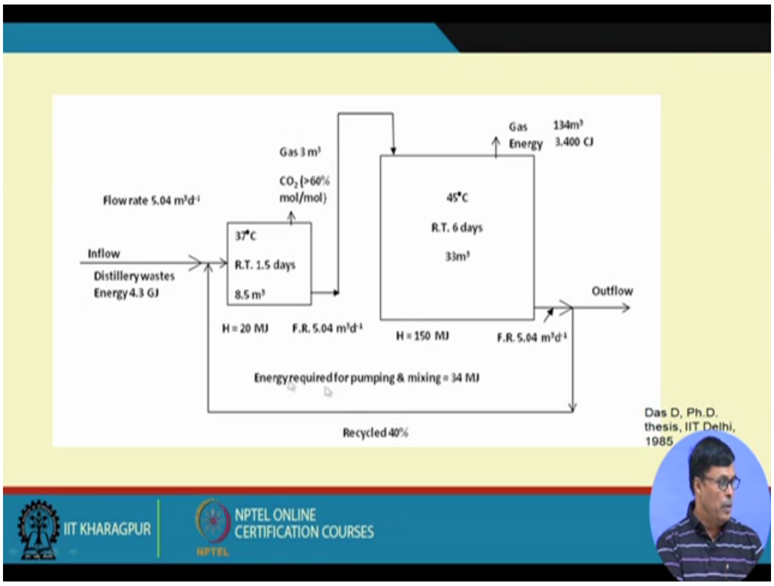
Now biomethanation actually from the waste to the form energy and producing low carbon gas while restoring the soil because most of the high carbon carboxylic when you burn it produce lot of particulate matters in the year that causes the environment pollution, and this is since it is the lowest hydrocarbon so amount of carbon emission it is very less as compared to any higher hydrocarbon so it is environmentally safe.

(Refer slide time 6:01)



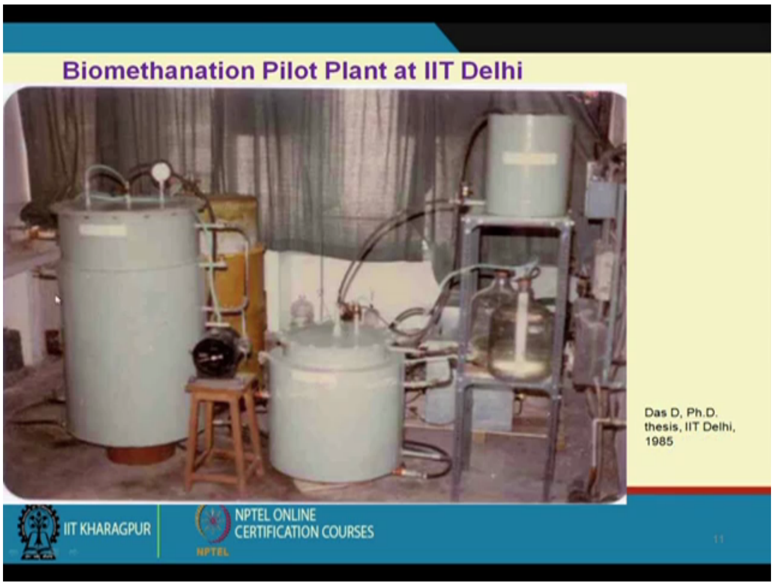
Now I told you that I want to make a comparative study with a chemical process how chemically if you produce the methane and how it can be comparable with the biological process. Methane can be produced from the coal I can tell you this the chemical routes from the coal and biological route is from the distillery effluent that our basis is 10 cubic metre methane production per day and assumption we have ambient temperature 30 degree centigrade, specific heat is 1 Calories per gram per degree centigrade. H1, H2 is the energy required for heating and overall loading rate is 10 point 7 kg per cubic metre per day.

(Refer slide time 6:47)



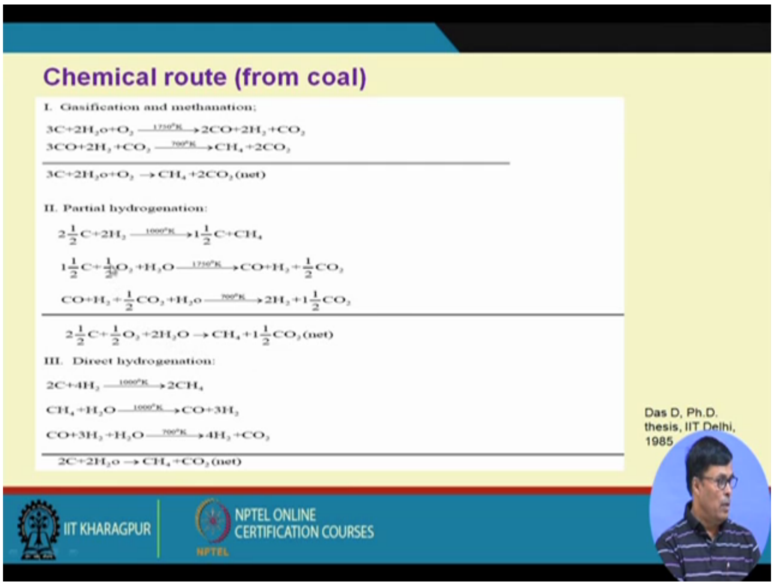
Now this is the process biological process I told you this is operated in two stages this is acetogens, this is methanogens in the acidogenic process the retention time is 1 point 5 days and in the methanogenic process retention is 6 days. Now this is when distillery effluent comes like this and goes like this, this is the energy required for this, the mixing and pumping is 34 Mega Joule and here it is in the form of substrate 4 point 3 Mega Joule and when you get that energy here also we get gas contains 134 cubic metres.

(Refer slide time 7:34)



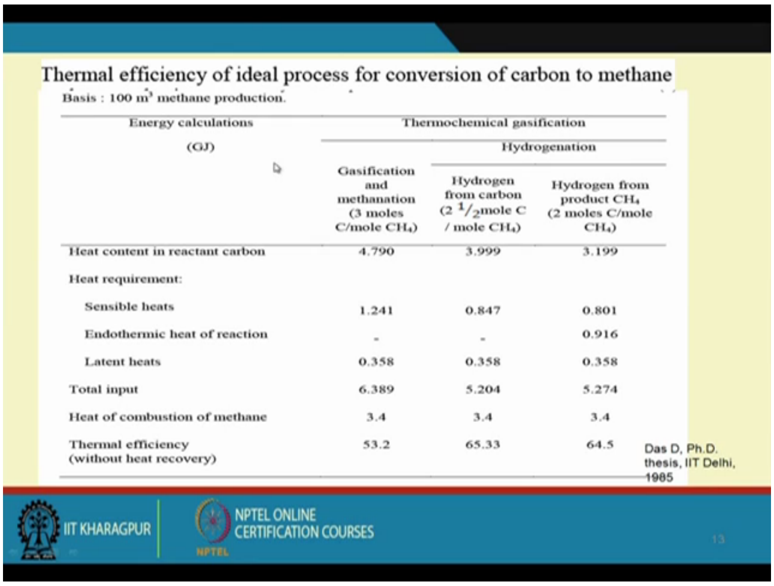
So, so this is the two stage process we operate at IIT Delhi. The is the acidogens, this is methanogenic reactor, this is pilot plant we operated very successfully and we find that the distillery effluent can be very easily used and we use for the production of methane and a carbon-di-oxide

(Refer slide time7:53)



Now if you look like chemical routes that carbon, how it is converted to methane this is 2 carbons. This is by using classification and methanation this is the stoichiometry how it produced methane. In partial hydrogenation this is the stoichiometry that we have, in the direct hydrogenation the stoichiometry of the process is like this.

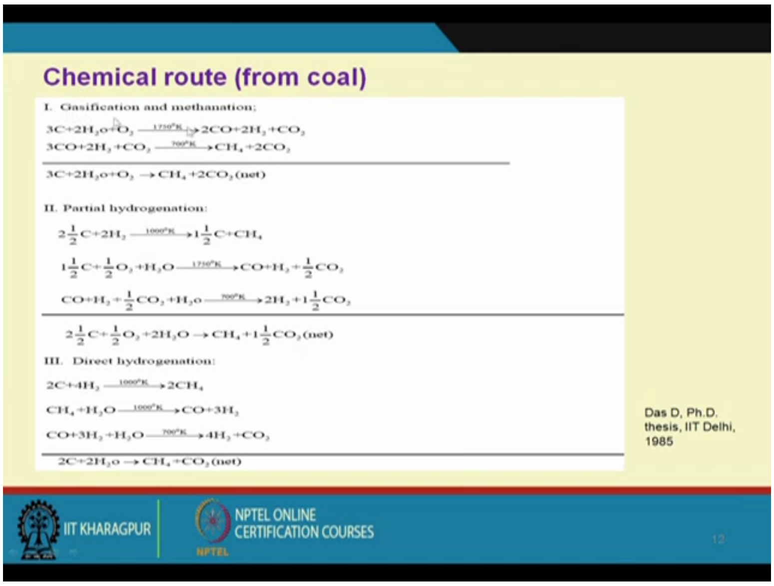
(Refer slide time 8:17)



Energy calculations (GJ)	Thermochemical gasification		
		Hydrogenation	
	Gasification and methanation (3 moles C/mole CH_4)	Hydrogen from carbon (2 $^1/_2$mole C / mole CH_4)	Hydrogen from product CH_4 (2 moles C/mole CH_4)
Heat content in reactant carbon	4.790	3.999	3.199
Heat requirement:			
Sensible heats	1.241	0.847	0.801
Endothermic heat of reaction	-	-	0.916
Latent heats	0.358	0.358	0.358
Total input	6.389	5.204	5.274
Heat of combustion of methane	3.4	3.4	3.4
Thermal efficiency (without heat recovery)	53.2	65.33	64.5

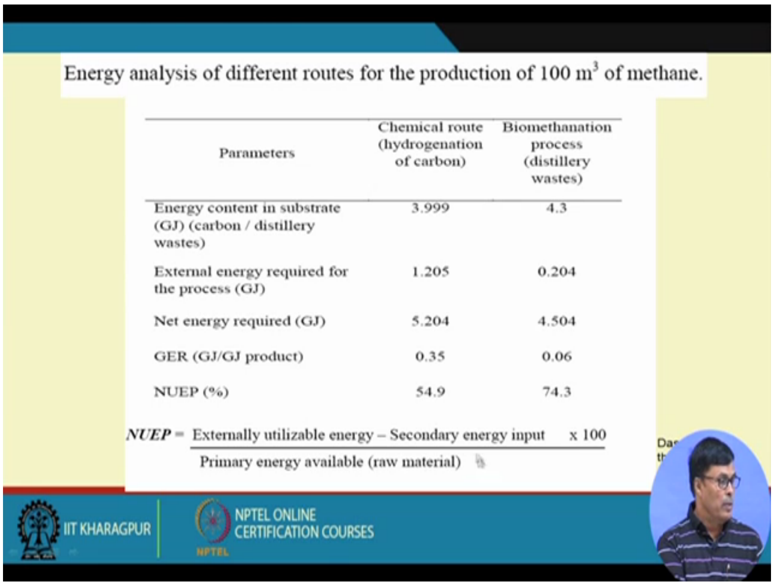
Now when you make a comparative study thermal efficiency of ideal process called conversion of carbon to methane, that basis is 100 cubic metre of methane production we have this kind of efficiency here 53 point 2 percent. In case of gasification and methanation in case of hydrogen from the hydrogenation from methane it is this, from carbon it is 65 point 3 percent hydrogen from the product methane this is like this.

(Refer slide time 8:53)



I can show you the gasification and methanation, partial hydrogenation and direct hydrogenation. If you look at this process and this process is find must that is the second process is appeared to be the better as compared to other two processes the partial hydrogenation is good as compared to energy point of view, it is quite attractive.

(Refer slide time 9:14)

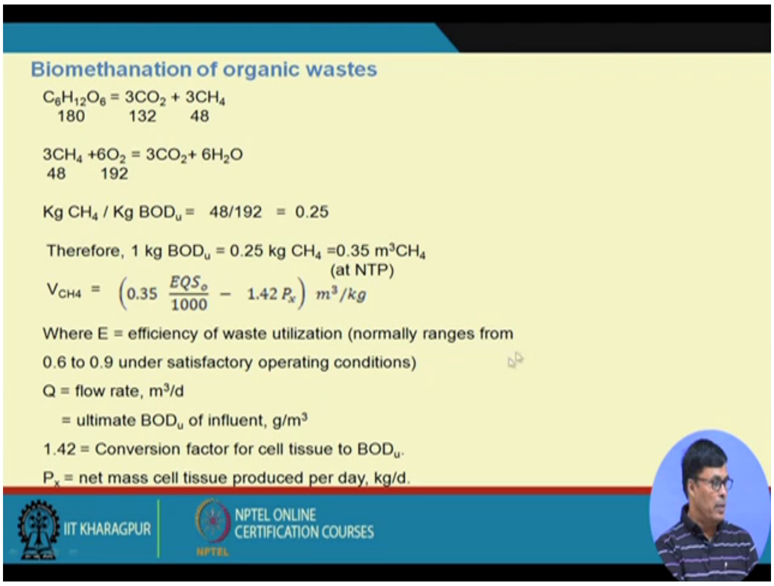


Now that is how we compare this process with the biological process, this is very interesting that energy content of the substrate in the form of carbon in case of this coal, it is 3.999 this is Gega Joules and in case of biomethanation process in the form of distillery effluent is 4.3, so that external energy requirement here is 1 point 205 this is Gega Joule and this is 0.204 because here this process is occurred at the high temperature and high pressure, this is occurred close to the ambient temperature and atmospheric pressure. So net energy requirement this plus this should be like this and this will be like this and here, gross energy requirement, gross energy requirement means how much energy is required per Gega Joule of product.

So here we find in the chemical process 0.35 Gega Joule of energy required per Gega Joule of methane production and in case of biomethanation process 0.6 Gega Joule of that energy requirement per Gega Joule of methane production. This is a very interesting parameter what you call net utilizable energy product, this is equal to externally utilizable energy minus secondary energy input this is what you call secondary energy input.

So primary utilizable energy, externally utilizable energy is this much, this minus this divided by primary energy available that if we multiply if we divide by this it is 54 point primary energy available in the form of , that is that raw materials that 54.9 percent and this is 74.3 percent that means that energy that you get in the form of methane largely you can use for other purpose because here the energy that is you recovered in the form of methane in less amount of energy is required for meeting the energy requirement of the process. This is how we can justify that biological process is more attractive as compared to the chemical process.

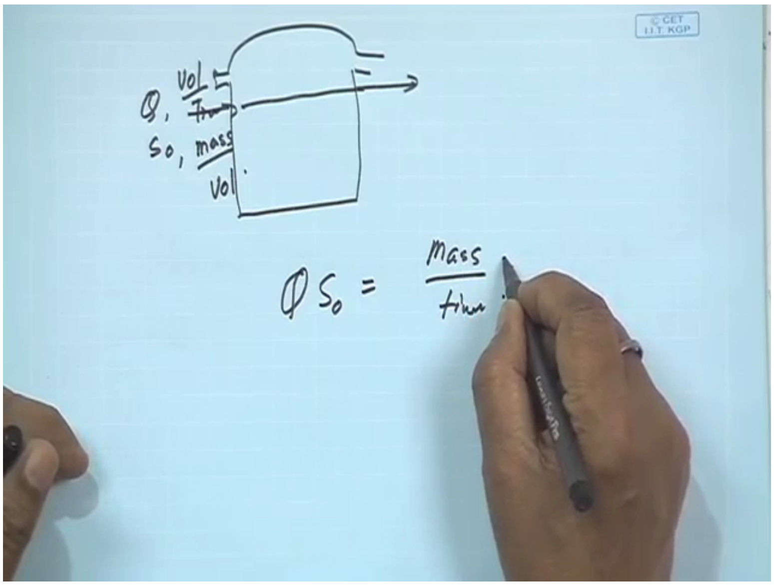
(Refer slide time 11:48)



Now other thing other stoichiometry I have, this is the kind of equation that we have that one mole of glucose when you oxidize we produce 3 moles of carbon-di-oxide, it produce actually 3 moles of acetic acid and 3 moles of acetic acid produce 3 moles of carbon-di-oxide and 3 moles of methane. So again when you oxidize this methane then you will get you require 6 moles of oxygen, so if you convert it how much kg of methane per kg of BOD this is how equivalent amount of BOD this is 48, this is 3 into this is what 12 plus 4 that is 16, 16 into 3 is 48, 48 divided by 192 it is 0.25 that means per kg of BOD removal actual theoretically production is 0.25 kg.

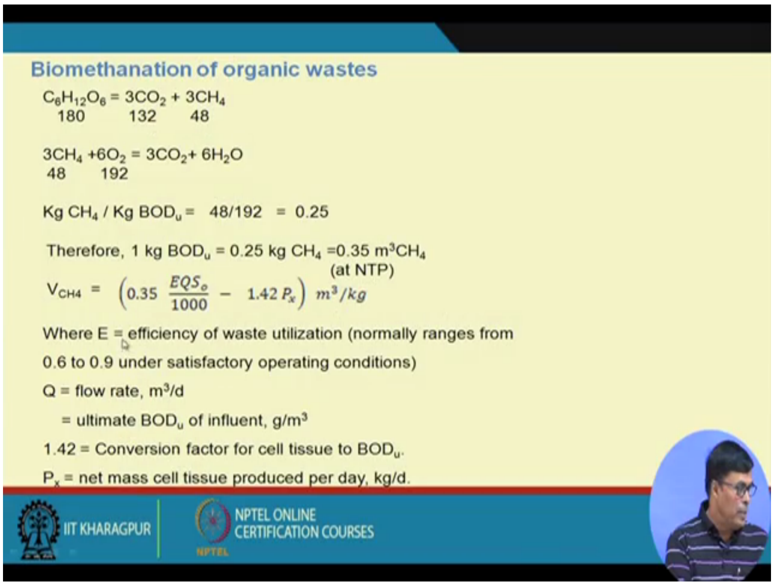
Now if you multiply with 22 .4 litres you will get this, that we know at NTP 1 gram mole of gas is equivalent to 22.4 litres. Now if you use that parameter you will find 0.25 kg of methane is equivalent to point 35 cubic metre of methane. Now that you know this is the equation that we have E is the efficiency of waste utilization normally is ranged from point 6 to 9 percent under the satisfactory operational conditions.

(Refer slide time13:29)



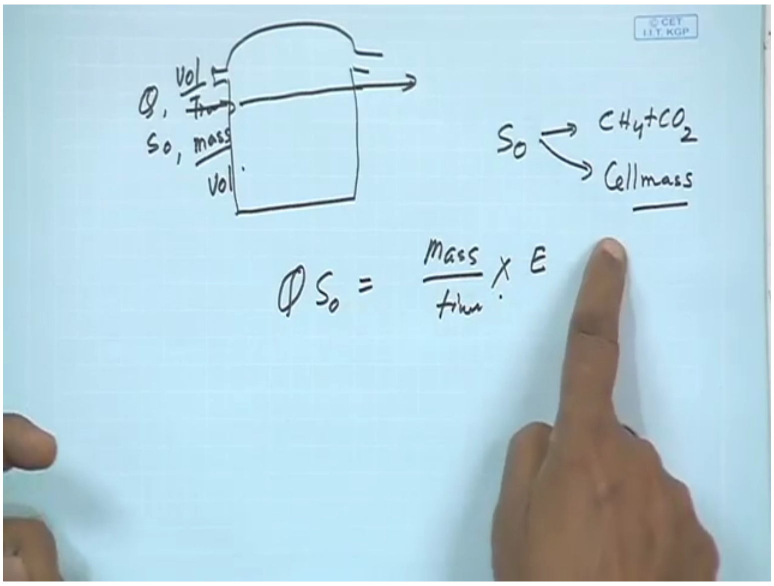
Now Q is I told you that suppose this is the process, suppose this is anaerobic digestion process and you are passing Q is the flow rate and S0 in the substrate so what is the unit of Q? Q is the volume per unit time and what is the unit of this mass per unit volume. So if you multiply Q into S0 it is nothing but mass per unit time.

(Refer slide time 14:08)

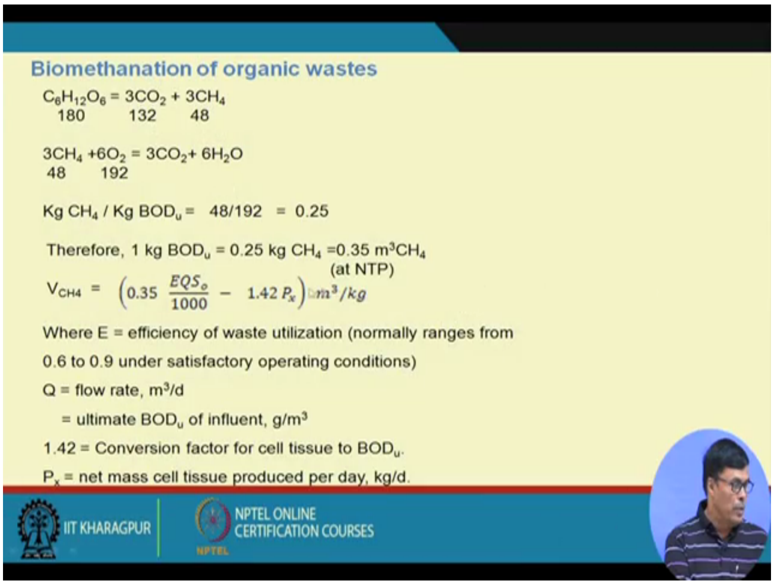


So now if you multiplied by utilization efficiency that is E then what will happen? E if you multiplied, this is multiplied by E then how much of this biomass can be converted into gas that you can find out? And you have already seen that 1 kg BODu can produce 0.35 cubic metre of methane, so if you multiply by this you will get how much methane is produced.

(Refer slide time 14:49)



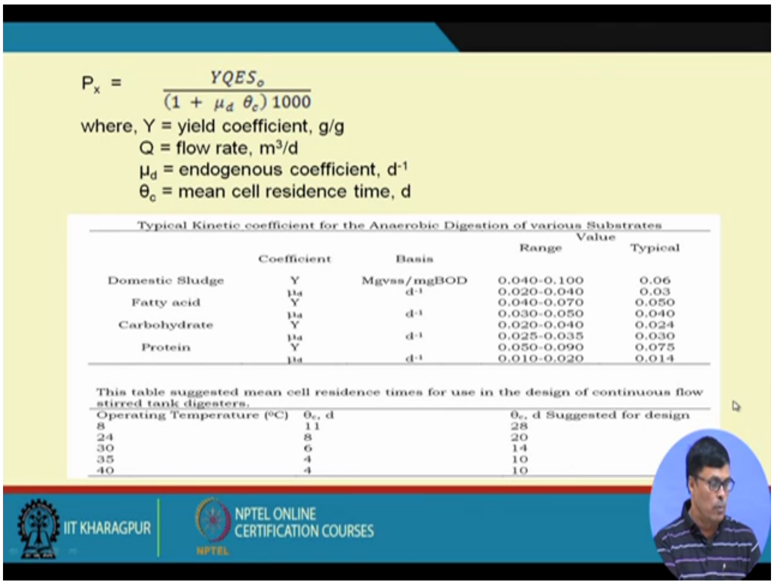
(Refer slide time 14:52)



Now problem is that when you consider this conversion process I told you this substrate a part will go for the methane and carbon-di-oxide and a part will go for cell mass production. So cell mass that remain in the system, so when you say the conversion, so that cell mass amount of energy that stored in the form of cell mass that also you have to minus. So this we have already seen, one for the oxidation of 1 gram of cell mass you require 1 point 42 grams of this oxygen. So if you minus with this then you will find what is the exact amount of methane is produced per kg of waste, this you can calculate.

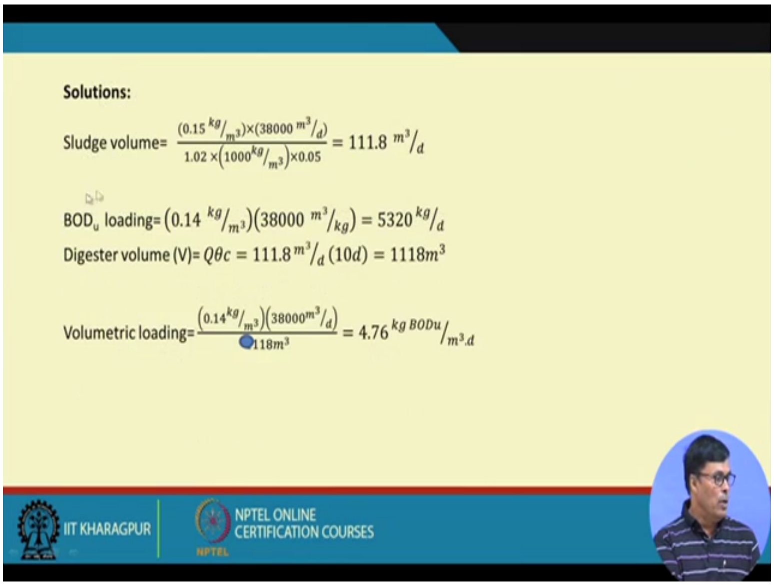
Now this is the equation, this is the rate of cell mass that formation it can be expressed like this, this is the formulae that we have and this is the typical kinetic coefficient of the anaerobic digester of various substrate we have used the domestic sewage, we have fatty acid, carbohydrate and protein. The value coefficient and specific death rate constant they varies from each other and the table shows the mean cell residence time what you call solid retention time at different temperatures will be different because you can see that how it varies with respect to because more temperature high, your this will be reduced because your organism will be more active.

(Refer slide time 15:58)

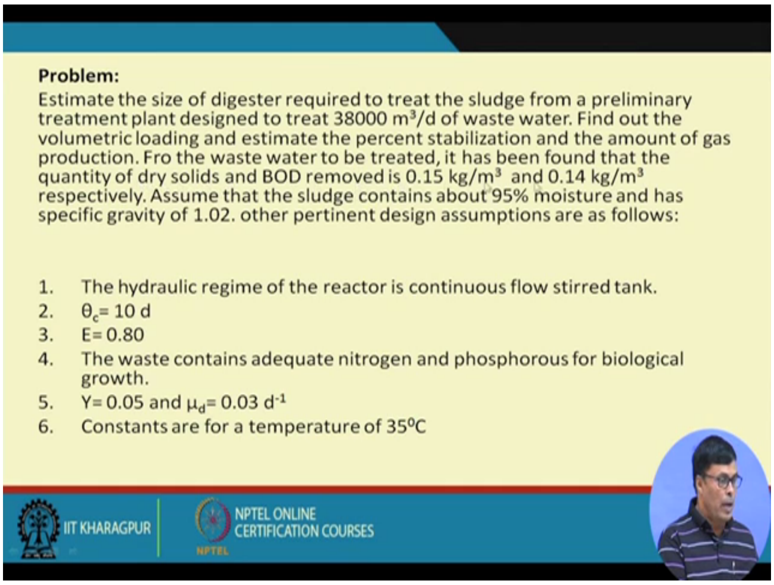


Now I want to solve one kind of problem, one problem that is very much useful for anaerobic digestion process. Estimate the size of digester required to treat the sludge from a preliminary treatment plant designed to treat 38,000 cubic metres per day of wastewater. Find out the volumetric loading estimate the percent stabilization and amount of gas produced from the wastewater to be treated. It has been found that the quantity of dry solids and BOD removed is 1.15 kg per cubic metre and 0.14 kg per cubic metre respectively. Assume the sludge contain 90 percent to 95 percent moisture it has the specific gravity is 1 .02 other pertinent assumptions are given below you have to find out that.

(Refer slide time 16:59)



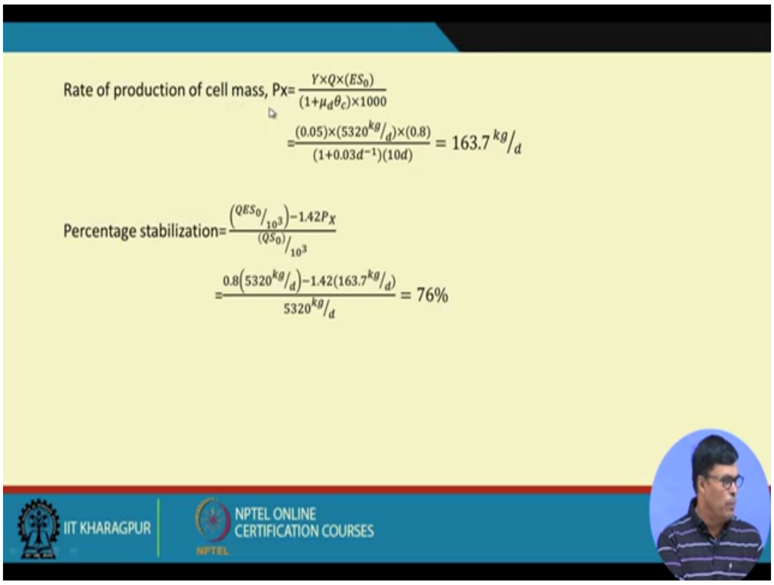
(Refer slide time 17:06)



So first we shall have to find out the sludge volume. We have already seen this is here, it is dry that you know that dry solid contain is 0.15 kg per cubic metre. So here this is the flow rate if you multiply by this you will find what is the total amount of sludge is there, net contain 95 percent moisture. So you divide by 0.05 you will get the weight mass and weight mass has the density is 1.02 into 100 kg per cubic metre if you divide by that you will get the volume of the sludge.

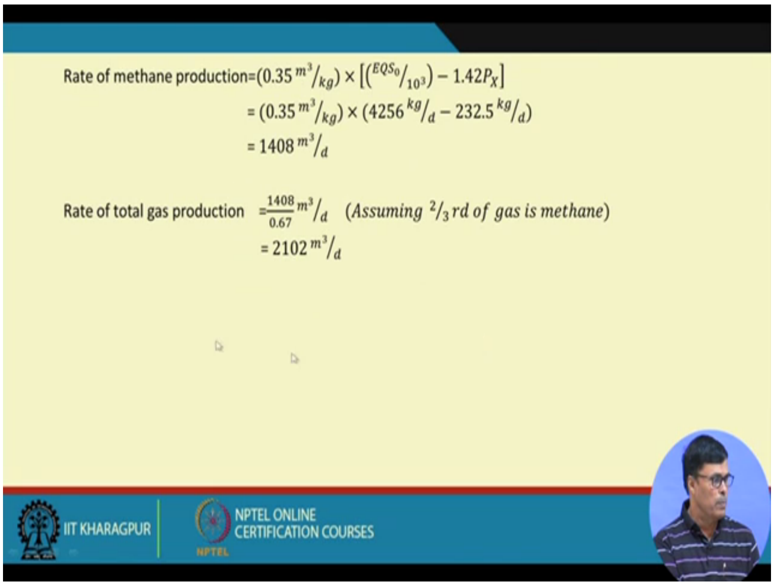
And then similarly you can calculate the BODu loading this is to be removed that is given digester volume you can easily calculate by Q into theta c that you can find out that how much cubic metre of multiplied that what is the volume of the digester you can easily find out then volumetric loading is how much total solid we putting in the reactor divide the volume of the reactor that you can find out the volumetric loading that per unit volume of the reactor, how much solid material you putting in the reactor that is consider as the volumetric loading.

(Refer slide time 18:23)



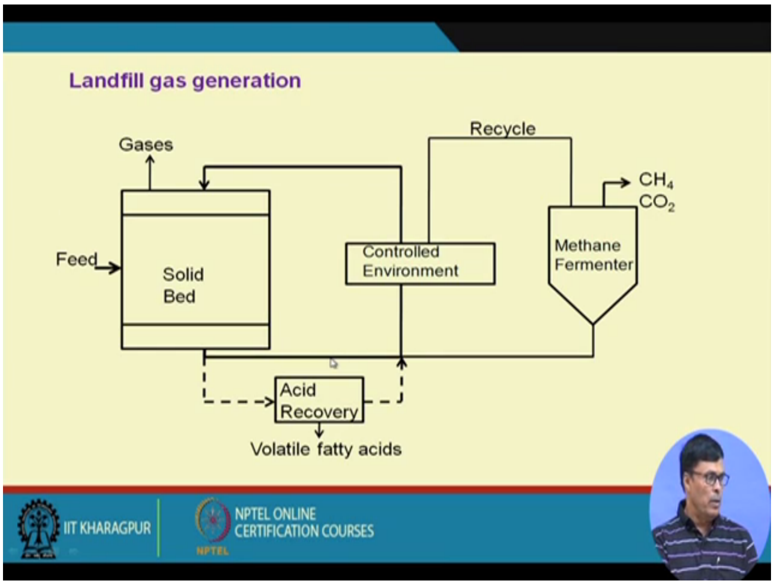
Now rate of production of the cell mass it can be expressed like this I have already shown and this value is like, this percentage stabilization this is the substrate removal efficiency, how much substrate is removed? And this is how much substrate that cell mass present in the reactor. If you minus this then you will find that actual amount of BOD that is removed from gas formation and this is the input of the substrate. So if you divide by that you will get the percentage stabilization that is how you can calculate 76 percent.

(Refer slide time 18:56)



The rate of methane we have already this equation; you put the different values in the equation you will get how much methane is produced? Now if I assume two third of the gas is methane, we can find out the total gas what is produced in the system?

(Refer slide time 19:12)



Now I want to clear with you a very interesting thing what you call land field gas generation process. Now because this process is largely in operation in the western country and unfortunately in India it is not in operation because every country generated lot of solid waste everyday and if you look at per capita production of the solid waste in the cosmopolitan city is much higher as compared to the village. Village is quite less because it has been observed that amount of waste that is solid waste generated by per person per day that also determines the economics status of the people.

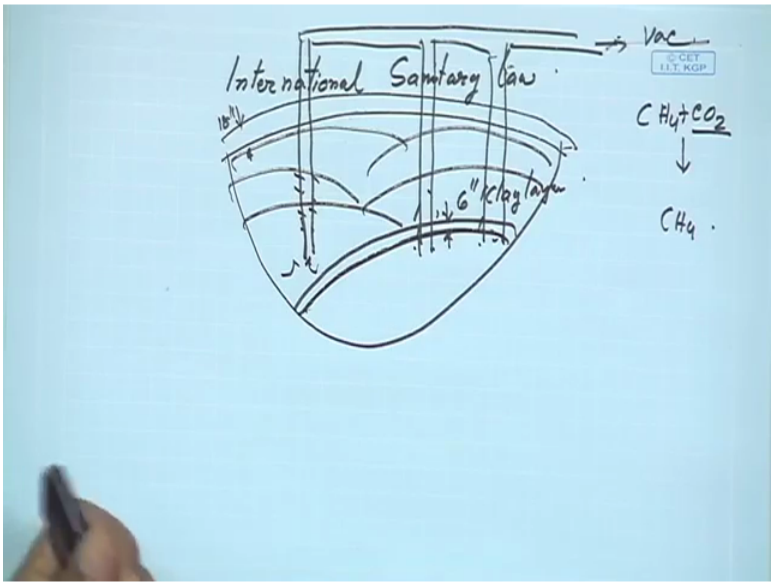
I can give a very typical example in case of USA the per capita production of the organic waste, municipal solid waste is about 2 kg but if you compare the cosmopolitan cities in India it is close to point 5 kg. So that indicate the kind of economic status of the people and it is huge but one thing we should remember in our country our number of population is very high as compared to the western country. So even the per capita production is very less but if we multiply with a number then the total amount will be very high. So what I want to point out the availability of the raw materials is very high

Now second important factor in the western country that kind of municipal solid waste they are generating they mostly containing the tissue type of material tissue papers, and tissue papers as you understand that tissue paper mostly comprises of the cellulose it does not have any kind of nitrogen source.

So your organism when I explain the growth of microbial cell in a particular media we not only require the carbon source, we require the nitrogen source, we required minerals, we required vitamins. So if your nitrogen source is very less your growth of the organism will be affected to a great extent. So you have 45, 45 means you have to put some kind of nitrogen source with this waste material so that if the bacterial growth can take place properly.

Now if you compare the quality of municipal solid waste generated by the western country and that of India, India most of the solid waste that we generated it contains the vegetables and as you know in the vegetables not only contains carbon but it contains good amount of nitrogen. So we do not have to supply any kind of nitrogen source here the whole raw materials is good enough for the bacteria to grow but only the problem is that in India we are not following the International Sanitary Law.

(Refer slide time 23:01)



Now International Sanitary Law says, suppose is a down land where you put your waste like this so if you pose any kind of solid waste that within 24 hours this should be covered with 6 inch clay layer, this is 6 inch clay layer, why? Because the reason is that they observed within 24 hours the biodegradation will take place and since the biodegradation take place, a lot of bad gasses will come out to the atmosphere and it pollute the environment.

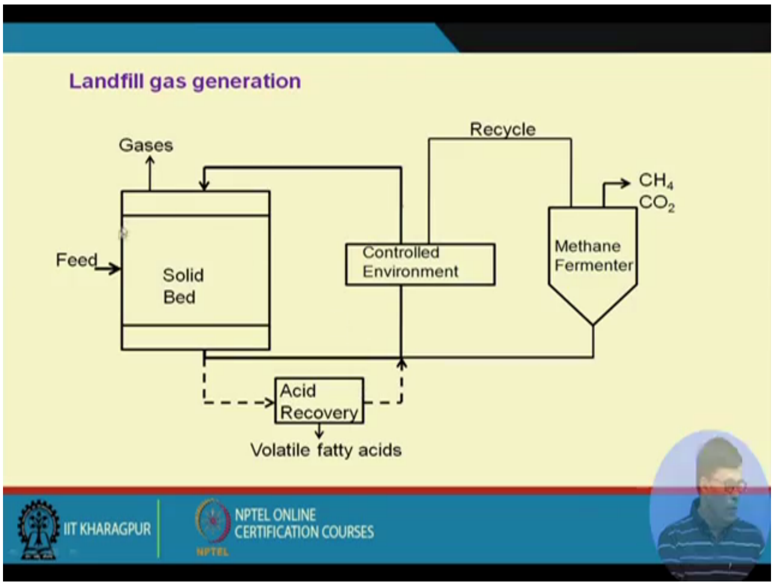
So to safeguard the environment within 24 hours it should be covered with 6 inch thick clay layer. So like this you can have another layer you can have another layer, you can have the layer like this you can fill up your land field, this is the International Sanitary Law. Now what is saying that at the end when it is totally filled then it is totally covered then it gets thick. It produce may be 18 inch layer, it produce thick layer that you put so that insure there is no gas going out from the system then what they do?

They make a well; this is the pipe perforated pipes we put inside this. So we put different perforated pipes here, and this perforated pipes we interconnect this. We can make the interconnection of the perforated pipes and we can make little bit of vacuum in this line then what will happen? Whatever gas is producing that will come here and this goes like this.

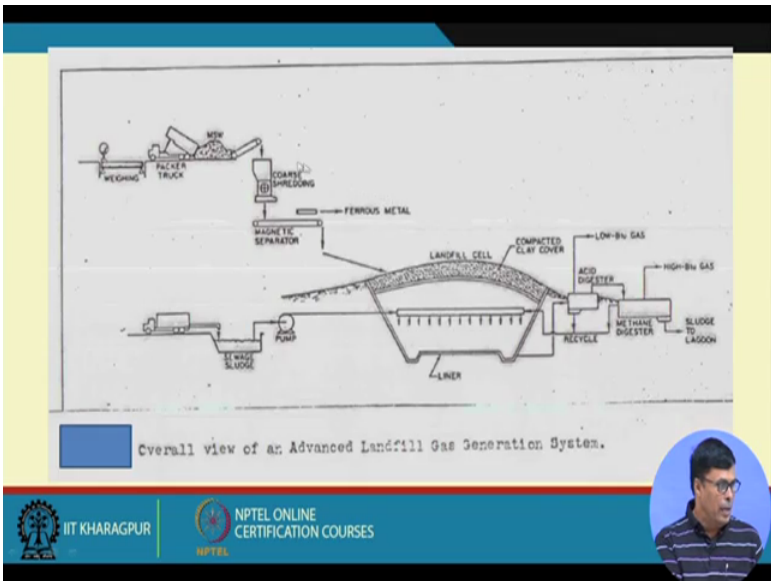
And this gas mostly contains methane and carbon-di-oxide then we pass this carbon-di-oxide absorption column, we remove the carbon-di-oxide we get pure methane. So this is largely in practice in the western country and after the stability of this process they can use this land field for the beautiful preparation of beautiful park, beautiful playground and you know amenity centres but only the disadvantage of this that nobody can build up the multi storey building here because the soil quality is not good as good as normal soil, because this we consider as a medi-fertile land.

So we can have a very good you know park and playground like this, okay. I was thinking about how best we can utilize the this municipal solid waste in India and I was considering that you know that if you look at the age of the land field is 5 to 10 years and 5 to 10 years is pretty long time, so we did some kind of research work just to find out how this time can be reduced? Because I told you already the Acidogenesis is very faster, rate of reaction is very fast as compared to methanogens.

(Refer slide time 26:06)



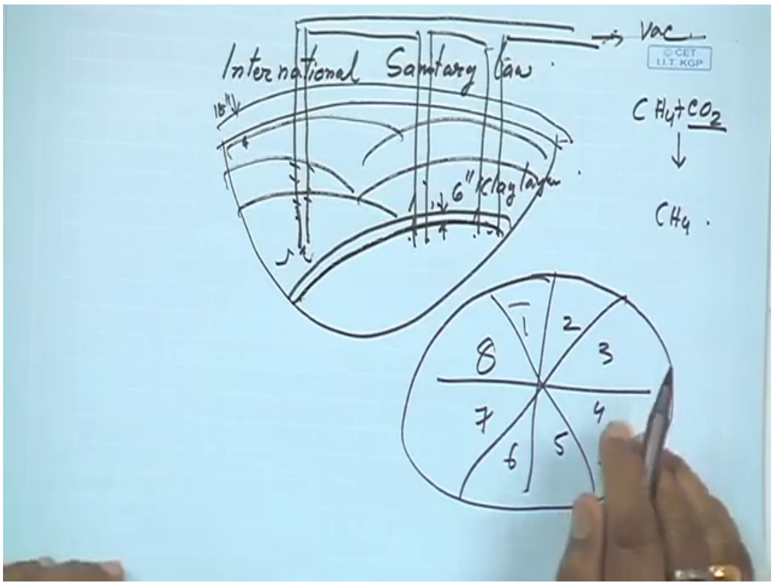
(Refer slide time 26:16)



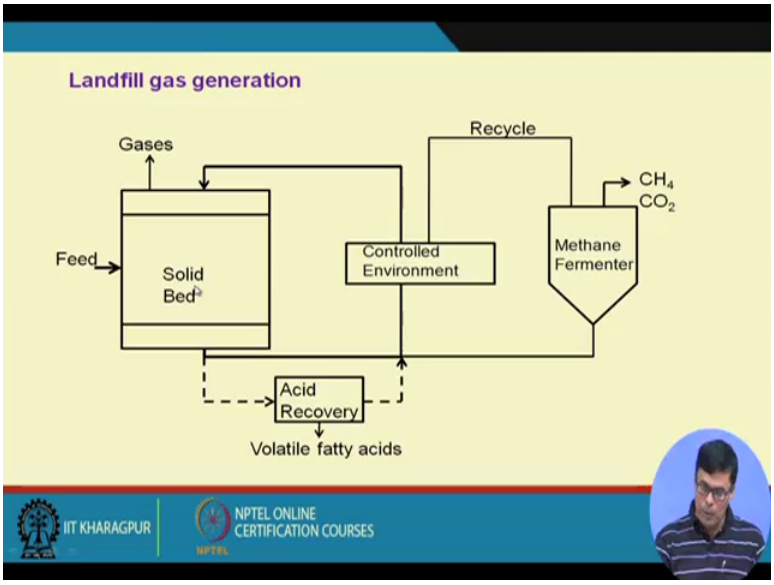
So what we did? We carry out this reaction in the Acidogenic reaction on a particular reactor now here we build up the solid bed and here we sprinkle the Acidogenic culture, recycle this again and again, we can recycle this again until and unless the stabilization takes place. When we find that this bed is totally stabilize then the liquid we pass through the methanogenic reactor.

So you know our suggestion was that suppose we consider this because here I want to point out one thing that as the time passes on, in the cosmopolitan cities the lands are very costly. So if we find that as the time passes on, most of the down land that will be filled with the waste material. Now they have to go to the distance places, so what you call the hauling distance? They increase in drastically, as the hauling distance increases the cost of transportation increases to a great extent.

(Refer slide time 27:08)

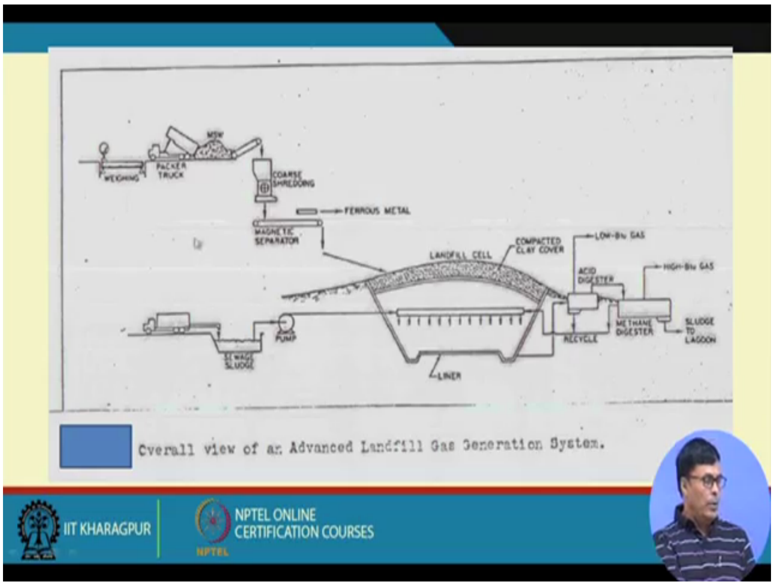


(Refer slide time 27:44)



Our suggestion was that if you can identify one particular land in a particular cosmopolitan cities and if we divide the land in suppose 1, 2, 3, 4, 5, 6, 7, 8 like this and different wells we can have and put the raw materials in different one after another, you know that and we find through our research work for stabilizing of this reactor we hardly require 40 days. If we keep 40 days here the organic material will be totally stabilized then we can fill it in such a way that when you come here then here might be 40 days then you start vacating this land.

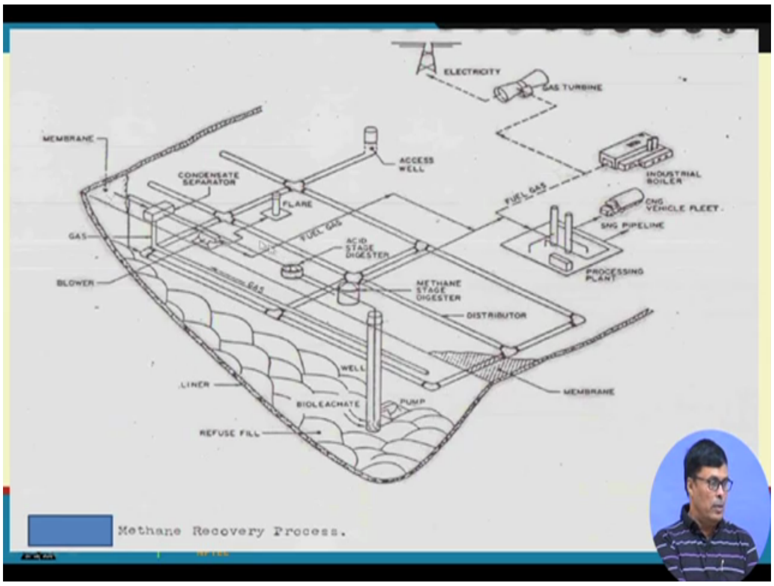
(Refer slide time 28:21)



And this digested material you can take it out use as an organic fertilizer and whatever liquid is there you can pass through the reactor and produce methane and carbon-di-oxide. In the outside you can pass through the reactor and produce methane and carbon-di-oxide. So this can be largely used, this is the kind of suggestion that we have and this is how industrially the land field operation is done.

This is skinning that you know that it is when truck comes then we take the weight after unloading we take the weight then we find out how much waste was there then we pass through the shredder, magnetic separator then we put it in the land field then we recycle this we take the liquid out pass through the methanogenic reactor we get methane and sludge can be used as a fine fertilizer.

(Refer slide time 28:55)



So this process, this is how it looks largely that's how methane recovery is done. I told you the pipe we can interconnect it and we can apply the vacuum and take the gas out, we can remove the carbon-di-oxide in the processing plant and we can have SNG pipeline here or CNG vehicles we can load here or we can use it for the generation of electricity. So it has very vast potentiality that we have land field and when I had opportunity to work in Timarpur land field area in Delhi, we found we do not follow the International Sanitary Law that is why the gas is going out from the solid material.

And you will be surprised to know that I observed at least 32-35 pockets through which I constantly observed the flame and when I asked them how the flame is burning then they are saying that all the truck driver when they come for unloading the waste material they might be using some cigarette, they throw it out and since methane is coming out when they come in contact with the methane it gives the flame and in the night it looks like Dipawali because you know whole land you have lot fire. So we are wasting lot of energy.

So we should think very seriously how fruitfully we can utilize lot of energy for the human benefit. So in conclusion I want to point out the anaerobic digestion has been found lot of potentiality throughout the world and it is not only useful for the industry, it is useful in the domestic sector also for the individual family, for some community, for municipality they use the organic material for the generation of biogas which can be used as a energy source for running vehicles and other things. So with this let me conclude this, thank you very much.