Water and Waste Water Treatment
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Lecture-17
Biological Treatment: BOD and Nutrient Removal

Hello, everyone, welcome back to the latest lecture session. In the last couple of sessions we discussed sedimentation in some detail. In sedimentation we remove these suspended particles. Then we mostly have the dissolved organics and some suspended particles, but we are not greatly concerned about that because they will be removed subsequently. Now our focus is on degrading or removing these organic particles that are dissolved or are soluble let us see.

Because there is dissolved ? You cannot really change phase as in earlier, what were we doing, we had the suspended particles and we were changing phase as in earlier, they were in water or aqueous phase and we removed them to the bottom and more or less they are called sludge and dewatering and treatment, you can take care of that. But here, the organics that we want to degrade, are what is it now soluble and thirst dissolved?

How do I do that? I cannot really settle them out or such. Here the aspect is that we are going to use microbes that are present out there. Here we are going to look at biological treatment.

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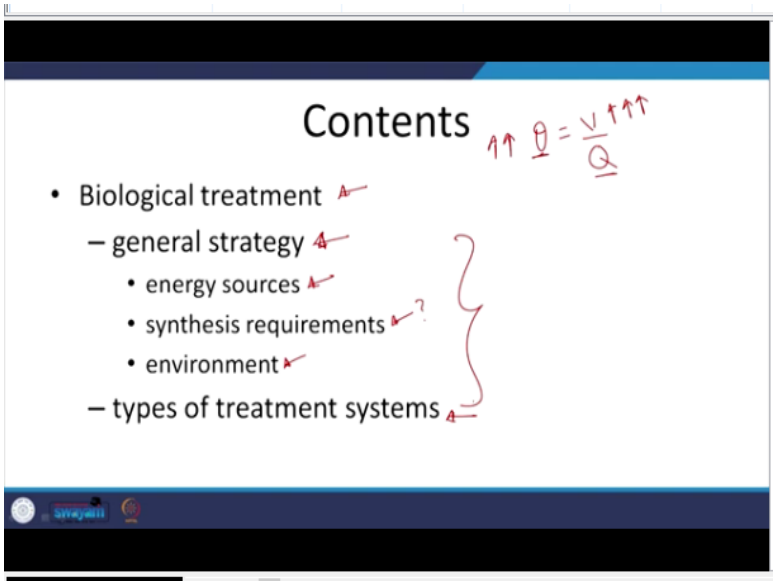

That is why we call that biological treatment. In this session, we are going to cover these aspects. What is the general strategy now as in I can let the wastewater stay there and without

the microbes just provide a lot of oxygen and maybe that will take a few years or months, if not years months and then I will be able to treat the water.But for that, if I am going to have to aerate water for a lot of time, my tank volume size will be a lot.

As in I know that theta = V by Q. Flow rate is constant. If theta is high, then the volume of the tank also will have to be high. That is not going to be feasible and also providing oxygen for a lot of time that is not an feasible option too, because of the costs. Another aspect is what we say putting in a lot of oxidising agent that is going to be costly.

What are we going to do? We are going to try to mimic what nature typically does? What does nature facilitate? It facilitates microbial growth. These bacteria degrade the relevant waste, are our wastes**.** We are going to promote that. How do we promote that? We promote that by creating conditions that promote bacterial growth and also by increasing the concentration of the microbes in this wastewater.

That is what we are going to discuss or that is the general strategy for the microbes, what do they need? They need sources of energy, why are they degrading it? Well, they do not have any sense of smell and they do not really like wastewater due its smells or such**.** They degrade the waste or our waste as their food or consider them as their food because they gain energy from it and then can synthesise new cells**.**

Energy sources to synthesise new cells, what is it that they need let us see, similar to us, they also need nutrients, we will discuss that and what about general environment as in are can be stressed we do have our own peer pressure and relevant issues work pressure issues, but we are always concerned with the environment too hot, too cold, and these kinds of environmental conditions.

Similarly, microbes also have environmental conditions, P_H, temperature and so forth. We will look at that. Then based on these fundamental aspects, there are different modes of treatment systems. We will briefly touch upon some but discuss activated sludge process in greater detail, because that is the most widely used form of wastewater treatment out there. Let us move on here.

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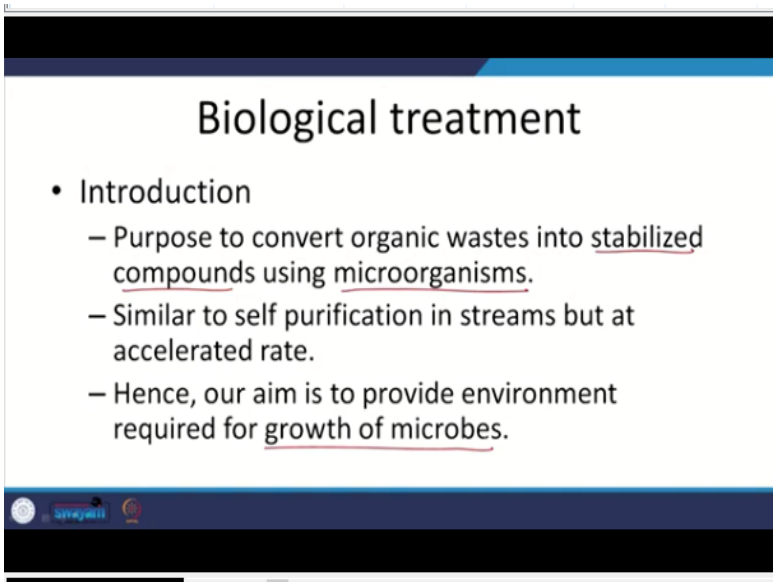

biological treatment, what are we trying to do? We are trying to see to it that the waste which if I leave it out there can lead to septic conditions smell because of what we say reduced forms of sulphur like hydrogen sulphide, being given out explosive gases like methane can be given out. Then you are going to have what we say flies because of septic conditions.

You do not want to have that you want to have a relatively stable compound. We are going to do get to that by using microorganisms which release enzymes**.** Our main aim is to degrade the organics, but by promoting the growth of microbes**.**

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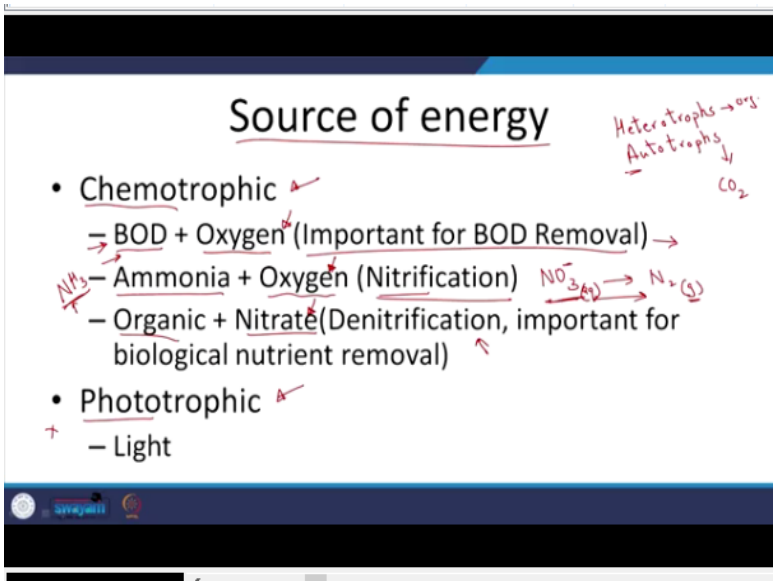

Let us move on. Sources of energy with respect to microbes or microorganisms we are looking at a source of energy or general source of energy. We can classify them as chemotrops or chemotrophic and phototrophic phototrophic photo. The source of energy is light, but we are

not concerned with that though if algae are such typically what we see are dependent upon what we say light or photosynthesis.

We are not really concerned with that because that is of no use to us**.** Here chemotrops, chemotrophic as in the sources of energy or chemical or chemical sources of energy, this is what are these are the microorganisms we want to make use of. What is it that we do? For example BOD or the waste or our organic content or our waste or the organic content, which is measured by BOD can be removed in the presence of oxygen or oxidised in the presence of oxygen.

, this we are going to use for our waste removal. Another aspect is we also give out ammonia. This is also as you can see a reduced form of nitrogen and we have oxygen as an electron acceptor and nitrification will take place and organics plus nitrate, here the electron acceptors were oxygen and oxygen**.** Here the electron acceptor is nitrate.

We will discuss this in greater detail as in from here we will get NO_3- but NO_3- is very soluble in water and you do not want it in water because it leads to what we say adverse effects in humans and certainly in the aquatic systems too. Once you convert this NH_3 in NO_3- you want to remove this from water. How do you do? You by promoting what we say formation of nitrate nitrogen gas pardon me and that is called denitrification.

First one is nitrification and then is denitrification. As in we are changing this from the aqueous phase, water to the gaseous phase, thus nitrogen is leaving our system. Sources of energy. In this context, one aspect to understand or another aspect is that we have heterotrophs. Hopefully my spelling is and autotrophs. One depends upon organic compounds or organic sources of carbon and the other inorganic source of carbon, namely, carbon dioxide.

This is what we say with respect to heterotrophs are done by heterotrophs. Then nitrification typically by what is it autotrophs so chemoautotrophs. You need to mug up anything, but for the serious listener or such I am just providing some information.

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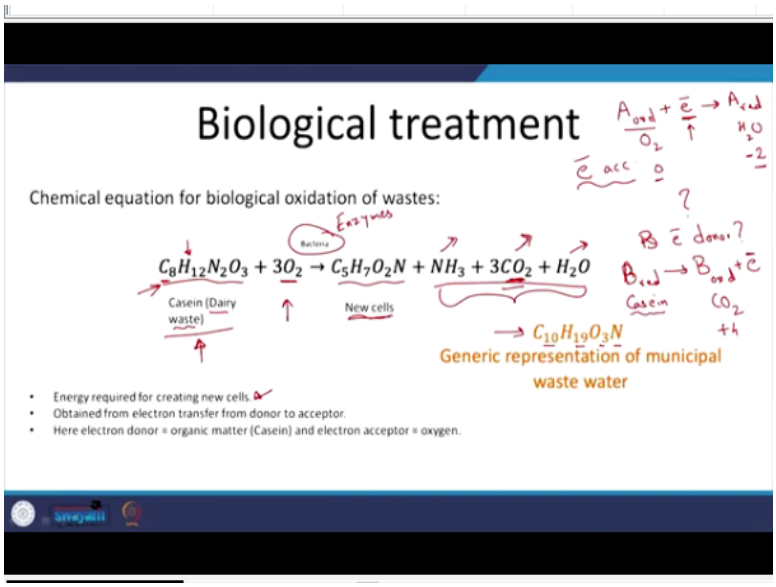

$$C_8H_{12}N_2O_3 + 3O_2 \rightarrow C_5H_7O_2N + NH_3 + 3CO_2 + H_2O$$

Biological treatment, let us just understand what typically happens. Casein the kind of protein We have it in the diary. Here what are we trying to do? We are trying to oxidise it, but as I said, the kinetics as in the rate at which this reaction goes through is probably not good enough for practical oxidation by just oxygen.

What are we going to do? We are going to introduce bacteria which release enzymes, they release enzymes which act as catalysts as they fasten or improve the kinetics of the reaction. Here there are 2 aspects, one aspect is new cells as in reproduction, as in new microorganisms are formed. Cell synthesis, and then while transforming it into other, by products, they gain energy.

Then they need the energy, 2 aspects, one for energy and one for cell synthesis. As you see, these compounds are relatively stable carbon dioxide leaves the atmosphere, we have by product of water NH_3OH if required, we will degrade further. Energy is required for creating new cells, How do we get that.

For example, we have redox reactions, explosives and how there are 2 aspects, there sudden release of energy and also sudden change in volume. But how is this energy being released because there is an oxidising agent, typically and a compound that certainly reduced. You have

a redox process reduction and oxidation occurring and then you are going to have transfer of electrons from the reduce compound to the relatively more oxidised compound.

Thus you are going to have a redox process and there is a release of energy. That is the same principle here. Here the oxygen is the electron acceptor or the oxidising agent and the relatively more reduced form or the compound is this particular waste or our waste you see this carbon that is typically the electron acceptable. As you can see it is bonded with H.
Here carbon is relatively oxidised**.** That is something to keep in mind. Here we looked at electron acceptor. What is it that typically happens? A, which is relatively more oxidised, gains electrons and goes to it is more reduced state**,** here it is more oxidised and here it is reduced. For example, here the example is O_2, O_2 oxidation state is 0.

And it is gaining electrons and going to H_2O where the oxidation state is - 2**,** oxidised form of oxygen reduced form. Similarly, for the redox process to go through you somebody has to or some compound has to take this electron. Who will take this electronics? you will have or who will give this electron party that was a minor error there.

Here for this oxidised compound to be reduced, somebody has to give the electrons. You need an electron donor. Why do you need an electron donor? who is the electron donor as you can see, it is this waste or our compounds. The reduced or B , B which is reduced, we will go to the more oxidised form and give out electron. This electron will be used by this particular half reaction there.

We have 2 half reactions. Here, what is the reduced format casein. And this is the reduced form and what is the oxidised form? As you can see, it is carbon dioxide. Oxidation state here is what is it now + 4. You can look at what the oxidation state of carbon is in this particular compound. This is the general aspect. For wastewater for presentation purposes, a general based on general ratio of carbon, hydrogen, oxygen and nitrogen, this is the value.

Bu , there is no one particular what we say value, not value compound, or such that we can use as being representative of all the kinds of wastewater, that is something to keep in mind. From this redox process, you can gain energy. But as you mentioned, there were 2 aspects. Let us see if we have that.

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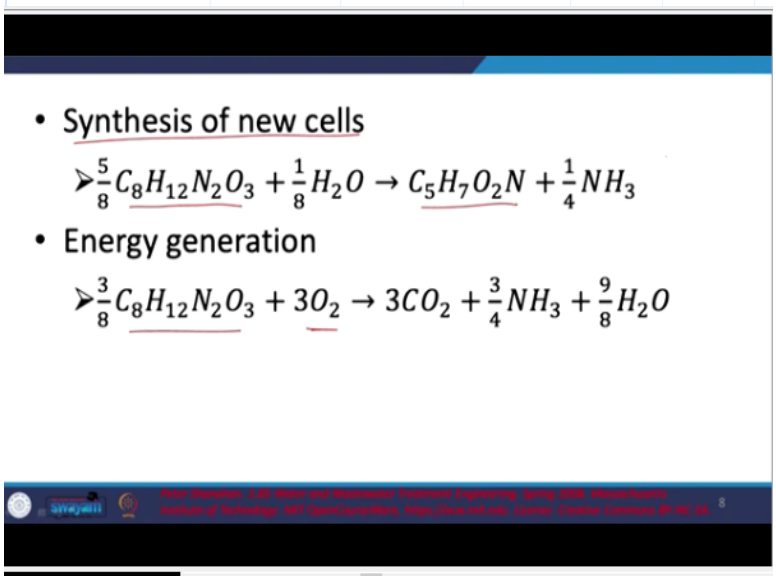

Synthesis of new cells

$$\frac{5}{8}C_8H_{12}N_2O_3 + \frac{1}{8}H_2O \rightarrow C_5H_7O_2N + \frac{1}{4}NH_3$$

Energy generation

$$\frac{3}{8}C_8H_{12}N_2O_3 + \frac{1}{8}H_2O \rightarrow 3CO_2 + \frac{3}{4}NH_3 + \frac{9}{8}H_2O$$

There are 2 aspects are one is synthesis of new cells. Then the cells are such one comes out of thin air. You are going to have breakdown of this particular compound and have formation of cell synthesis. You can look at this stoichiometry, but we are not going to go into that detail. Energy generation, different fraction. Now oxygen is the electron acceptor, and then you have the relevant by products.

2 aspects out here, we broke down that equation into 2 aspects. Here for each reaction here that we have, we are going to have 2 half reactions. Let us look at that.

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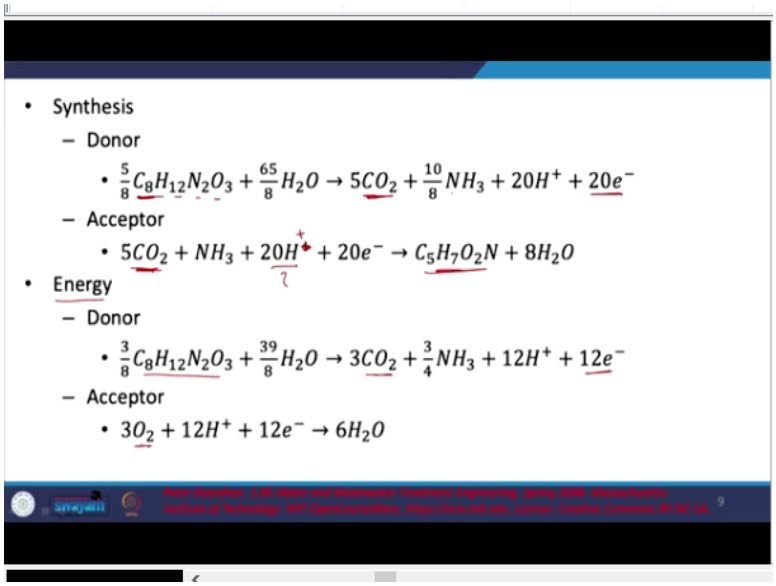

Synthesis

-Donor

$$\frac{5}{8}C_8H_{12}N_2O_3 + \frac{65}{8}H_2O \rightarrow 5CO_2 + \frac{10}{8}NH_3 + 20H^+ + 20\,e^-$$

Acceptor

$$5CO_2 + NH_3 + 20H^+ + 20\,e^- \rightarrow C_5H_7O_2N + 8H_2O$$

Energy

-Donor

$$\frac{3}{8}C_8H_{12}N_2O_3 + \frac{39}{8}H_2O \rightarrow 3CO_2 + \frac{3}{4}NH_3 + 12H^+ + 12\,e^-$$

Acceptor

$$3CO_2 + 12H^+ + 12\,e^- \rightarrow 6H_2O$$

For cell synthesis the donor here. The electron donor, it is giving out these electrons and that process carbon is being oxidised**.** You can check the oxidation rate of nitrogen, but primary focus here is carbon. Carbon here is relatively more reduced. By giving out electrons, it is going to a more oxidation I mean oxidised form. These electrons who is accepting that so.

We have some error out here**.** It is $20H^+$ I thought it was an error. That is $20H^+$, these electrons are going to be used for self census. Carbon dioxide is the electron acceptor**.** Because when we club the 2 half reactions, then we do not see these relevant aspects. But this role of electron acceptor is more clear when we look at energy.

What is the electron donor, it is still the relevant wastewater, or our waste and we see electrons being given out and the more oxygen is formed, what is the electron acceptor? It was oxygen and that is what you see oxygen going from 0 oxidation state to - 2 out here by taking up these electrons**.** That is what we see out here. In this process, the energy is released, which is used in this particular reaction.

There are different what do we see electron acceptors that you can use to achieve different objectives. Let us just look at some of the different electron acceptors**.**

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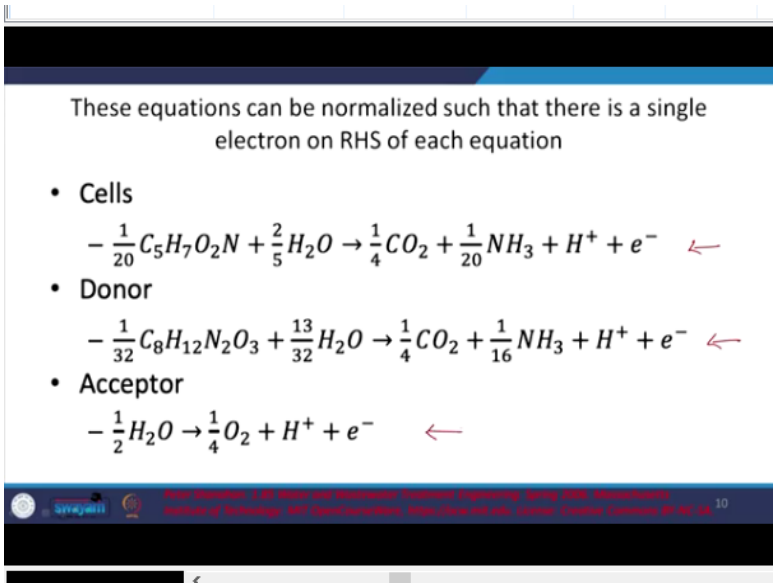

Cells

$$-\frac{1}{20}C_5H_7O_2N+\frac{2}{5}H_2O \rightarrow \frac{1}{4}CO_2+\frac{1}{20}NH_3+H^+ + e^-$$

Donar

$$-\frac{1}{32}C_8H_{12}N_2O_3+\frac{13}{32}H_2O \rightarrow \frac{1}{4}CO_2+\frac{1}{16}NH_3+H^+ + e^-$$

Acceptor

$$-\frac{1}{2}H_2O \rightarrow \frac{1}{4}O_2+H^+ + e^-$$

If I club these reactions such that there is 1 electron on the hand side of each equation. Cells, you have this and the donor case you have this for cells and for the donor and the thermal electron acceptor you can say is going to look something like this. But, we no need to go into this detail here.

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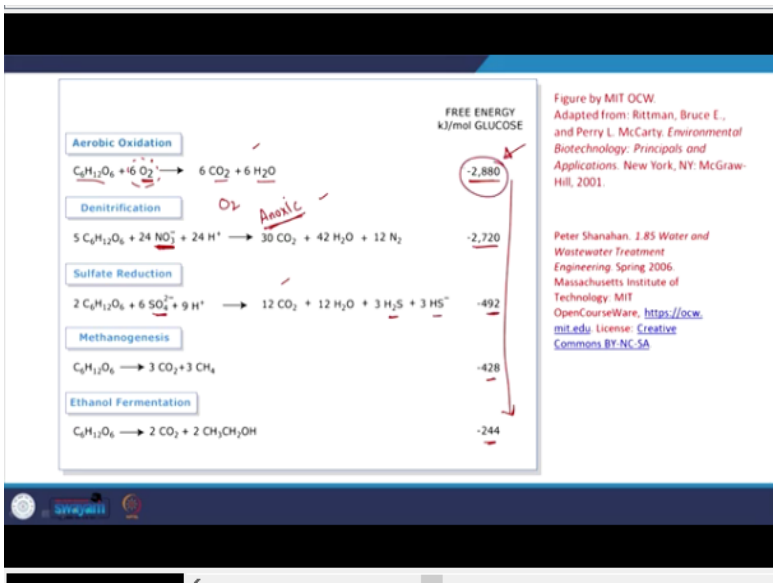

We can look at different electron acceptors. The most what we see widely available electron acceptor is oxygen, as we see out here. Here we have glucose and glucose being oxidised to form carbon dioxide and water. Here we see 2880 kilojoules per mole of glucose. That is the energy that is released. If it is in denitrification, the electron acceptor is not oxygen, but as I mentioned, the electron acceptor is NO_3^-

What do we see here? We do see,similar but not as high, what do we see amounts of energy as in the case of aerobic oxidation. Why do we see aerobic? because oxygen is there . Here there is oxygen but it is not in the form of what we say free oxygen if I may say so. It is the electron acceptor is NO_3^- . These conditions we call as an anoxic conditions.

There is still an electron acceptor in the form of oxygen if I may say so not oxygen. Here we have oxygen. The electron acceptor but not oxygen, we have we call it the anoxic conditions**.** Then do you have different other electron acceptors sulphate out here**.** Sulphate is reduced to hydrogen sulphide and less energy as you can see.

Methanogenesis and fermentation where you do not have what we say, an external respiration mechanism here with respect to the cells, but as you can see, as we look at different electron acceptors, or fermentation, we see that the energy being released decreases. Microbes, similar to us or human beings are the students, they do not want to take my class because they need to go through a lot and need to submit a lot of what we say homeworks.

They will take the path of least resistance they will go to the relevant person who will give easier grades with lesser work , microbes do they want more energy. Typically, looking at this

analogy, Lemans analogy we see that typically aerobic oxidation is preferred, only when there is no oxygen will this denitrification take place**.** That is something to keep in mind.

And when there is no nitrate only then if there is sulphate will this reaction go through. Different microbes are going to be prevalent at each we are going to carry out each of these reactions, why do they do that? Because they want to get this energy that is something to keep in mind.

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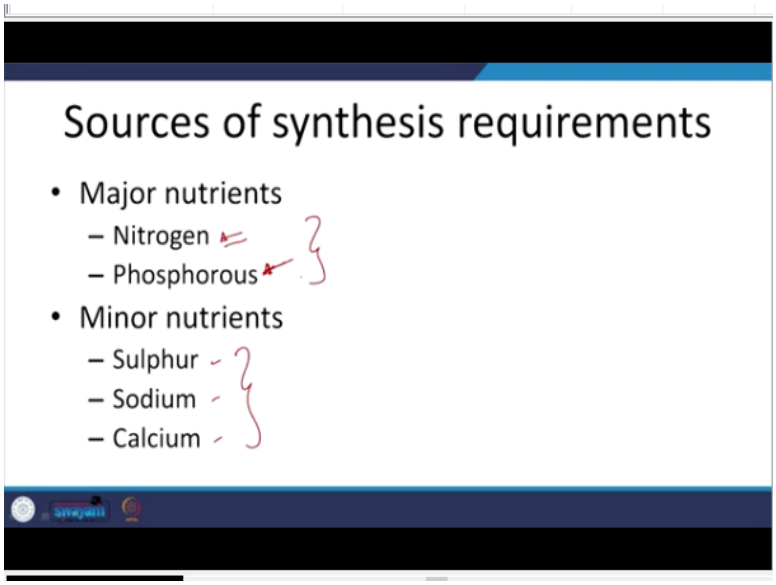

What else do they require? One is energy which we just looked at and different electron acceptors lead to different amounts of energy and synthesis requirement, what do they need similar to us, they need nitrogen and phosphorus. We typically take in nitrogen in the form of amino acids or proteins and other nutrients are also required sulphur, sodium, calcium and so forth. But they are required at much lesser concentrations compared to nitrogen and phosphorus.

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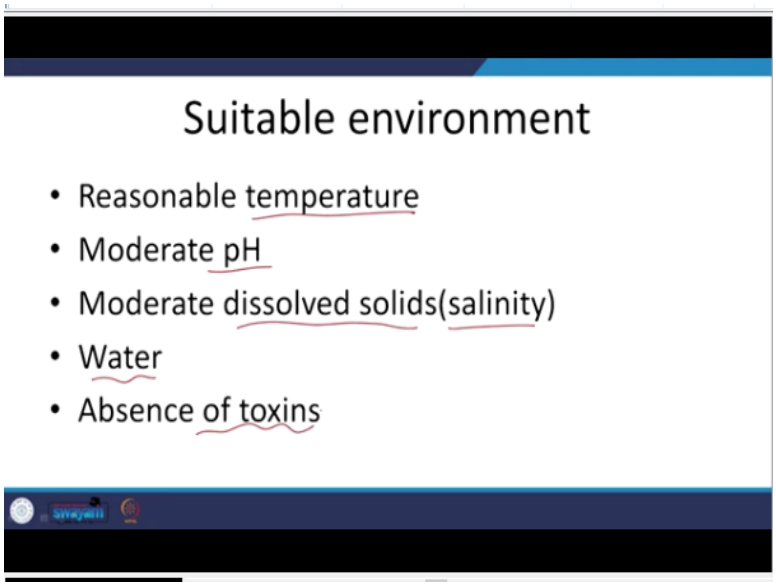

And suitable environment, similar to us they want reasonable temperature, moderate ph, they do not like too much salinity total dissolved solids should not be too high, water and if you have toxic compounds coming in along with the wastewater, they are going to affect the growth of your microbes, they can do the job but maybe not as efficiently and they do not thrive as much. They do not like a lot of toxins to be present in the relevant environment.

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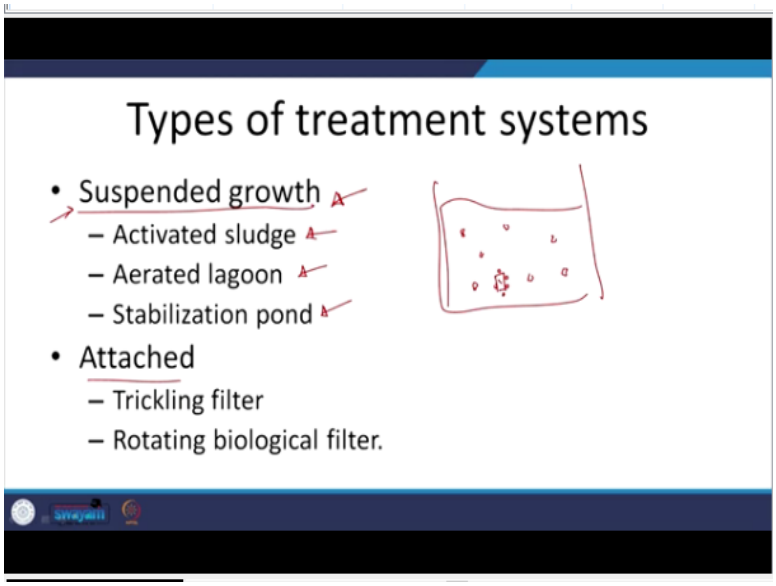

, types of treatment systems, one as we mentioned quite often was activated sludge, we will look at a video 2 sessions down the line and earlier when the concentration and also the flow rate were relatively less and land was available people used to look at aerated lagoons and stabilisation ponds, but we will not look at that now, people are phasing that out at least in India. The key difference between this kind of system and this system is that here we have suspended as and if this is my tank and this is the water.

The microbes are suspended. Here they are attached, but attached on to what some media. For example, I can provide a media upon which the microbes can grow so, attached growth, suspended growth and attach growth, more often than not people have been looking at activated sludge process which is suspended growth of microbes. But sometimes people also look at attached and suspended growth to increase the efficiency. That is something to keep in mind.

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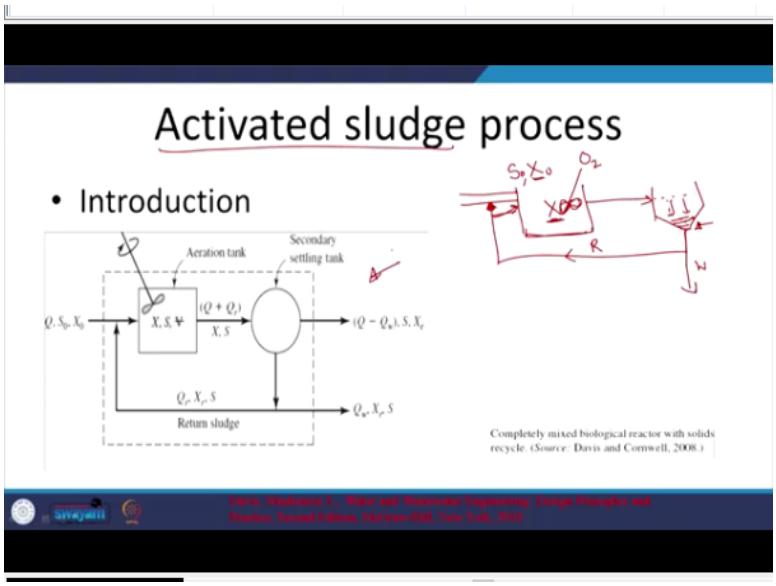

Activated sludge process. Why do we call that activated sludge? My wastewater is coming in this is after the primary sedimentation, what does it have? It has a lot of organic content, which I am going to call substrate, which is my waste and what is it the food for the relevant microbes. But the concentration of the microbes in this relevant sewage, or wastewater, which I am going to represent by X is going to be less**.** There are going to be some but not enough for what we say fast degradation. Also the kind of microbes that are present might not lead to wthe degradation of the kind that we are looking for. What am I trying to do or what do I want to do? I do not just want this X, I need a X that is remarkably high.

This is X_0 and S_0, I need a concentration of X are the microbes in my tank to be very high? how can I achieve that? I need a source of microbes**.** where this will come from. In this tank, what else do we need to provide? I am going to provide mixing and I am going to provide oxygen. Here I am going to provide conditions such that the microbes thrive and the concentration is high.

Once we stop aeration we send that to what is called a secondary clarifier or secondary sedimentation tank, what happens is if we maintain the conditions, the kind of bacteria that form here include are what we call flock forming bacteria with some filamentous bacteria. We looked at this figure, I think in what we say the last session, where you we looked at the microscopic pictures.

And we saw the flocks being formed along the filamentous backbone. These particular flocks are kinds of microbes, they are going to settle down and they are going to settle down at the bottom. Typically, you can waste it or you can recycle that or for recycle, such that when it comes into should not draw it here, maybe I should draw it here.

I can recycle it such that the concentration of the microorganisms in this tank where the actual reaction and degradation takes place is pretty high. That is why we call it activated sludge as in this sludge, which has the microbes activated sludge is reused activated sludge process. That is what we have, that is the relevant schematic .

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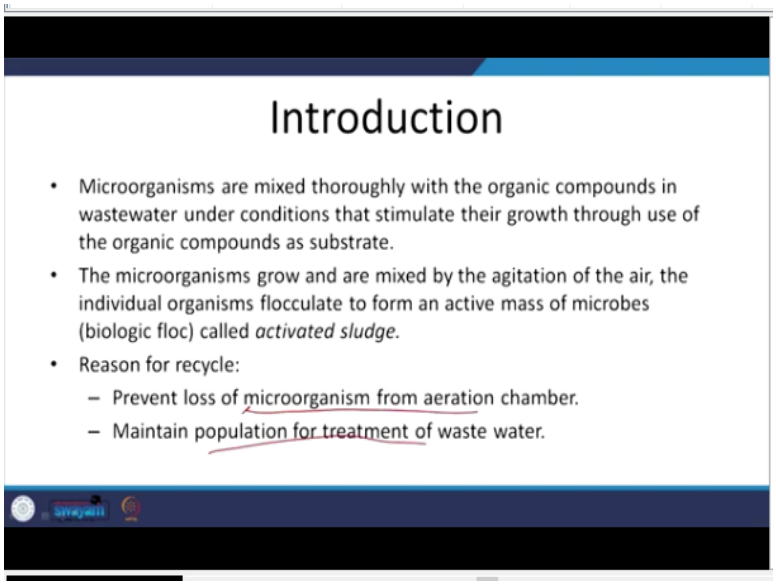

Why recycle loss of microorganisms, you cannot keep bringing them and you want to increase the concentration.

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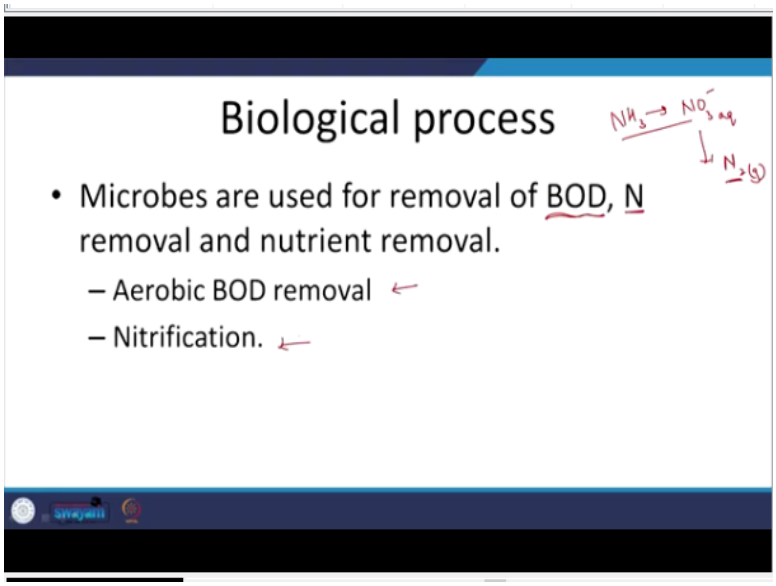

And what are we trying to use it depending on the design, you can decrease the organic content which we are measuring by BOD, if the ammonia content is high, you can design it such that nitrification first as an NH_3 goes to NO_3^- and then with the denitrification. This is aqueous phase and now nitrogen which is in the gaseous phase will be formed, this is nitrification, then denitrification because we are forming nitrogen gas which will leave the aqueous phase or the water. We can look at the relevant aspects. Aerobic BOD removal nitrification we can achieve that.

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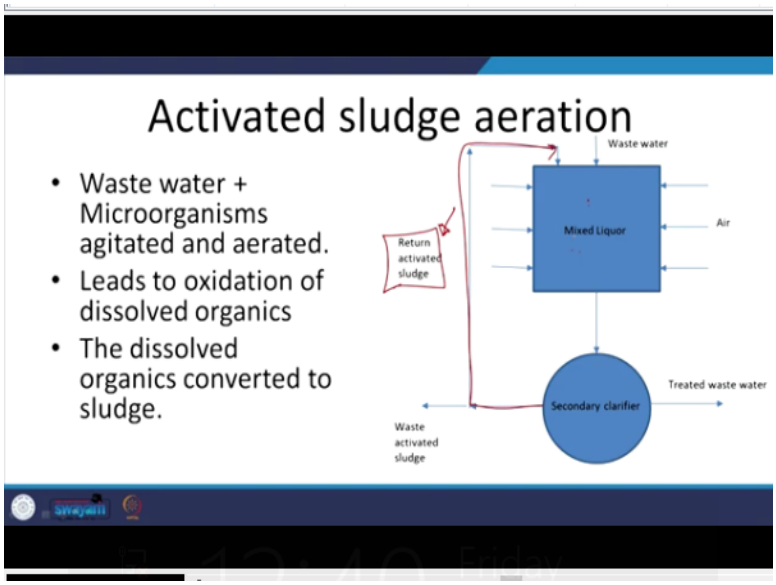

Activated sludge aeration, the primary aspect is this return activated sludge. One aspect to note here is that in India people do not maintain these, clarifiers or maintain the recycle. What does that lead to? That leads to very low concentration of the microbes in this particular aeration tank.

What happens when you have less concentration of microbes. First, the kinetics**.** As in there is 10 kgs of ladoo and 100 people faster consumption within maybe 10 minutes or so. But if there is only 1 guy it is going to be an issue as in the time or the kinetics are going to be pretty slow. Same case here people do not maintain the conditions for the microbial growth or do not maintain sufficient concentrations of the microbes.

That is why different treatment plants either industrial or sewage treatment plants and India typically affected**.** That is something to keep in mind**.**

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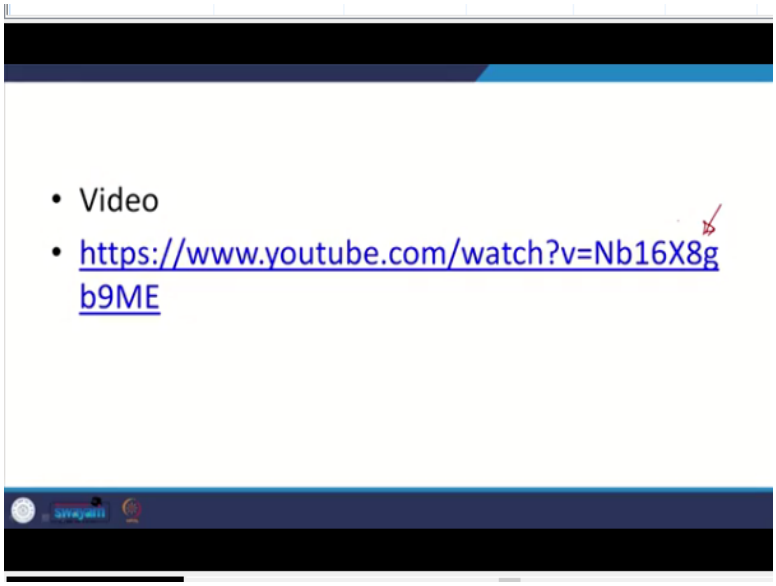

I have one video you can look at this video, which looks at the different aspects and I will play or I will try to play another video that is out here. You can look at the link and search and the reference. We are just trying to look at the schematic.

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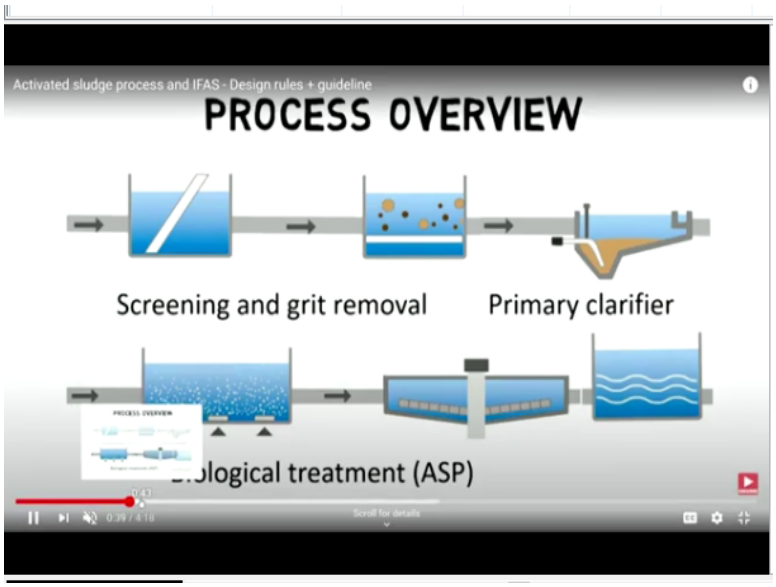

process what do we have? We have the grid chamber or the screens pardon me particles, racks then the primary sedimentation basin and then you have the primary sedimentation basin out here, grid removal primary sedimentation basin and then we have mostly only the suspended matter and here this, I hope you can see the arrow, we have the biological process where air is provided microbes are coming into the picture.

That is why the biological process and then the secondary clarifier, or secondary sedimentation tank. Let me just play this a bit further. What we just mentioned out here and in the biological process, what do we see happening?

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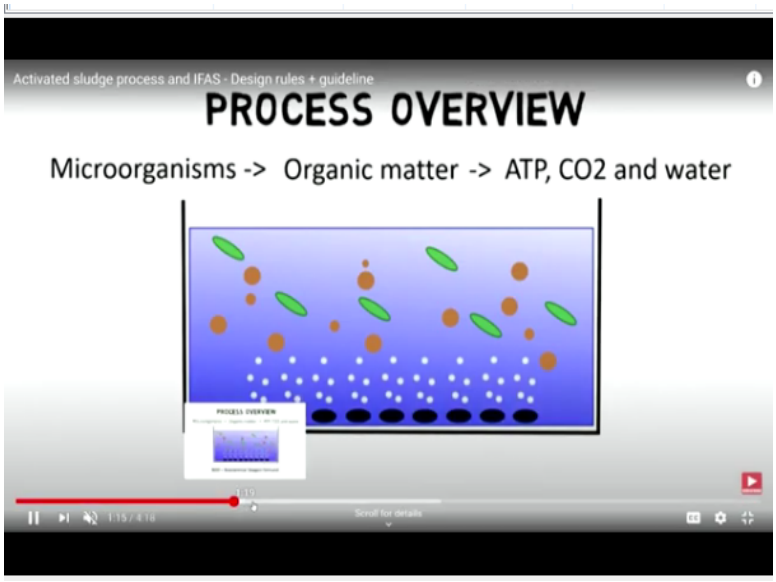

What do we have? We have our waste faecal matter, we provide the relevant microbes**.** Then microbes are, going to degrade the organic matter to the relevant by products. But what do they

need? They need an electron acceptor, which is oxygen. That is what we are providing here**.** **(Video Starts: 25:50)** And then so what do we have here, we have these microbes or flocks that come into picture here.

Here this other or the video maker says we add flocculants. But in wastewater treatment, we rarely favour or never add flocculants, the kind of bacteria that are going to be formed, if we maintain the conditions to be good, they are going to see to it that this particular sludge settles down and some will go to waste. Some is recycled back. That the concentration of the microbes in your relevant aeration tank is high enough.

That is why we call it as activated sludge. The sludge, which is activated is recycled and used out here. That is enough for now. **(Video Ends: 26:34)** But you can look at the other video, which is not a schematic but from a relevant treatment plant**.**

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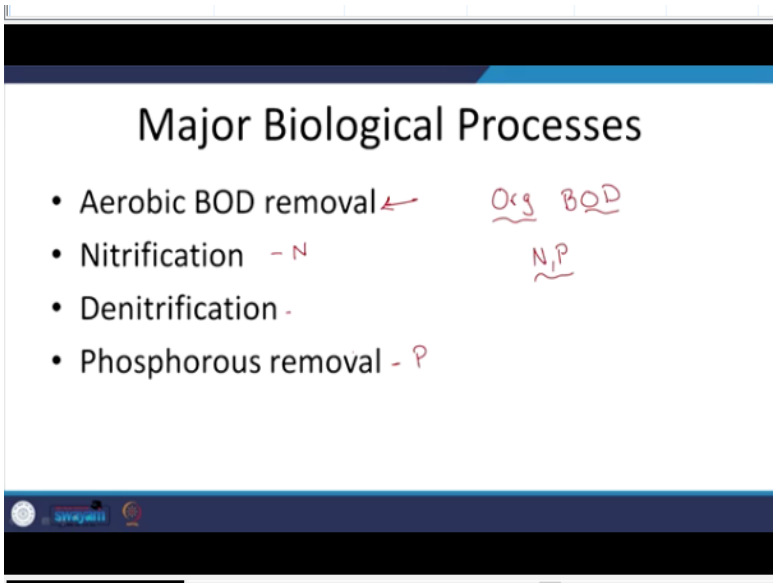

let us move on. What are some of the major biological process that we try to use. As we looked at in the class or sessions beforehand, we want to look at those compounds which have or exert an oxygen demand or the organic compounds which exerted oxygen demand**.** This oxygen demand we were measuring by BOD. We want to remove the BOD.

And also we mentioned algal growth. We want to remove the nutrients depending upon the concentration. We remove nitrogen by nitrification and then denitrification. Then we also look at phosphorus removal, let us just briefly look at the relevant aspects out here.

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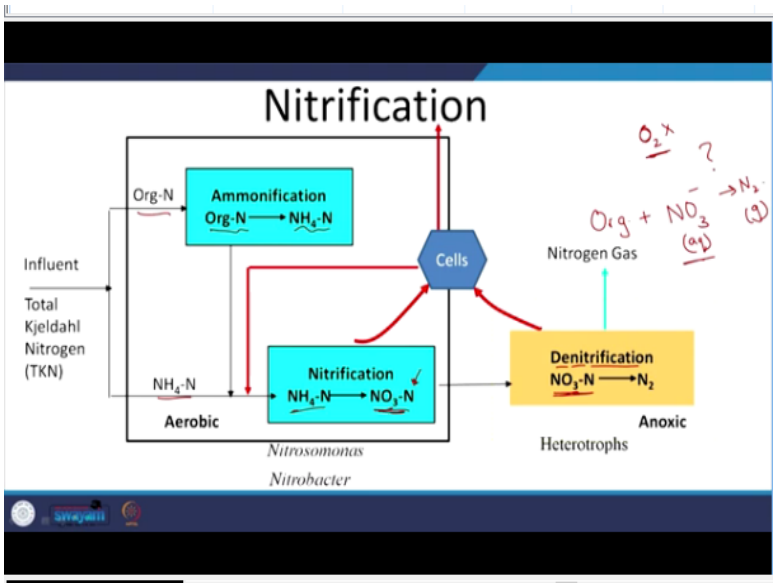

nitrification,we already looked at aerobic BOD, removal in considerable detail. Let us just look at nitrification and denitrification briefly and then phosphorus removal. We will come back to this later. But we are just understanding the principle here. That is something to keep in mind. TKN, we know what it is going to give us you have organic nitrogen and this NH_4 and NH 4 or $NH_4\,N$.

And what is it that we are going to try to do by nitrification, this NH 4-N is going to what we say be transformed into or oxidised to nitrates and NO_3^- . But, this is a simplistic diagram, we will look at that later. In during that time, the organic and will be degraded by microbes to NH_4**.** Then that NH_4 to NO_3^- but as I mentioned NO_3^- are the nitrate is toxic to humans and you do not want it to be in the water.

you have to remove it. But, it is very soluble. What do you want to do? You want to see to it that it changes phase such that we can remove it. That is where we have denitrification, as in nitrate, NO_3 and NO_3^- expressed as and so you do not need to really look at this nitrate, which is NO_3^-. Now is going to be reduced to nitrogen. But here the issue is this is an aqueous phase and this is gaseous phase.

And then this nitrogen gas is going to leave the system. That is something to keep in mind. But how is this reaction going to come about? Please note that this will not occur in the presence of oxygen, why we looked at the relevant electron, I mean, not electron transfer energy generation for different electron acceptors. You would have seen that with this particular electron acceptor.

They do not gain a lot of energy. If there is oxygen present, the different kinds of bacteria will thrive. What do we need? We need a more reduced compound, organic compound and then what is it nitrates which are the electron acceptors and that is what you will have.

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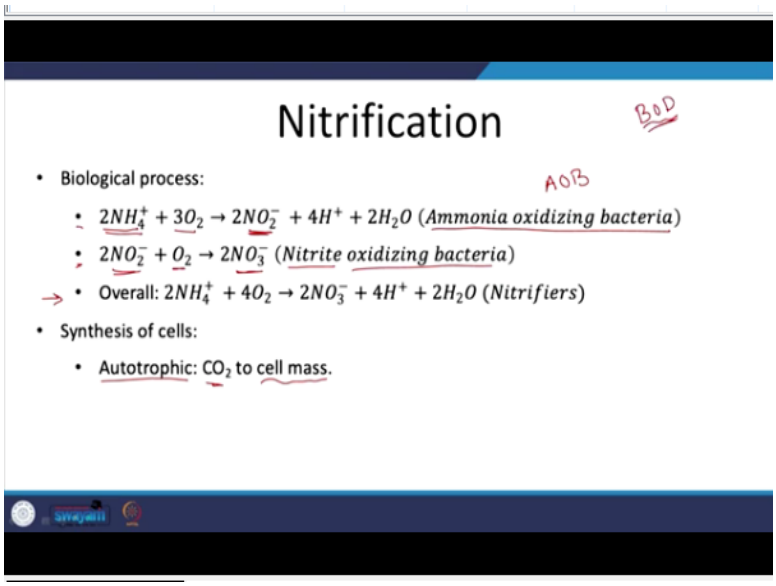

Biological process

$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ (Ammonia oxidizing bacteria)

$2NO_2^- + O_2 \rightarrow 2NO_3^-$ (*Nitrite oxidizing bacteria*)

Overall : $2NH_4^+ + 4O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ (Nitrifires)

let us look at the relevant reactions. Biological process. Ammonia oxidase by oxygen, but directly you would not have formation of nitrate, first you will have formation of nitrite. This is called or the type of bacteria that do this are called ammonia oxidizing bacteria. That is the relevant reaction. Then what happens to this nitrite? Nitrite is further oxidised by oxygen to nitrate by what we call nitrite oxidizing bacteria.

Here, ammonia is being oxidized. Then here we have nitrite being oxidized. Over all though if we cancel out nitrate this is what it looks like. But please note that we have 2 kinds of what we say reactions involved here. We have different kinds of bacteria. Here one aspect to note that here is we have no organic compound present here. No organic compound. How do these bacteria, grow or such not grow cell synthesis. How does that occur? They are autotrophs not heterotrophs.

That is why they use inorganic carbon to form their cell mass for production of cell mass, but for the BOD removal, the kind of bacteria that are heterotrophs, they need organic compounds for cell synthesis, we already looked at the relevant reaction.

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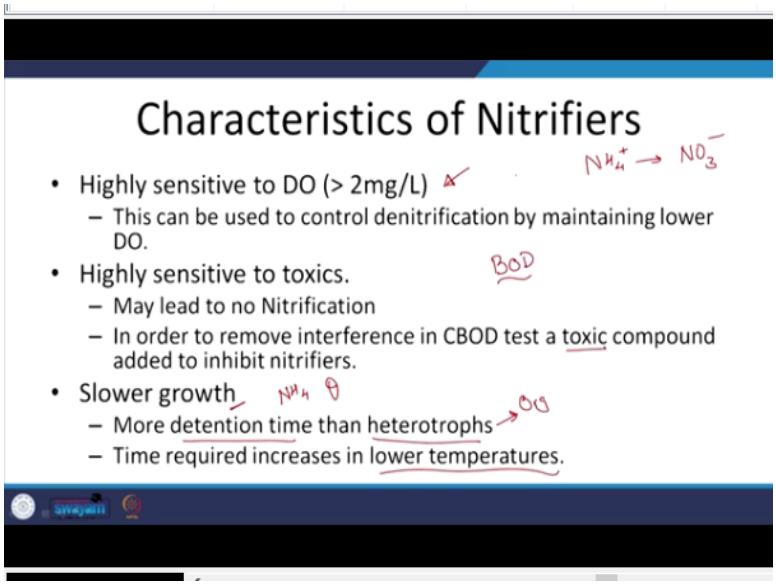

What are the characteristics or how do based on this I can also figure out when to have nitrification taking place and so forth. They are very sensitive to DO and as on only when the dissolved oxygen is high will this takes place is it, so, you need a lot of oxygen. Dissolved oxygen has to be high. If the dissolved oxygen levels are relatively low, this nitrification and then the subsequent denitrification will not occur**.**

They are highly sensitive to toxics. That is why if you remember in the BOD test, we add denitrifies, which more or less means we are adding a compound that is fiscally toxic to these nitrifying compounds as in the ammonia oxidising bacteria and nitrite oxidising bacteria**.** We add compounds that are toxic to this, that is something we do in the BOD test, but they are highly sensitive to toxics compared to the other compounds.

And they are slower, growers if I may say so. More time is required than the heterotrophs which will do the job for organic compounds. These compounds, which look at NH_4 are the ammonia, they require more time. HRT is typically high. Time required increases when lower temperatures, that is something that we already know.

We looked at what is it now nitrification as an NH_4^+ going to NO_3^- two reactions, not half reactions and then you will have denitrification I should have another slide here before enhanced phosphorus removal.

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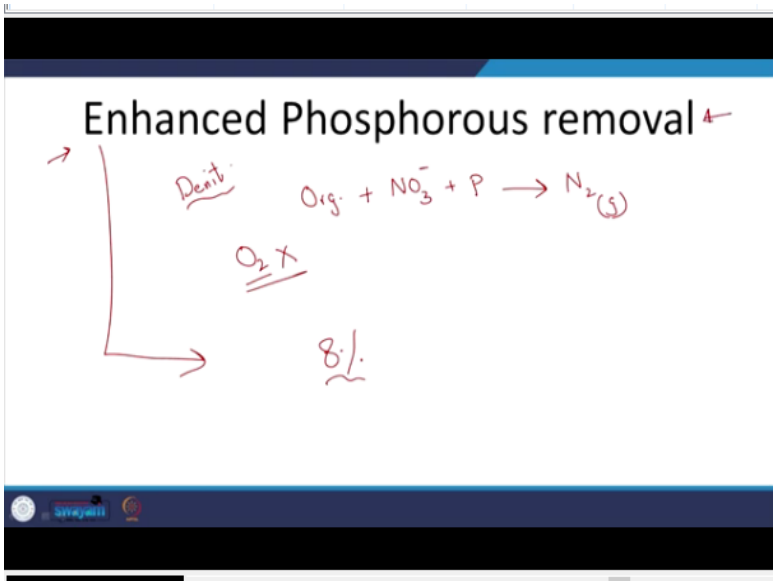

You have denitrification. For that, what do you want? You need organic compounds, you need an electron acceptor, which is what we are trying to remove NO_3^-. Here if oxygen is present, this would not occur**.** Obligately anoxic so that is one aspect. Oxygen is present, this would not occur and then you need some phosphorus and then you are going to have the relevant reaction going through.

Similarly for what is it enhanced phosphorus removal. Well, typically phosphorus is accumulated by a certain kind of microbes. You are going to create conditions such that you have these microbes thriving and the phosphorus is accumulated in these relevant compounds and then they are degraded. What do we have with respect to denitrification, nitrogen gas is formed.

, for enhanced phosphorus removal, we are trying to achieve accumulation of around 8%. But this we will , discuss later see. There are certain conditions you need to maintain for these phosphorus accumulating bacteria to thrive**.** Let us move on.

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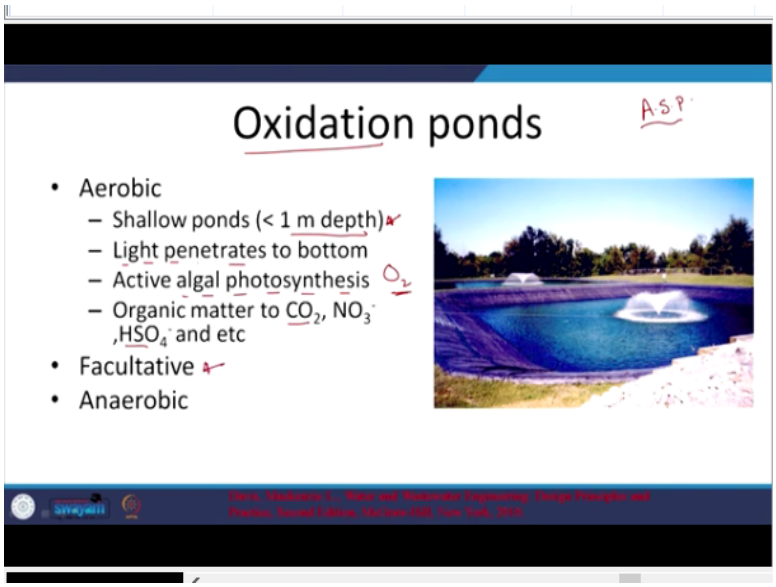

Let us also look at the different what we say treatment mechanisms, which are sometimes still used in the Western world, or where used in India. Oxidation ponds, oxidation. You will have a source of oxygen. That is why oxidation, but they are shallow.

Why if not shallow, you are going to have anaerobic conditions as in no oxygen conditions at the bottom. Here light penetrates to the bottom because it is shallow too. Then you are going to have algal photosynthesis that will lead to your presence of regeneration of oxygen, algae photosynthesis and you are going to have presence of oxygen and around this algal system you will also have bacteria which will use this oxygen. Then degrade the organic matter to the relevant byproducts. Depending upon the size you can have facultative an anaerobic zones, I think we are going to discuss this.

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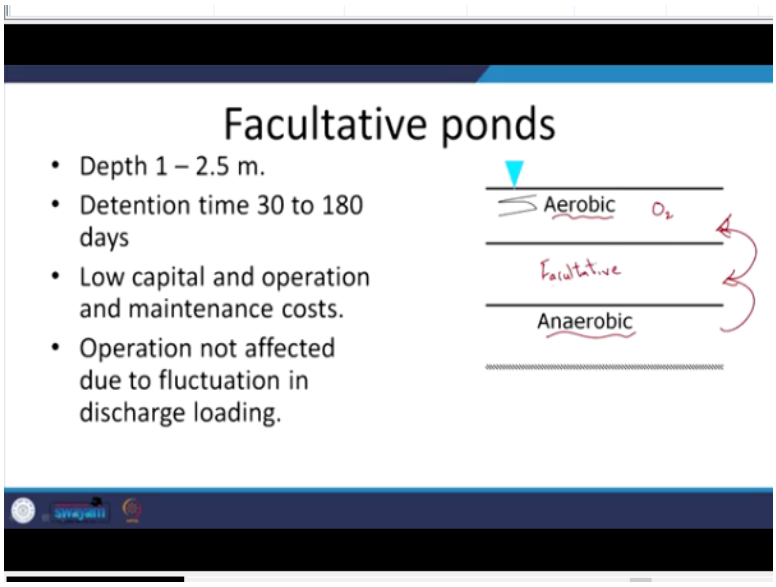

If I increase the depth, 2.53 metres, what am I going to have? The light is not going to penetrate to the bottom. I will only have oxygen generation here. Aerobic conditions here. At the bottom it will be anaerobic conditions, no oxygen. I am going to have anaerobic conditions at the bottom different kinds of microbes will thrive here. But, there is a symbiosis between these 3 layers.

Here, you are going to have facultative those that can, more or less do both if I may say. Why will people choose this? As you can see here, you are not providing oxygen. It is cheap. But why would not you choose this, especially in India? Well, we do not have as much land.

Also water is a much precious resource here in India. Then if you have a relatively less removal efficiency, you are not going to be able to use your relevant wastewater because, the nature can degrade your effluent. That is one aspect to keep in mind. Let us see what else I have. We are going to look at, microbes.

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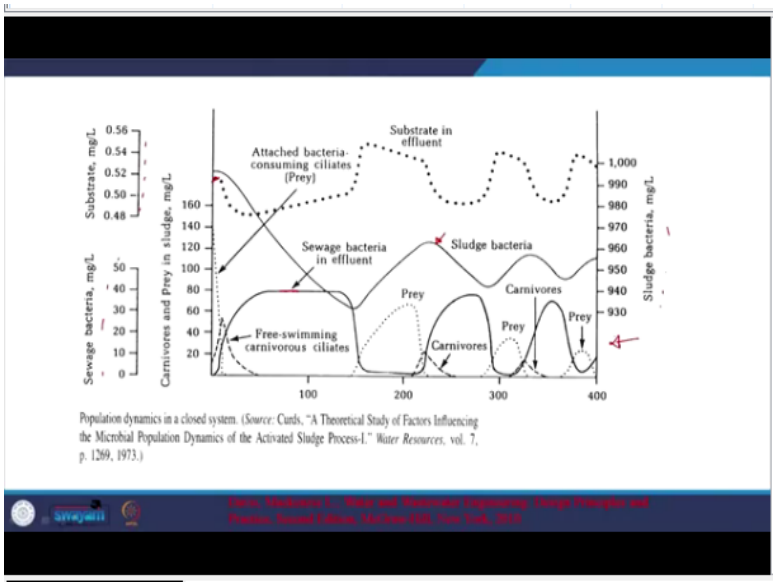

Population dynamics in a closed system. (*Source:* Curds, "A Theoretical Study of Factors Influencing the Microbial Population Dynamics of the Activated Sludge Process-I." *Water Resources*, vol. 7, p. 1269, 1973.)

And how they grow? the picture that we have here is that this is a closed system and I provide some substrate initially, we just maintain some substrate very low substrate, how is the system going to behave? substrate, that is what we have sewage bacteria presented by this, represented by this and then sludge bacteria are represented by this.

As you can see, at different times, you will have different types of microorganisms thriving? Why is that? Once certain kinds of bacteria thrive, then you are going to have the carnivores which are going to feed on these kinds of bacteria. But when you do not have these bacteria, which can feed the carnivores, then the carnivores are going to die.

Then you will have a different kind of bacteria growing, and so forth. It is cyclical. That is what you can see out here, we are not going to go into detail here. Let us move on.

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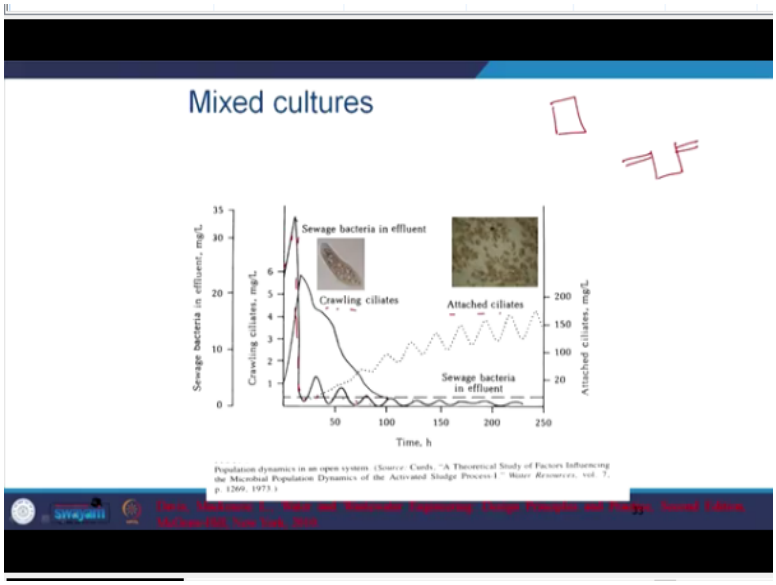

But in continuous flow systems, the earlier one was closed system. But here if it is continuous flow as and what we experienced in the wastewater treatment plants. What do you see here, it is a dynamic system? Initially, one kind of what we see bacteria and then the different kind. here, as you can see, this system is pretty sensitive too. But over time, you are going to try to achieve the kind of bacteria that will increase the efficiency of your relevant treatment process**.**

What do we see I have here sewage bacteria in the effluent? That is what we have here. That is going to decrease out here. Why? Because the kind of bacteria that are going to thrive in your aeration basin are going to eat up, are not going to create conditions that are going to favour other kinds of bacteria. For example, one aspect I remember is that fungi, and bacteria which one will grow.

It depends on which one has access to more food, bacteria being smaller, have greater surface area, so they can absorb the food faster. Not the case with fungi. Over time, the bacteria are going to thrive. That is what you are going to see. That is one aspect to keep in mind.

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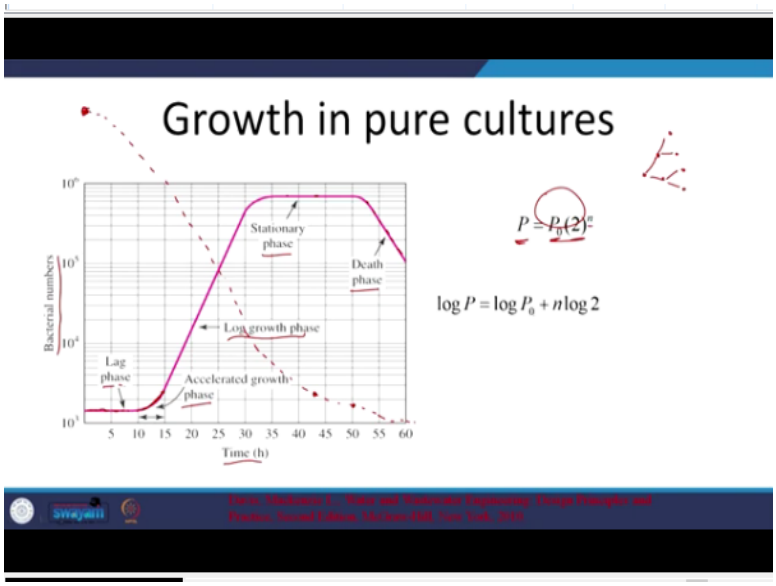

How are they going to grow? We looked at one aspect here, where we looked at it in detail. But if we look at a general case, I take a closed system, put some microbes and just look at the overall microbial growth. In this graph, let me also put in my substrate or my food waste, my waste, which is the food for the microbes.

What is going to happen? Initially, we are going to have the lag phase, on the y axis we have bacterial numbers, on the x axis the time. Initially, the bacteria get used to the relatively new environments, so you are going to have lag phase, they are still getting used to the relevant environment, once they are used to the environment, you are going to have an accelerated growth phase.

Here different bacteria are going to have different rates of growth, but they are going to start growing. Then we are going to have lag growth phase. As you can see, it is linear. More or less, the growth rate is relatively uniform, or a regular growth rate and then stationary phase. During this time, what is going to happen? All this time your substrate or the food waste is going to come down.

At this point, as you can see, there is no more food for the microbes or maybe even here. Here the cell or dead cells itself are going to serve as food for the other microbes. Afterwards, that you have nothing there and then you have the death phase, so 4 phases, lag phase, accelerated growth, log growth and stationary and in general death, but in a continuous flow system, you are going to try to see to it that you provide food continuously.

There will be some decay, but that is a different aspect. We are going to look at this log growth phase. This is how bacteria can grow. We have a relevant numeric problem later. Population, after what we say n number of generations initial what we say population as in 1 goes to 2, 2 goes to 4**.** Based on the generation time you can calculate that. Let us see what we have. Log P = log P_0 + nlog 2.

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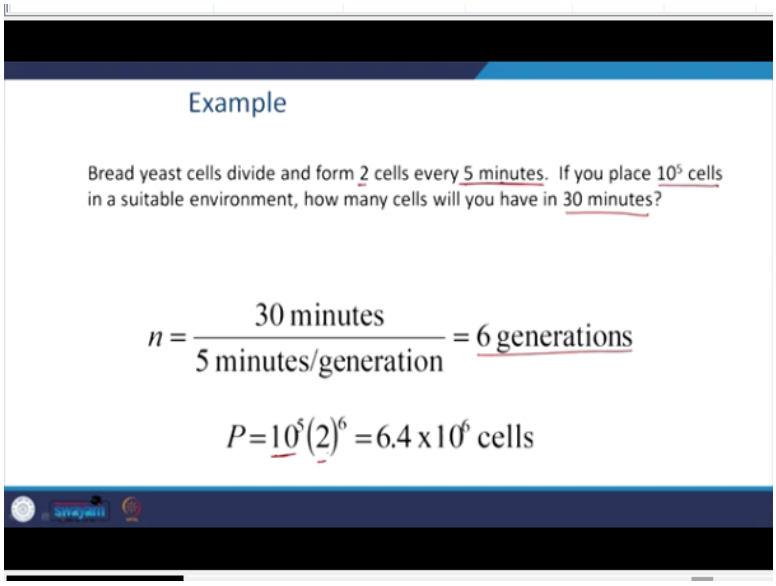

bread yeast cells dived and form 2 cells every 5 minutes, 5 minute generation time. If I initially have 10 to the power of 5 cells in a suitable environment, how many cells will you I have in 30 minutes ? 6 generations out here . 30 minutes by 5 minutes per generation is 6 generations. P= 10 power 5 initial P_0 into 2 to the power of n number of generations. You see 10 power 5 end up to be 6.4 into 10 power 6 within 30 minutes. They grow a lot, the mass would not increase but they grow a lot it is the number that count not the mass. That is one aspect to note here.

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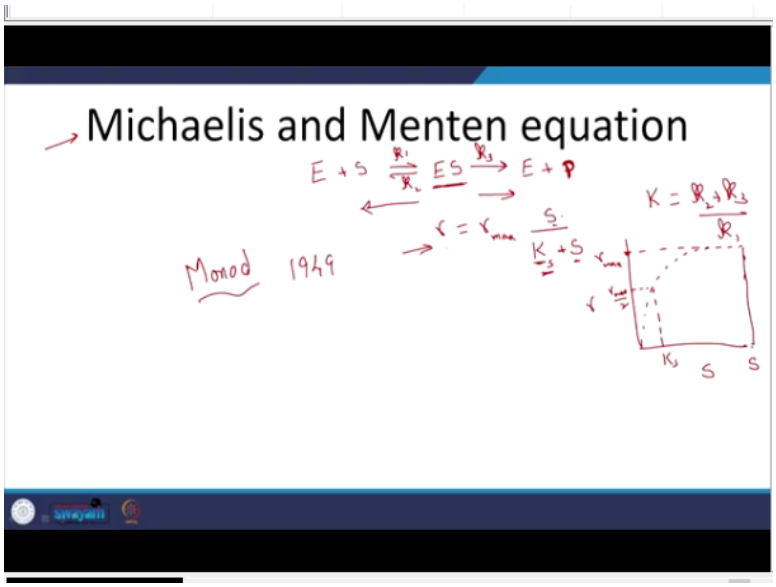

How is that the microbes degrade your relevant substrate or our waste, we are going to look at this particular equation but we are not going to derive that. What do we have, we have enzyme and the substrate and then you are going to have an intermediate product yes. K1 K2 forward reaction, backward reaction and then this will go to the product K3**.**

Yes this is what you have and the rate of production of this products are such you can get it by applying this mass balance on this particular what is it ES and then you can get it and it is just looking at the reactions that lead to formation. What are leading to formation K1 I mean E + S is leading to formation and the backward reaction is leading to loss and this reaction also is leading to loss.

You can apply mass balance and get it, but we are not going to do that here but more or less if I am not wrong or will be going to be equal to r max into S by K + S, S is the substrate concentration and K is nothing but equal to K2 + K3 by K1 you can look at the relevant derivation. What does that tell us what will the profile look like if this is r and if this is substrate?

The profile will look like something like this and at this point it is S, when the S is high and here is the r max at this point r is r max as in when S is far greater than K what do you see S, S cancel out and r equal to r max**.** That is what we have and also another case when it is at half when S = Ks you can think of that then it will be r max by 2 KS **.**

This is the Michaelis-Menten equation**.** Similar to this people observed that are Mr. Monod or Dr. Monod observed that I think it was in 1949, the microbes also have a similar profile, profile

for growth and that is what we are going to look at, the profile is similar to this r = r max to S by Ks + S. This is a constant as you can see and S is the substrate. One aspect to keep in mind we will just discuss this later.

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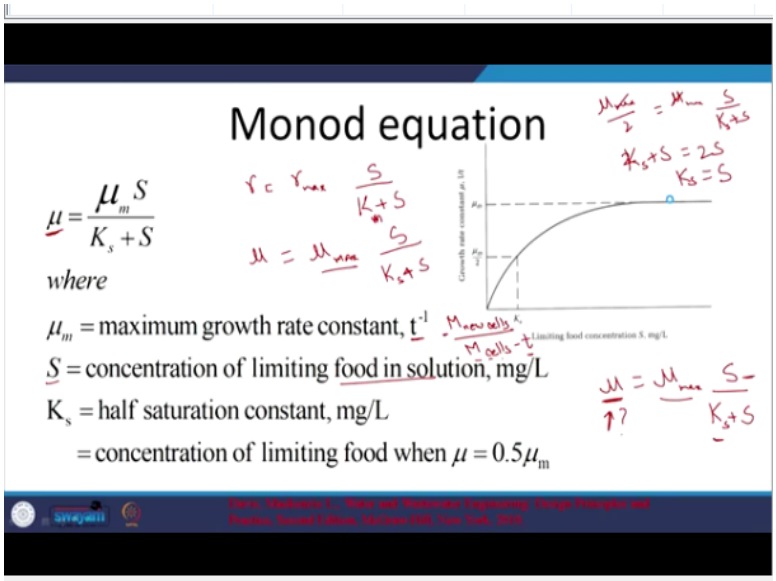

What do we have let us see. Monod equation as you can see is similar to this. Let us look at what the variables are here**.** This is the specific growth rate different names. You can look at that specific growth rate . Here mu max similar to R = r max into S by K + S I think earlier it was K m and now it is called K s, here you have mu specific growth rate is equal to mu max into S by Ks + S.

Earlier it is KM, here it is KS**.** What is this maximum? It is a maximum growth rate constant of the microbes as in this will tell me the mass of new cells per the cells existing already per time. These 2 cancel out and that is why units are per time but they are more or less giving me an idea about how much new cells are being generated per the existing what we say cells per time.

And S is the concentration of the food for the microbes or our waste that is what we have, KS is the half saturation constant as in when will the mu max be half that is what we have and what else do I have here**,** half saturation concentration of limiting food when mu = 0.5 mu**.** That is something you have you can plug that in and see that out here, let us see that mu = mu max into S by Ks + S.

This is going to give me an idea about why is this important now I want to know how cells are growing or how the microbes are growing. This is what will give me an idea about how the microbes are growing. As was observed by Mr. Monod and that is why we are calling that the Monod equation, we have the specific growth rate being depend upon the maximum the food and this relevant constant out here.

And I was just trying to say when will this be the case let me just look at that. You want uh K s is when mu max is equal to half, let us see in which conditions will that turn out to be let us see**.** If this is mu max by 2 = mu max S by K s + S, K s + S will then be equal to 2S as you can see this is the case when K s = S, that is what we also looked at in this case out here.

This was supposed to be KM. That is what we have. Why is this important? Let me see what we have out here.

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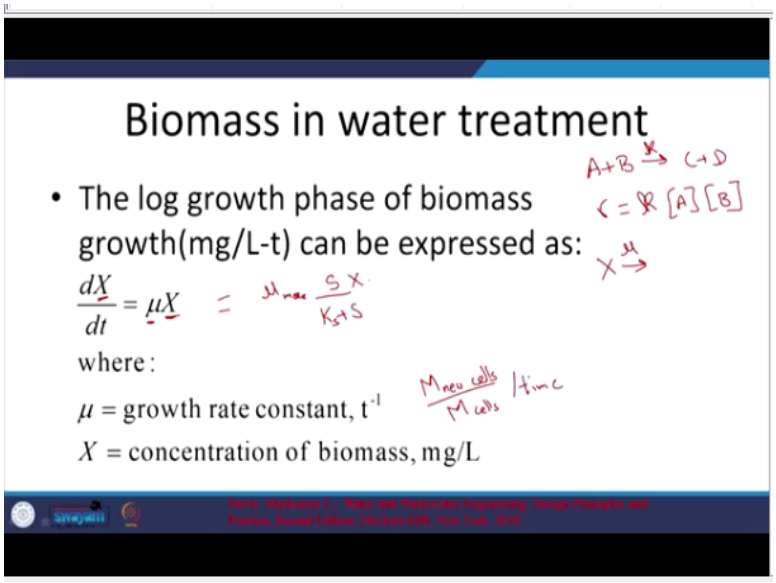

That in general when we have A + B going to C + D and rate constant is K, the rate of this reaction is equal to rate of reaction rate constant times concentration of A and concentration of B. Similarly here if I want to look at the growth rate of microbes I am going to say as we mentioned we are going to look at the concentration of microbes, we are going to express by r. What is it going to be depend upon?

It is going to be depend upon the concentration of the microbes now. X they are increasing and the rate constant I can assume it to be this**.** Dx by dt = mu times X mu is the growth rate constant

mass of new cells per mass of total or existing cells per time. That is what we have out here. This will give me the rate of growth of the relevant microbes.

What is this going to turn out to be we know that mu = mu max into S by K s + S into X. That is your rate of growth of the relevant microbes.

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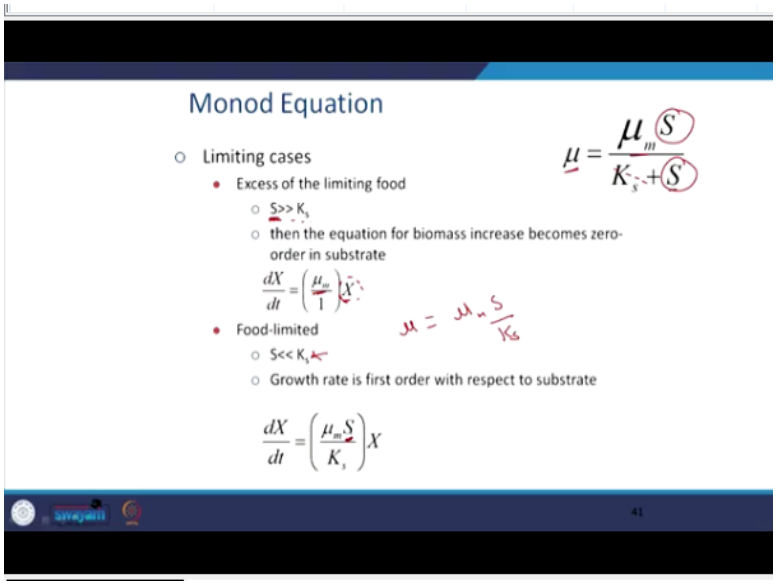

Let us move on Monod equation there are limiting cases here, one is when we have a lot of food S is far greater than Ks. When there is a lot of food the food is no more limiting factor for the microbes, it is not dependent upon the relevant what is that K s as in when S is far greater than Ks we can neglect Ks and then S, S cancel out, then mu becomes mu maximum 1, that is what we have out here.

It is only depend upon the amount of cells but if food is less. A food is less, say it is far less than or S is far less than Ks. What is going to happen mu is going to be equal to mu max into S by Ks. It is then very much depend upon the food and its first order, that is what we see and these are the 2 limiting cases out here.

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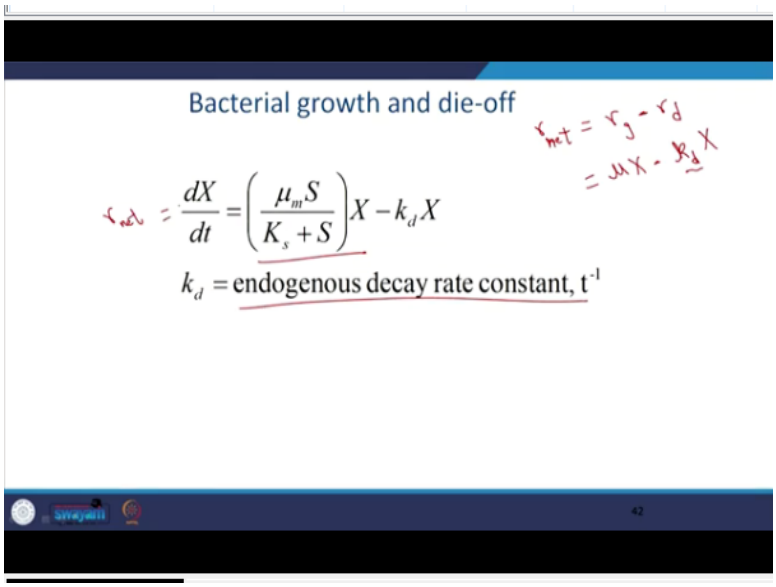

Bacterial growth as we saw are r_{net}, r_{net} is going to be depend upon rate of growth of the bacteria and also rate of decay or death of the bacteria. Here we already developed the equation for rate of growth which was equal to mu times X, that is what we have out here and death that will also have a rate constant decay endogenous decay rate constant into the concentration. That is what we have. This is the r net considering the bacterial growth and the death**.** Let us move on.

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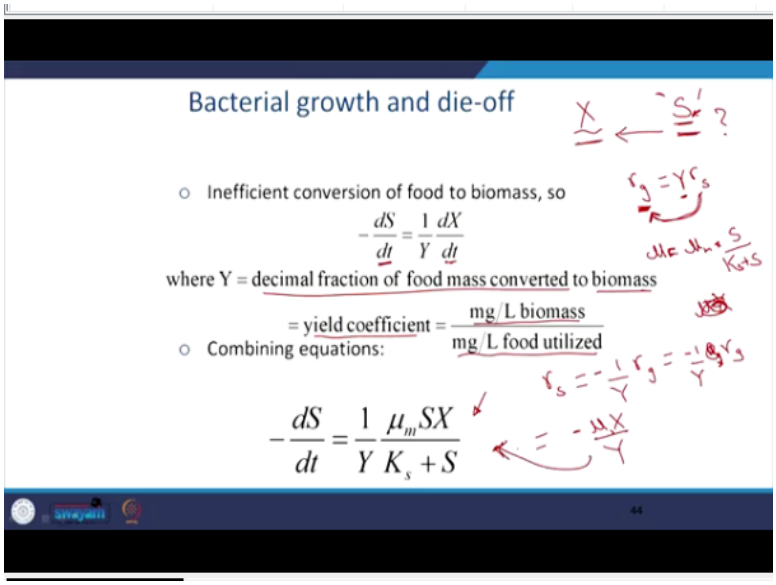

Bacterial growth and death**.** Why am I concerned with this bacteria at the end of the day I am not here to feel philanthropic and have a lot of bacteria, it is because I want to degrade the waste which I am representing by S, but what is S going to be depend upon as we know, it is going to be depend upon how many bacteria are there**.** The rate of removal of S will depend upon the rate of growth of the relevant bacteria**.**

Here we have 2 aspects so rate of growth of the microbes will be related to the rate of loss of the substrates, but both are not going to be the same why is that it is not so efficient, the process is not so efficient you have relevant electron transfer . There are other aspects. It is not going to be as efficient.

That is why you are going to have a variable here which we call the yield coefficient, what is the yield coefficient going to give you an idea about let me see if I have that. Here they are representing R s by ds by dt negative because it is being lost, rate of growth of microbes dx by dt and 1 by Y they are bringing it out here. Rate of growth of microbes we are going to have a fraction out here.

What is this fraction called? It is called the yield coefficient, decimal fraction of food mass food that is converted to food converted to biomass, as we know not everything will be converted, some of it will be used up for energy, only some will be coming be used up for or converted to cell synthesis or for cell synthesis. That is why you have this less than 1 yield coefficient.

This yield coefficient is nothing but milligrams of biomass for the milligrams of food utilized. That is what you see out here. From here I can calculate how much my the rate of my loss of substrate is. Rate of substrate loss is equal to 1 by Y rate of growth of the relevant microbes and negative because it is being lost. What do I have I know that - 1 by Y into depending on what equation you are using you will have this.

dx by dt we already looked at that there. Rate of growth of the relevant microbes, which is nothing but mu times x. Mu times X, what is mu? Mu is mu max into S by Ks + S. Rate of growth that is equal to minus mu times X by Y and because we know that mu is equal to this particular equation we end up here. That is what we see.

You do not need to mug anything up, let me just summarize and end this session for today. What are we trying to do I am trying to understand how microbes grow and what is the equation that tells you about it, it is the Monod equation and what does this depend upon it tells you are what is it depend upon this growth rate or specific growth rate which we are saying is a constant it depends upon the substrate how much food is there.

That is what we know which is nothing but mu max into S by Ks + S and from that we can calculate how the microbes are growing, rate of growth, why is that important because we know that the microbes grow by breaking down our waste. We can relate our what we see waste loss to the rate of growth of the microbes, but not all the waste that is being degraded will turn into the cells of the relevant microbes**.**

you are going to have to have a fraction that is called Y or the yield coefficient**.** With that I will end today's session and in the next session we are going to look at understanding how to design the system, but how do I design the system as in I know how much food is coming in. I have to design how much waste can be degraded within a certain time as in the time required. Then the volume of the tank and then how much microbes I am going to have to maintain in the relevant tank**.** With that I am going to end today's session and as usual thanking you for your patience I bid I do.