Water and Wastewater Engineering
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Biological Unit Process: Activated Sludge Process
Lecture - 21

In the last class we started about the biological process for water and wastewater treatment and we have seen that the selection of the treatment processes is based upon the nature of the pollutant present in the water either it is biological or physiochemical processes because when we talk about wastewater treatment why we are going for biological processes is the majority of the solids are organic in nature so it is very easy to remove the organic matter by the help of microorganisms. And we were discussing about what are the different types of reaction or how can we classify the reactions based upon the kinetics. We have seen what is the zero order reaction, first order reaction and second order reaction.

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We also discussed that in biological processes we assume that most of the reactions are of first order though many times it may be deviating. We have also discussed about what are the different reactor configurations available. We discussed about what all are the advantages of plug flow reactors and CSTR reactor and what CMBR reactor is. It seems that plug flow reactor needs less volume compared to a CSTR reactor if you want to achieve the same degree of treatment or same degree of removal. Today we will discuss about the biological process in detail or we will be starting on activated sludge process. So, coming to the secondary treatment we have already discussed what is the primary treatment.

The primary treatment is based on physical unit operation. That means the gravity force is the prominent force there so it will be removing the solids which will be having high density or high particle size. We have also discussed about primary sedimentation tanks usually employed in wastewater treatment and it is working on type two settling. We have already discussed the design procedure when we were talking about sedimentation tank.

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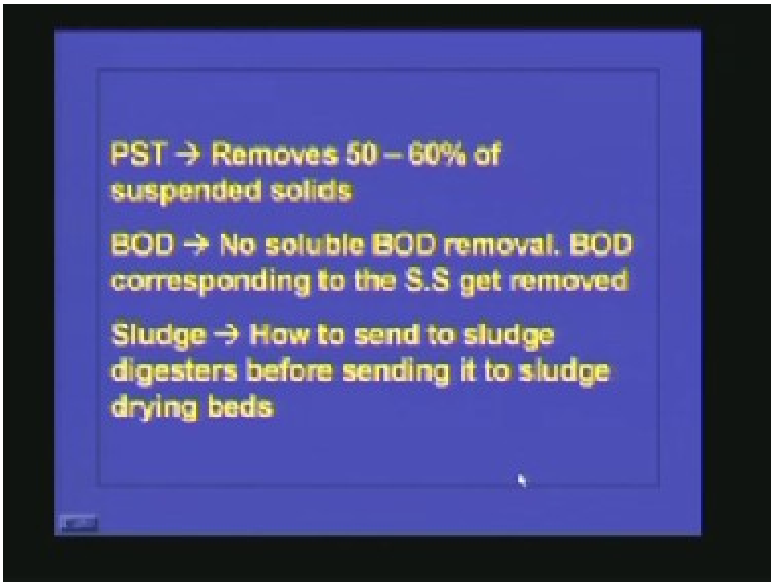

In wastewater treatment the primary sedimentation tank removes around 50 to 60% of the suspended solids. But coming to the soluble BOD the removal is almost negligible. What we do with this sludge? This sludge whatever is collected in the primary sedimentation tank it is of organic nature or most of them are organic matter so we cannot directly dispose them off so usually what we do this sludge along with the secondary sedimentation tank sludge and send it to sludge digesters where the sludge treatment or sludge stabilization will be taking place under anaerobic conditions and as a result we will be getting biogas or carbon dioxide and methane and stabilized sludge. This stabilize sludge can be put into sludge drying beds afterwards can be used manure or you can use it for land filling also. So these are the typical values of a primary sedimentation tank which is commonly used in wastewater treatment processes.

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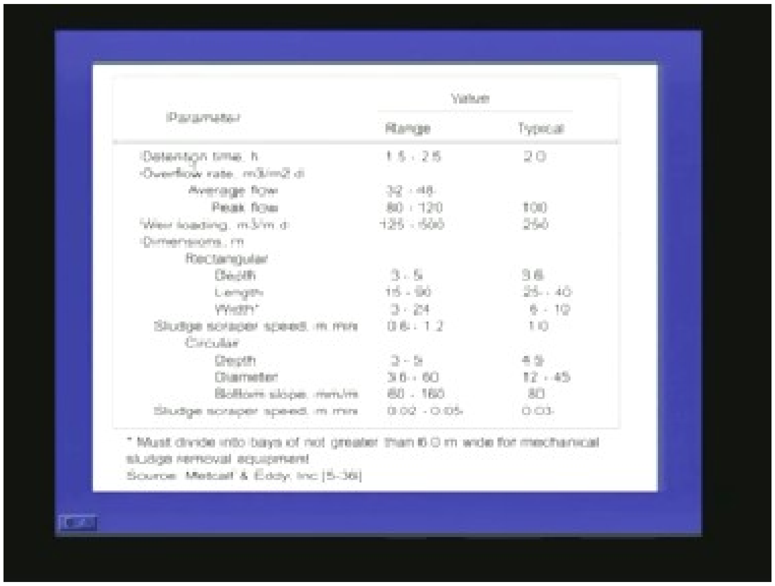

Parameter	Value	
	Range	Typical
Detention time, h	1.5 - 2.5	2.0
Overflow rate, m3/m2.d		
Average flow	32 - 48	
Peak flow	80 - 120	100
Wier loading, m3/m.d	125 - 500	250
Dimensions, m		
Rectangular		
Depth	3 - 5	3.6
Length	15 - 90	25 - 40
Width*	3 - 24	6 - 10
Sludge scraper speed, m/min	0.6 - 1.2	1.0
Circular		
Depth	3 - 5	4.5
Diameter	3.6 - 60	12 - 45
Bottom slope, mm/m	60 - 160	80
Sludge scraper speed, m/min	0.02 - 0.05	0.03

* Must divide into bays of not greater than 6.0 m wide for mechanical sludge removal equipment

Source: Metcalf & Eddy, Inc [5-36]

The detention time varies from 1.5 to 2.5. As we discussed earlier if the detention time is higher then whatever is the organic matter that is settled in the bottom of the tank starts degrading anaerobically and that generates gas that gas will be creating turbulence in the sedimentation tank and it will be affecting the efficiency of the tank. and our flow rate varies from 30 to 48 and wier loading is in the range of 125 to 500 and these the dimensions of the tank (Refer Slide Time: 5:35) depth of the tank varies from 3 to 5 meters, length from 15 to 90 and width 3 to 24 meter and typical value is 6 to 10 meters and sludge process speed is around 0.6 to 1.2 meter per minute and if it is a circular tank the depth is the same of that of rectangular tank that is 3 to 5m and diameter 3.6 to 60 meters and typical value varies from 12 to 45 meters and bottom slope is 60 to 160 mm per meter and typical value is 80. So this is the primary sedimentation tank designed parameters. It is almost similar to the primary sedimentation tank of water treatment but here we are assuming it is type two settling so we cannot use stock's law for the design of the sedimentation tank of wastewater treatment.

Earlier we talked about many secondary treatments and we have also seen that in certain secondary treatment units they do not require a primary treatment at all. for example, oxidation pond and aerated lagoons because that system itself will be acting as a primary unit so everything will be settling down in the bottom of the tank and we are giving such a large detention time so the particles whatever is coming either it is suspended or it is inert material everything will be getting settled and that itself it will be acting as primary and secondary treatment unit. Now we will see in detail what this secondary treatment is. Each unit we will be seeing in detail.

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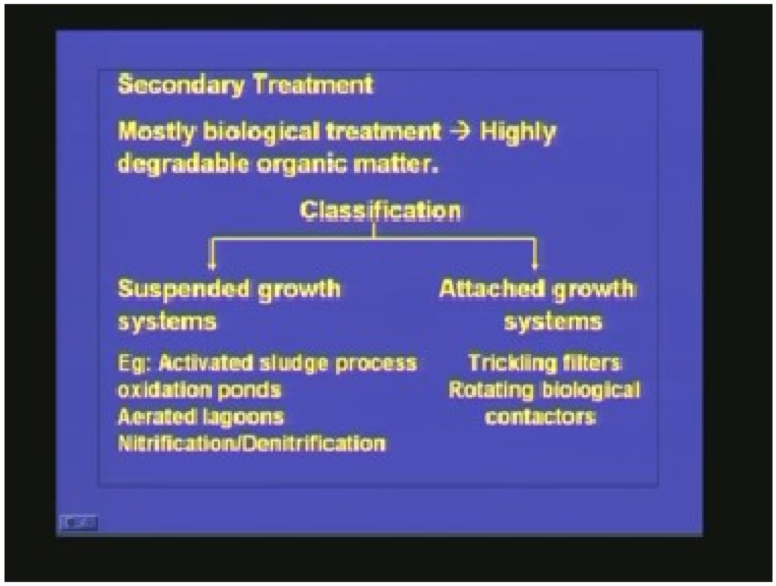

Secondary treatment in domestic wastewater: mostly biological treatment is being employed. The reason is the most of the solids are organic in nature so biological treatment is the most cost effective one and the organic matter whatever is present in the wastewater is highly degradable organic matter or we take the BOD COD ratio the ratio is very very high so we can go for biological treatment. When we talk about the biological treatment we can classify the biological treatment into two different categories; one is suspended growth system and another one is attached growth system.

In suspended growth system the entire biomass is in suspension. For example, activated sludge process is a suspended growth system and another suspended growth systems are aerated lagoons, oxidation ponds and nitrification and denitrification process. And coming to attached system tricking filters is an example and another one is rotation biological contactors.

Anyway we will be discussing each of these units in detail as what the design parameters are, how to design, what are the important factors we have to consider etc. So before going the biological treatment systems we should know what are the nutrients requirements or the microorganisms, what are the environmental conditions conducive for the microorganisms and how the metabolism of microbes are taking place and what is the relationship between the microbial growth and substrate utilization because in any biological treatment process when we talk the microorganisms are the workers so we have to create conducive environments for the workers otherwise they will not be doing the work properly so our treatment system will not be performing better.

First we will discuss about the nutrients. We have seen the microbial growth curve and most of the biokinetic parameters in the previous lectures. So what is the purpose of these nutrients?

The nutrients are essential for supplying material for the creation of cell material. That is very very important. From where they will be getting the carbon molecule for the creation of the cell materials, for this purpose nutrients are required. The microorganisms require a lot of energy so this energy source is also from the nutrients and the last one is how the microorganisms are generating the energy. They are generating the energy by a series of biochemical reactions. Most of them are oxidation reduction reactions.

If the oxidation reduction reaction has to take place there should be one electron donor and electron acceptor. Unless the electron donor and electron acceptor are there oxidation reduction reactions are not possible. Therefore, in an aerobic system the organic matter will be acting as the electron donor so the organic matter will be giving the electrons. So that will be passing through a series of steps and finally the electrons should be accepted from the system. Now, who will be accepting the electrons? In some cases the nutrients itself will be accepting the electrons or sometimes it will be oxygen in an aerobic system. These are the essential things required for the microorganisms.

Now, coming to the environmental parameters the pH temperature etc should be conducive. We know that microorganisms are not able to survive either at low pH or at high ph. when we were discussing about disinfection we have seen that if the pH is reduced below 3 or if you increase the pH above 10 then most of the microorganisms will die. When you talk about the biological system we should see that the microorganisms or the ph conditions in the system are within this limit and we should be able to provide the optimum condition. The optimum condition is most of the time it will be near the neutral pH.

Coming to the temperature we all know that the enzymes or the proteins whatever is present in the cell of microorganisms will be getting denatured at high temperature in most of the cases. But there are microorganisms which can survive very high temperature and very low temperature. But most of the microorganisms whatever we are employing for this wastewater treatment they come under mesophilic temperature range or mesophilic microorganisms. That means their optimum temperature is around 35 to 37 centigrade. So if you reduce the temperature or increase the temperature the microbial activity will be reducing.

It was shown that for every ten degree change in temperature the activity will be varying 100%. So we can see that how the environmental condition is going to affect the microorganism. Now coming back to the nutrients itself depending upon the nutrients selectivity we can classify the microorganisms into various categories. The nutrients will be acting as a energy source, as an electron acceptor and as a carbon source. First we will see the carbon source.

The microorganisms can use either organic matter as the carbon source or inorganic materials like carbon dioxide or bicarbonate as the carbon source. The organisms which are using inorganic carbon as their carbon source for cell synthesis are known as autotrophic microorganisms. Once again the microorganisms which use inorganic carbon for their cell synthesis is known as autotrophic microorganisms. The microorganisms which use organic matter or which takes carbon from organic matter are known as heterotrophic microorganisms.

Now, coming to the energy source they can derive energy from sunlight, they can derive energy from chemical reactions. The microorganisms which derive energy from sunlight is known as phototrophs and the microorganisms which derive energy from the chemical reactions are known as chemotrophs. In chemotrophs itself the microorganisms which use organic matter is known as chemoorganotrophs or chemoheterotrophs. And the microorganisms which require chemical reactions for the energy but they use inorganic components for this reactions are known as chemoautotrophs.

We have seen different types of microorganisms; one is autotroph and another one is heterotrophs. And depending upon the energy requirements we can see that they are phototrophs, chemoautotrophs and chemoheterotrophs. Phototrophs are the ones which generate energy from photosynthesis. Just like plants there are many microorganisms which can get energy from the photosynthesis reactions. autotrophs the ones which use inorganic carbon for their cell synthesis and heterotrophs the ones which use organic matter for their cell synthesis.

Now, coming to the donor acceptor we have seen that for any oxidation reduction reaction there should be one electron donor and one electron acceptor. So, when we talk about wastewater treatment in most of the cases the electron donor is in the wastewater itself or the organic matter present in the wastewater but who is the electron acceptor. The electron acceptor can be either oxygen or inorganic compounds containing oxygen like nitrate, sulphate etc so they can also act as electron acceptors and get reduced. The third one is the organic matter itself can act as electron acceptor. So depending upon the electron acceptors we can divide the processes into different categories those are aerobic process anoxic process and anaerobic process in aerobic process oxygen molecular oxygen is the final electron acceptor.

Hence, organic matter releases the electrons and it will be traveling through a series of reactions and because of this oxidation reactions a lot energy will be released that will be utilized for the metabolisms purpose of the cell and finally electrons will be accepted by molecular oxygen and it will be getting reduced to water. But in certain cases when oxygen is not available inorganic compounds like nitrate, sulphate etc can be accepted by the electrons. For example, if you talk about nitrification, denitrification what is happening nitrate is getting converted to nitrogen this is very essential when we talk about high ammonia containing wastewater because there is a limit for nitrate discharge to the receiving water so if you have excess nitrate how we can remove that one.

We can use biological process for the nitrate removal that process is known as dinitrification. Denitrification is an example of anoxic process. Here no molecular oxygen will be available so nitrate will be acting as the electron acceptor. Once the compounds accept the electron it will be getting reduced so nitrate will be getting reduced to nitrogen gas. Those processes are coming under anoxic category. Now we will see what is antrophic? Anaerobic means either oxygen or inorganic compounds which is having oxygen are not present. So organic matter themselves will be acting as the electron acceptor.

For example, in anaerobic process of wastewater the organic matter itself will be acting as the electron acceptor and gets reduced to methane gas. That is why we are getting bio gas or methane gas from anaerobic processes. These are the various classifications. These classifications are very very important because when we select the microorganisms for a particular treatment we should know what type of microorganisms we want and what type of microorganisms can be used as a particular pollutant and converted into environmental friendly byproduct.

Hence, the important terms one has to remember is; what is an autotroph, what is heterotroph, what are phototrophs, what are chemoautotrophs and chemoheterotrophs and what is the difference between aerobic process and anoxic process and anaerobic process. Now we will come back to our activated sludge process.

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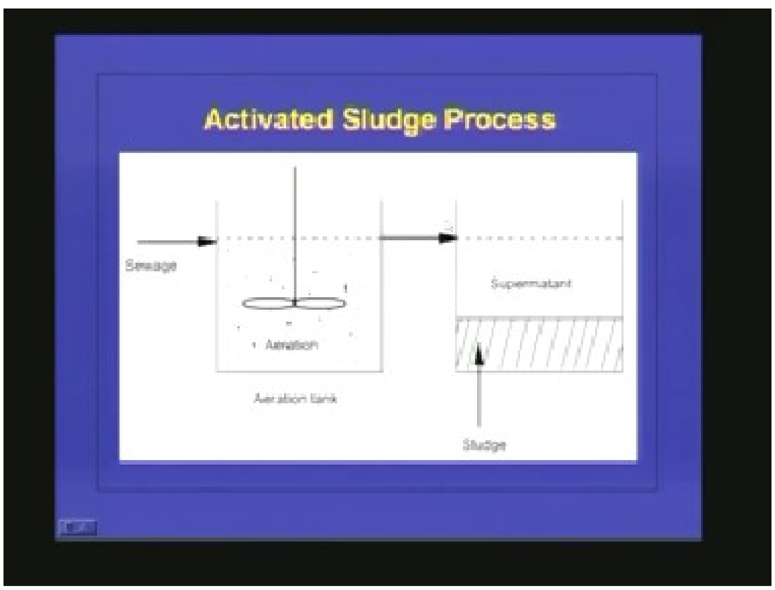

This is the most commonly used biological process for domestic wastewater treatment. Here what is happening is the wastewater is coming and we are aerating the wastewater. The wastewater will be having a lot of microorganisms so when we supply sufficient quantity of oxygen the microorganisms will be utilizing the organic matter present in the wastewater and they will be converting it into carbon dioxide, water and more and more cells. That is what is happening in activated sludge aeration tank.

In aeration tank the dissolve form of organic matter is getting converted into colloidal form of organic matter or new cells so all these cells are discrete in nature. So if you let them out like that there will not be any COD or BOD removal as such because we are synthesizing more cells into the system. Thus, the secondary sedimentation tank of the

activated sludge processes is very very important. And if you see the aeration tank of the activated sludge process what is the nature of the microorganism present in that?
It is a mixed population. So that mix population of microorganisms will be utilizing the organic matter whatever is present in the wastewater and more and more cells are generated and it is coming to the secondary sedimentation tank. But here we have to separate the cells. Therefore, how can we separate the discrete cells, it will be very very difficult. It is seen that when the microorganism reaches a particular growth stage

We have discussed about the growth curves. Are you remembering? We have seen the lag phase, low growth phase, stationary phase and endogenous or declining growth phase. Therefore it was found that if the microorganisms reach the end of that stationary phase or if they start coming to the endogenous phase they start producing some extra cellular polymers. These exo-cellular polymers are having some binding properties. So because of this binding property all these colloidal cells will aggregate and they will form flocs. So once they form the floc the settling will be very very easy.

Hence, in the sedimentation tank the flocs will be settling and we get clear effluent that can be removed. We also have to treat this sludge carefully because this sludge is containing lot of active biomass so we cannot just discharge it. Some sludge will be recycled to the aeration tank and remaining will be sent to the sludge digesters. What is sludge and why it is called as activated sludge process?

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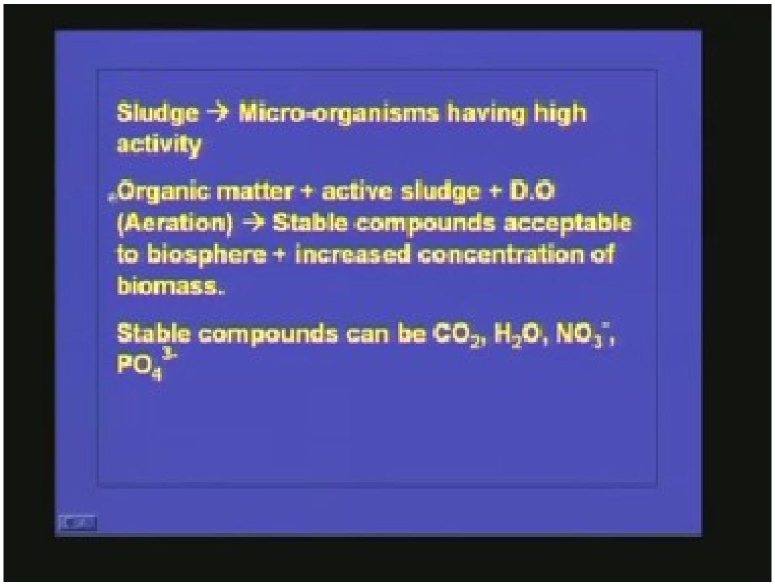

This sludge is nothing but microorganisms having high activity. The reason why it is known as activated sludge is because the sludge has an activity. This is the reaction taking place in the aeration tank; organic matter plus active sludge or microorganisms plus dissolved oxygen gives stable compounds acceptable to biosphere plus increased concentration of biomass. The stable compounds can be carbon dioxide, water, nitrate phosphate depending upon the compound or depending upon the nature of the wastewater.

What is happening in the aeration tank is the soluble organic matter coming to the secondary treatment unit is converted to settable organic matter. So if you take the aeration tank alone we cannot call it as a treatment system because what is happening is only the nature of the solid is getting converted from the soluble form to colloidal form. So if you want to get removal of the solids we have to have the sedimentation tank. The sedimentation tank or secondary sedimentation tank is an integral part of activated sludge process.

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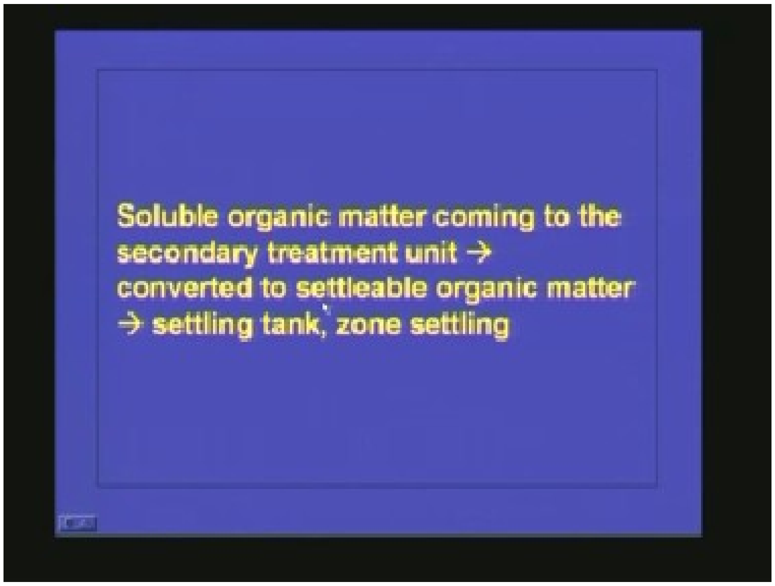

We have already seen that the settling tank the secondary sedimentation tank has to be designed based upon zone settling because the particles are flocculant in nature and it is concentrated suspension. So concentration suspension with flocculant particle is coming under zone settling and towards the bottom of the sedimentation tank the concentration of the particles is so high so they will be experiencing the compression settling.

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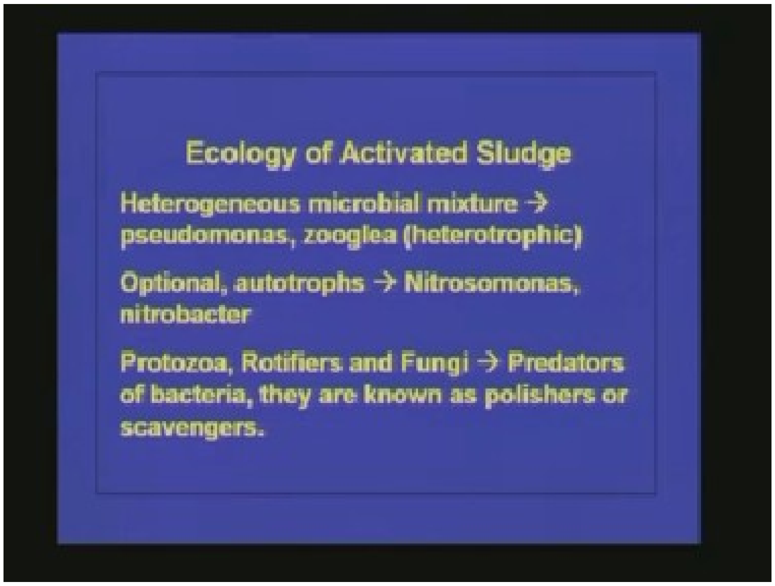

Now we will talk about the ecology of the activated sludge process. we all know that it is not a pure culture system, not only one single type of microorganisms is present but there are multiple groups of microorganisms present which are responsible for the conversion of organic matter into carbon dioxide and water and more cells. And if you see the ecology of activated sludge process we can see that mostly it is bacteria which are converting the organic matter into carbon dioxide and water. But there are protozoa or rotifiers and fungi present in the activated sludge process.

If you see it is a heterogenous microbial mixer mainly pseudomonas and zooglea are present. Both these microorganisms are heterotrophic in nature. Heterotrophic means they use organic matter for the cell synthesis and the energy is derived by oxidation reduction reaction and here also organic matter is being used. But in activated sludge process also there can be autotrophs for example nitrosomomonas and nitrobacter. These microorganisms are coming into the picture whenever we talk about ammonia oxidation because we know that protein contains lot of amino acids so naturally the wastewater will be containing lot of organic nitrogen.

So, if you aerate the wastewater for long time, first all the organic matter that will be getting oxidized and afterwards this organic nitrogen whatever is present in the wastewater will be getting converted to ammonia and that ammonia will be further oxidized to nitrite and nitrate. So these nitrosomomonas nitrobacter are responsible for oxidation of ammonia to nitrite and nitrate. These are autotrophs; that means they use only inorganic carbon for their cell synthesis and their energy. The energy also generated from chemical reactions but inorganic substances.

Coming to this protozoa, rotifiers and fungi we have seen that mainly microorganisms or bacteria are responsible for the removal of organic matter whatever is present in the activated sludge present in the wastewater. But what is the role of this protozoa rotifiers and fungi?

Protozoas are very very important. They are known as polishers or scavengers of activated sludge process. What they do is, this protozoa are predators of bacteria. In the activated sludge process we have seen that the floc formation is there so once the floc is formed it is very easy to settle the sludge. But there will be bacteria which are present in the liquid as discrete particles. so if the discrete particles are coming to the sedimentation tank it will not be settling down so those bacteria will be coming out along with the effluent so naturally when there is solid present in the effluent that too organic solids the BOD and cod of the effluent will be very high so naturally you will not be getting the efficiency of whatever you require to meet the effluent discharge standard. So what this protozoas does is they will be eating **away** the discrete microorganisms or discrete bacteria whatever is present in the system so in a way it is polishing the effluent what is coming out of the secondary sedimentation tank that is why those are known as polishers or scavengers.

Protozoa present here are also an advantageous thing for activated sludge process to increase the efficiency.

Now will see the microorganisms are utilizing the organic matter present in the system. We are aerating the system and lot of organic matter either in the colloidal form or dissolve form is present in the water. We have also seen that the bacteria are using the organic matter. So how they are using the organic matter, what are the steps involved in this one. It is basically a four step process.

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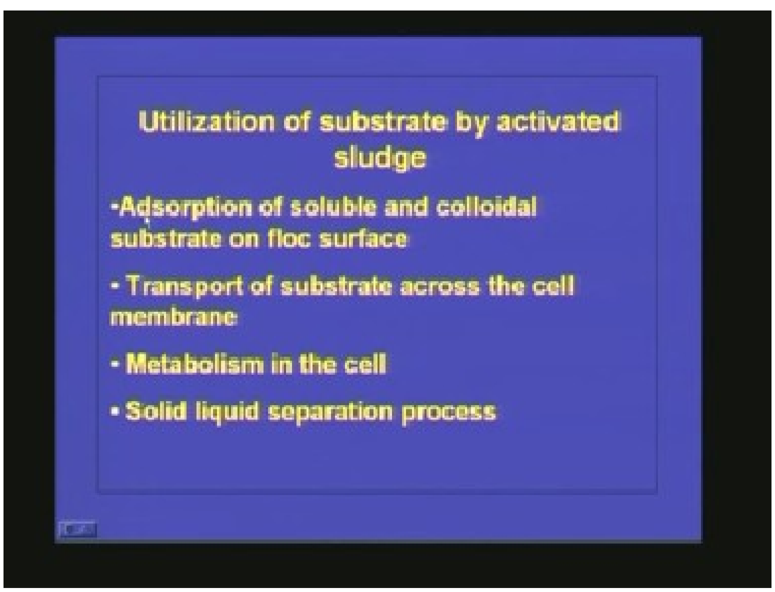

The first one is adsorption of soluble and colloidal substrate on floc surface. Whatever is present in the system has to get adsorbed to the microorganism. Then after the adsorption the organic material will be getting transported from outside the cell to the inside of the **cell.** It has to pass through the cell wall and the cell membrane. If metabolism has to take place it has to reach the interior of the cell. So once it reaches the transport area then metabolism will be taking place. That is the third process and the fourth one is solid liquid separation.

We have seen that the wastewater will be containing dissolved solids as well as colloidal solids. But if the colloidal solids get attached to the cell it will be bigger in size so how they can penetrate into the cell wall, it will be very very difficult for them to penetrate into the cell wall. So how the cell is able to handle these colloidal particles?
It is very interesting. What they do is the cell will be creating some sort of an enzyme and that will be hydrolyzing the organic matter which is in colloidal form. So once it is hydrolyzed, the hydrolysis is nothing but adding water molecule to the organic compound and because of that one it will be splitting into small parts. Now, once the hydrolysis is done, the molecules will be smaller in size so they can easily penetrate into the cell. Once it penetrates into the cell metabolism will be taking place depending upon the condition whether it is aerobic, anaerobic or anoxic process. Then because of the metabolism energy will be generated and more and more cells will be synthesized.

Therefore, in your system the organic matter whatever is present in the dissolved form or colloidal form will be getting converted to new cells. So the last step is solid liquid separation because if you allow the cells to go out of the system the treatment will not be proper. These are the four steps that usually takes place;

- Adsorption of soluble and colloidal substrate on floc surface
- Transport of substrate across the cell membrane
- Metabolism in the cell and
- Solid liquid separation process

We have already discussed about the agglomeration of bacteria. Agglomeration of bacteria is possible because of biopolymers. The biopolymers secretion depends upon the nature of the system. If all the microorganisms are in the low growth phase they will not be generating any of this biopolymers so it is very very difficult to separate the microorganisms from the liquid. But if they are in stationary phase, the end of the stationary phase of endogenous phase the biopolymer secretion will be very high so it is easy to separate the microorganisms or flocculent sludge.

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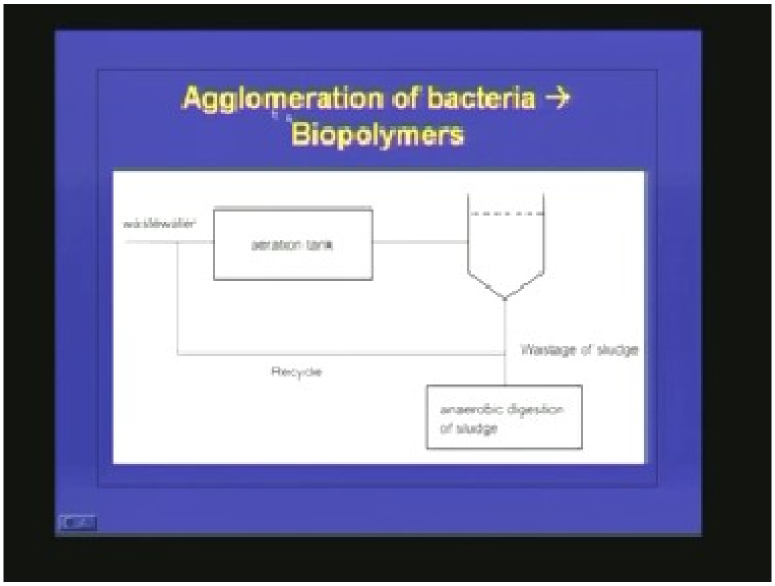

This is the typical activated sludge process. Wastewater is coming here and this is the aeration tank. Here what is happening is we are giving lot of oxygen, so under aerobic condition the organic matter is getting converted to carbon dioxide water and new cells and from the aeration tank entire liquid is going to the secondary sedimentation tank. So here settling will be taking place because excess sludge will be generated and here we will be getting clear effluent and a portion of the sludge will be wasted that will be going to anaerobic sludge digester and a portion will be recycled to the aeration tank to maintain a constant biomass concentration in the system. We have to provide more and more workers then only the process will be efficient. So the purpose of recycling activated sludge process is to increase the biomass concentration in the aeration tank.

Now we will see how we can design an activated sludge process. You know what is the amount of wastewater coming to the system and what is the amount of ultimate BOD of that wastewater. Whenever we talk about biological wastewater treatment processes we are interested only in the BOD because BOD gives us the amount of organic matter that is biodegradable. But if you talk about COD it will be giving you all the compounds which is present in the system which is either biodegradable or non biodegradable.

Therefore if you want to decide whether we have to go for biological processes or physiochemical processes what we have to do is first find out the BOD of the system BOD of the wastewater and cod of the wastewater and see what is the BOD by COD ratio. If BOD by COD ratio is more than 0.5 we can go for biological processes. That means whatever is the total organic matter present in that system above 50% is biodegradable so naturally we can go for a biological system followed by some other treatment.

When we talk about the domestic wastewater this BOD by COD ratio varies from 0.6 to 0.8 depending upon the wastewater. That means it is highly biodegradable. We will discuss about the design activated sludge process based upon kinetic principles.

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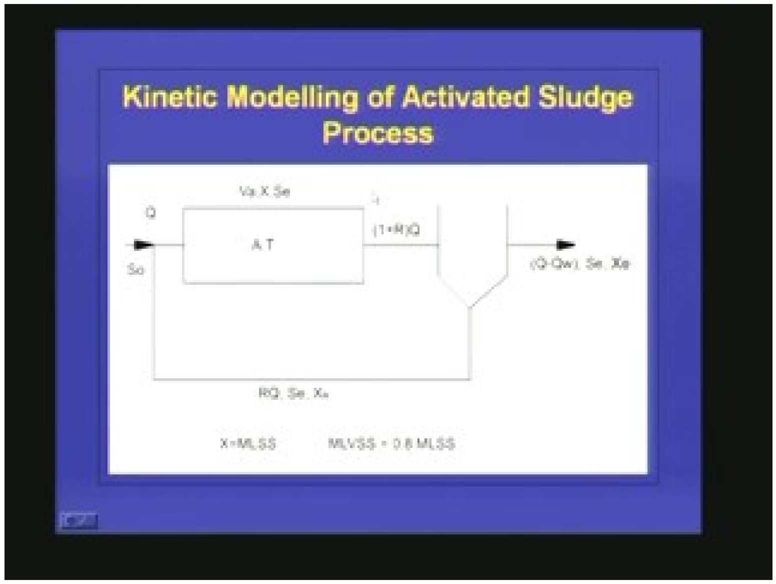

We have seen what all are the biokinetic parameters of microorganisms so based upon that one we can design the activated sludge process. So, if you want to make a mass balance of liquids, solids and biomass we can write it as something like this, this is Q (Refer Slide Time: 34:38) this is the quantity of wastewater coming into the system and So is the substrate concentration or ultimate BOD of the wastewater and we are assuming that the microorganism concentration present in the incoming wastewater is very negligible compared to the biomass concentration in the system that is why we are not giving any X value here and this is our aeration tank the volume of the aeration tank is Va and biomass concentration is X and substrate concentration or BOD concentration is Sc. this aeration tank we are assuming that it is a CSTR reactor continuous flow tired tank reactor.

What is happening here is, as soon as this So enters in the system instantaneously the concentration will be changing to Se as what we have seen yesterday, and the same thing happens here. And here (Refer Slide Time: 35:35) the flow is 1 plus r into Q and we will be having X and S**e** our substrate concentration and biomass concentration and this is the secondary sedimentation tank and here we will be having a sludge wastage of Qw.

So if you want to see here this is Q minus Qw because Qw will be wasting here, I forgot to put it here (Refer Slide Time: 36:00) and Qq minus Qw is the flow coming out and Sc is the substrate concentration on BOD and Xe is the biomass concentration and a portion of sludge will be recycled to the aeration , Rq is the flow rate, R is the recycling ratio and **Se** is the BOD because same Se will be coming and biomass concentration is Xr because it is the same sedimentation tank so the biomass will be getting concentrated and we are recycling the concentrated sludge.

Always we use this X to the present MLSS. MLSS is nothing but mix liquid suspended solids. So if you have the mixed liquid and if you find out the suspended solid concentration in that liquid that is known as MLSS. So we assume that mainly that is biomass. Or another term is there that is mLVSS mixed liquid volatile suspended solids. Sometimes along with the wastewater along with organic solids the inorganic solids also will be there so what will happen is this MLSS will be containing organic and inorganic solids. But if you want to find out what is exactly the microbial concentration then we have to go for mLVSS.

Many studies have shown that the ratio of MLSS and mLVSS is like this; if you have the MLSS value, if you multiply by point eight that is mLVSS or for the total MLSS around 80% is mLVSS that means volatile suspended solids are fresh cells. And when we talk about the activated sludge process another important term is hydraulic retention time. The amount of time the liquid is staying in the treatment system is the hydraulic retention time. That can be calculated by V by Q.

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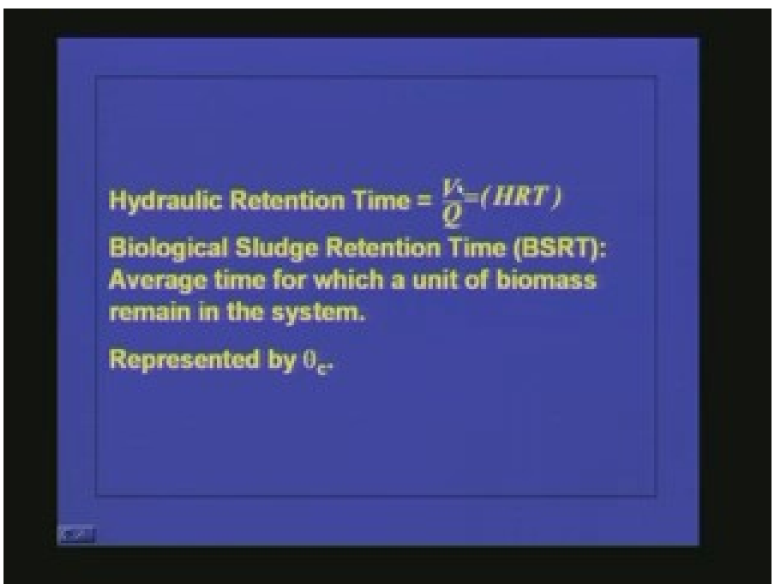

Therefore, v by Q is the hydraulic retention time and another important time is Biological Sludge Retention Time that is BSRT. BSRT is very very important in any biological treatment system which is nothing but biological sludge retention time. The definition is average time for which a unit of biomass remains in the system. The biological retention time is nothing but the total time the biomass staying in the system once the biomass enters the system or is generated in the system.

The BSRT is small in the system. What does it mean? It means the biomass concentration is the system is more because more and biomass is getting generated and it is staying in the system for a longer time that is BSRT. It is represented by theta$_C$ and most of the design purposes this is the most important criteria theta$_C$ which tells us what is the biological sludge retention time we are providing in the system.

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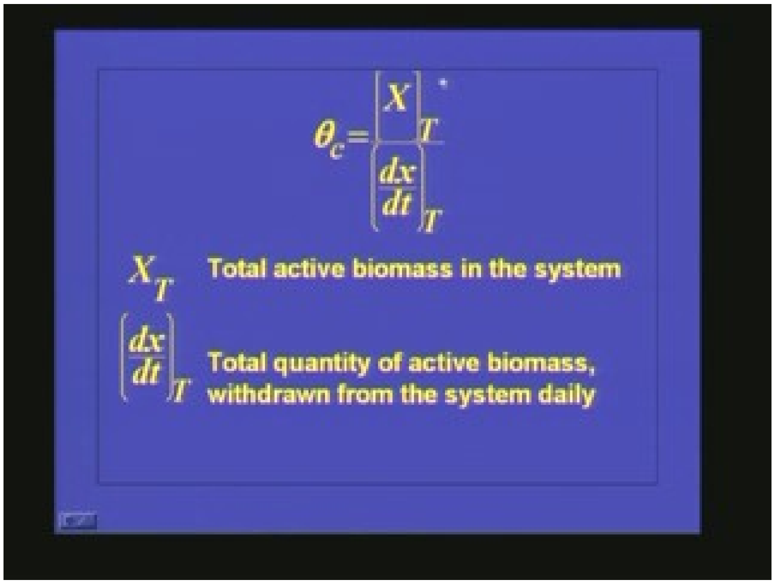

This is the mathematical expression of theta$_C$. That means what is the time the biomass is staying in the system. So how can we find out this one? It is nothing but the total biomass concentration divided by the biomass wasted from the system daily. Here X_T is the total active biomass in the system and dx by dt is the total quantity of active biomass withdrawn from the system daily so we will be getting theta$_C$ in terms of days.

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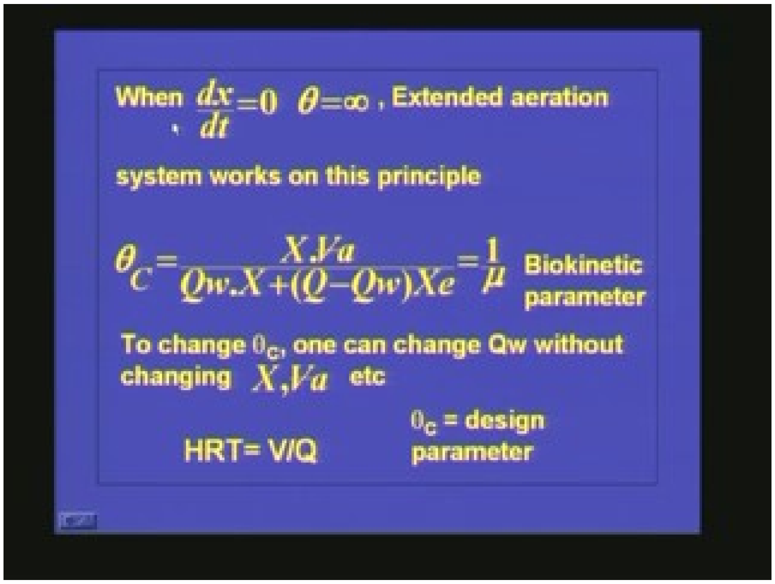

When dx by dt is equal to 0 that means if you are not withdrawing any sludge from the system. That means whatever sludge is generated entire sludge is staying inside the system so what does it mean? It means that $theta_C$ or the biological sludge retention time of that system is infinity because we know that $theta_C$ is nothing but total X divided by dx by dt and when the term dx by dt becomes zero naturally $theta_C$ become infinity. The process modification of activated sludge that is extended aeration system is working on this principle and there, there will not be any sludge wastage or sludge recycling theoretically so there the $theta_C$ will be infinity and all the sludge whatever is generated in the system will be undergoing auto oxidation or they will be in the endogenous respiration phase and will be auto oxidized.

Therefore, if you want to find out the $theta_C$ of an activated sludge unit we can find out like this; X into Va this will give you the total biomass present in the system that means in the aeration tank so Va is the volume of the aeration tank and X is the biomass concentration per liter or per meter cube. Now, what is the biomass wasted from the system, it is nothing but Qw into X where Qw is the quantity wasted into what is the concentration of biomass in the wasted liquid plus Q minus Qw into Xe this is coming out along with the effluent from the secondary treatment plant. So it is nothing but one by mu.

Here we have seen what is mu which is the specific growth rate. The specific growth rate is nothing but the growth whatever is taking place per unit biomass or dx by dt by X so this is nothing but X by dx by dt so $theta_C$ is nothing but one by mu. Hence, if you know the specific growth rate of the system we can find out what is the $theta_C$ of the system. We have seen that this is the most important design parameter of activated sludge process or any biological process where we get to know, for how much time we can retain the sludge in the system.

Hence, if you want to change the $theta_C$ to get different efficiencies or to modify your system we have to change the design parameter $theta_C$. How can we change the $theta_C$ without affecting the volume of the time? Once we design the tank the volume will be fixed. So if you do not want to change the volume how can we change the $theta_C$?

here as per the equation; $theta_C$ is nothing but x into Va by Qw into X plus Q minus Qw into Xe so if you change the Qw without changing either x or Va we can change $theta_C$ and another one is HRT Hydraulic Retention Time that v by Q and $theta_C$ is the design parameter this is very very important.

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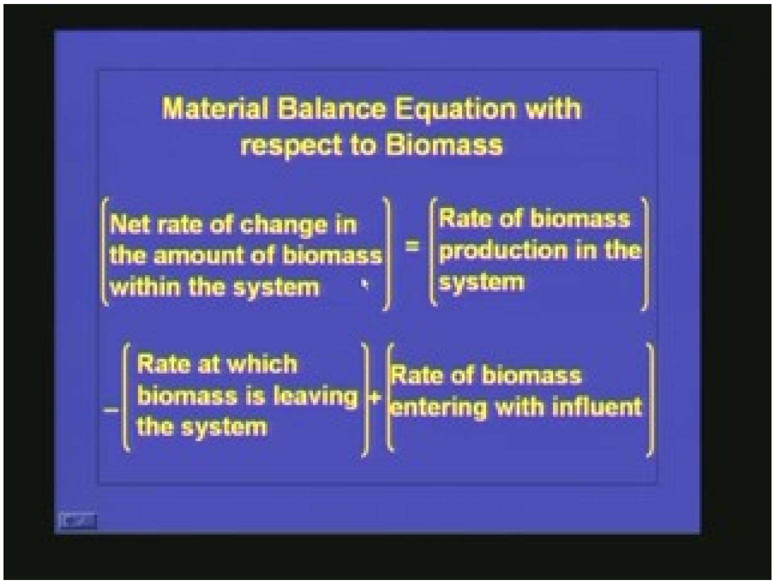

Now we can see how to find out the theta$_C$ if you know what is the theta$_C$ we can provide and what is the influent BOD and effluent BOD required. We know what is the treatment required, it should meet the discharge standard. So in terms of BOD it is 30 milligrams per liter. So if you want to find out the volume of the tank how we can go around?

Therefore we will make the material balance equation with respect to biomass. So if you want to take the material balance how can we do it? The net rate of change in the amount of biomass within the system is equal to rate of biomass production in the system minus rate at which biomass is leaving the system plus rate of biomass entering with influent. This is the biomass concentration. This is the activated sludge process; we are taking the biomass concentration in the aeration tank so we have to take the net rate of change of biomass concentration here that is equal to the biomass generated here and the biomass leaving the system and the biomass entering the system. If you take all those three into account we can get the mass balance that is what we have done here.

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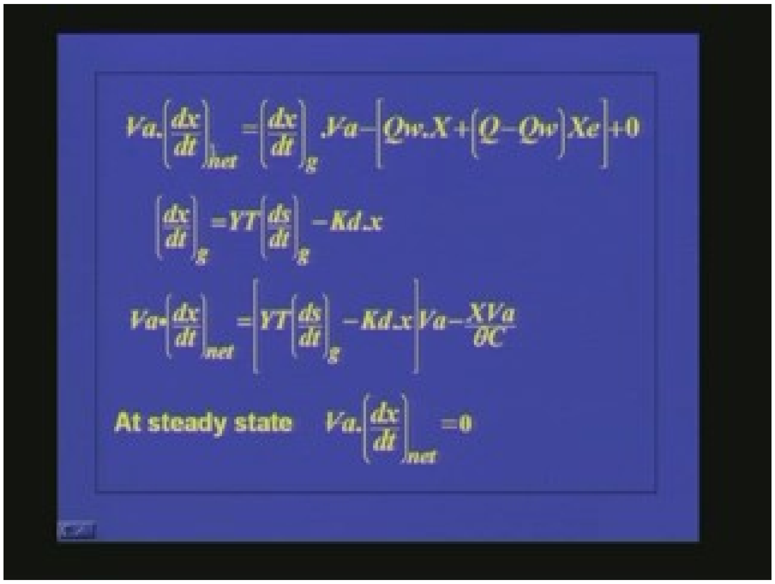

So if want to write the mathematical expression for that one it is like this; Va this is the volume of the aeration tank into dx by dt changing microbial concentration net change that is equal to dx by dt growth into volume of the tank that means whatever is generated in the system minus Qw into X plus Q minus Qw into Xe this is the entire biomass leaving the system. This is because of the sludge wastage and this is going out through the effluent from the secondary sedimentation tank and this zero (Refer Slide Time: 45:20) is coming because we are assuming that whatever biomass is coming to the system is zero. We are assuming that the biomass concentration in the wastewater is very very negligible compared to the biomass concentration in the aeration tank.

When we discussed about the biokinetic parameters we have seen that dx by dt by X that is the specific growth rate so if you multiply that one with X we will be getting dx by dt growth equal to Y_T into dx by dt growth minus kd into X. that means whatever is the yield coefficient into dx by dt minus kd (Refer Slide Time: 46:06) which is the endogenous decay constant kd into whatever is the biomass present initially. Therefore, if you substitute this one for dx by dt in this equation the final equation will be; Va into dx by dt net equal to y t into dx by dt g minus kd into X into volume because volume is coming in common minus this term which we can find out from the $theta_C$ equation (Refer Slide Time: 46:33) $theta_C$ is nothing but x into Va divided by Qw into X plus Q minus Qw into Xc. So we can write this term as x into Va by $theta_C$.

We also know that at steady state the net biomass generation is equal to zero. Whatever is generated is leaving from the system or at steady state Va into dx by dt net is equal to zero so finally this entire term will become zero and we will be having zero is equal to Y_T into dx by dt g minus k into kd into X into Va minus x into Va by $theta_C$ or x is equal to $theta_C$ into YT into Q into So minus Se by volume of the aeration tank into 1 plus kt $theta_C$ so we can find out what is the biomass required for the particular treatment efficiency.

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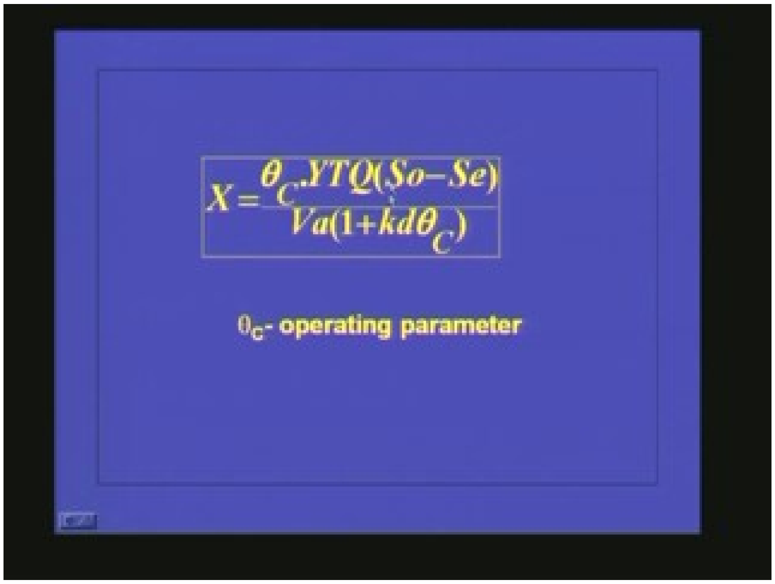

So minus Se is the substrate removal from the system that means this is the efficiency of treatment. For example, if you have a BOD of 300 initially and se is 20 milligram per liter So minus Se is the one which is getting removed from the system and kd we will be knowing and Y_T will be knowing because these are the biokinetic parameters and theta_C is nothing but 1 by mu. So X we can find out using this formula and similarly we can develop an equation for substrate concentration. We know that mu is equal to one by theta_C which is equal to YTQ minus kd or and we know what is the definition for Q, Q is nothing but specific substrate utilization rate, what is the substrate utilized by unit biomass in the system so Q is equal to ds by dt by X where dx by dt is the rate of change of substrate concentration in the system or Q is equal to Qmax Se by ks plus Se this is the maximum substrate utilization rate and this is the half saturation constant. We have discussed all these in detail earlier.

Or we can write like this; ds by dt, what is the rate of change of substrate concentration in the system that is equal to Q_{max} into Se whatever is the substrate concentration present in the system by ks plus Se into X. But in activated sludge process what we assume is the substrate is limiting. That means as soon as it enters into the system So will be getting converted to se because it is the CSTR reactor so the biomass the substrate or the food available for the biomass is always under limiting condition. In other words, compared to this ks value this Se value will be very very negligible, Se is very very less compared to ks value. So how can we write this equation? We can write it like this.

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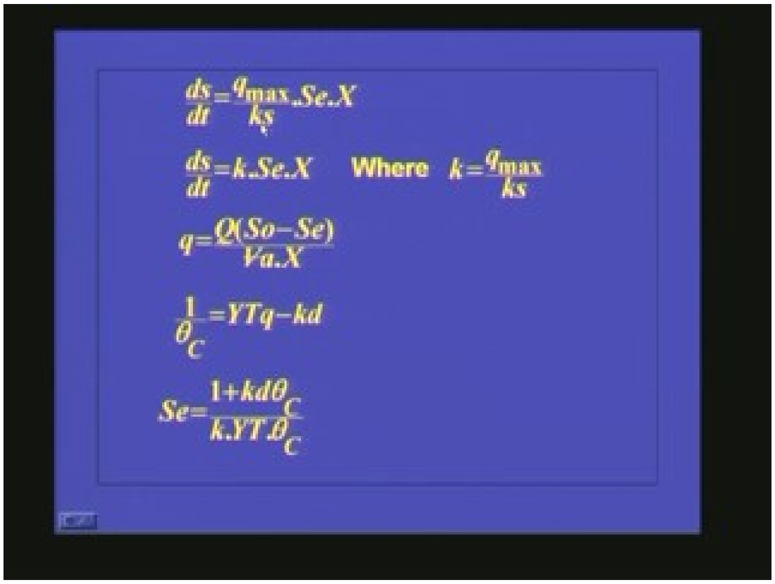

It is; ds by dt equal to Q_{max} by ks, we have neglected Se in the denominator into Se into X or we can replace this Q_{max} and ks by a single constant small k because Q_{max} is a constant for the system and ks is also a constant for a system so two constants will give another constant so that is why we are replacing that one with another constant k. So ds by dt is equal to k into Se into X where k is Q_{max} by ks. In other words we know what Q is in an activated sludge process. What is ds by dt? It is Q into So minus Se that is the total substrate concentration change in the system and the total biomass concentration in the system is nothing but Va into X so Q is nothing but Q into So by Se by Va into X and we know 1 by $theta_C$ is equal to Y_Tq minus kd.

Now, if you substitute this one here we can get the value for Se, we have to substitute this one here then we will be getting Se is equal to 1 plus kd $theta_C$ by k into Y_T into $theta_C$. So what does it mean? The substrate concentration as well as the biomass concentration in the system is depending upon the biokinetic constants of the microbial population present in the system. So Se is a function of kd which is the decay constant and $theta_C$ and $theta_C$ is nothing but 1 by mu and Y_T is the yield coefficient and k is nothing but Q_{max} by ks

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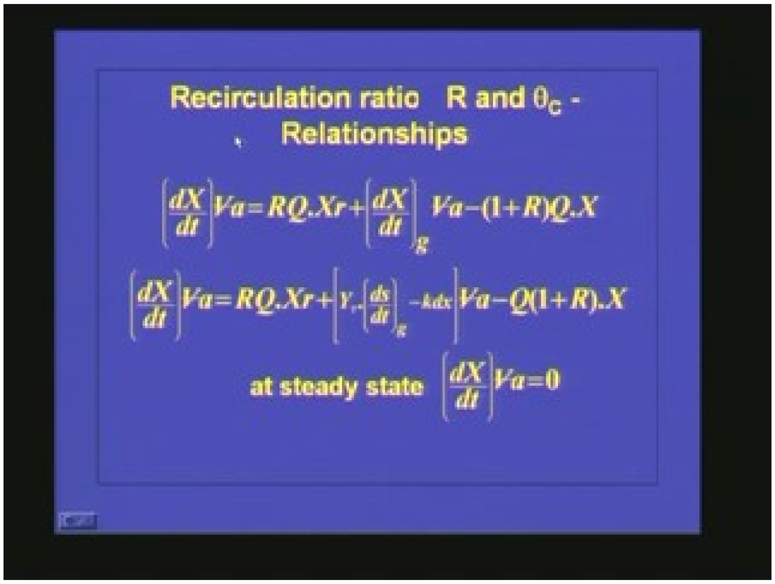

Another important thing in activated sludge process is the recirculation ratio R. How this recirculation ratio R is related with the theta$_C$ the biological sludge retention time. Again we can take the mass balance dx by dt is equal to RQ into Xr whatever biomass that is coming into the aeration tank plus dx by dt into V$_a$ minus 1 plus R into Q into X this is the biomass mass balance for the aeration tank alone. So we can write like this; RQ into Xr this term (Refer Slide Time: 52:10) we are replacing by Y$_T$Q minus kd multiplied by X into V$_a$ minus Q into 1 plus R into X.

At steady state again this term will be becoming zero so we will be getting another relationship 1 by theta$_C$ equal to Q by V$_a$ into 1 plus R minus R into Xr by X. again we can see that if the theta$_C$ is fixed, the volume of the tank is fixed and the flow rate is fixed and the R is depending upon the concentration of the recycle sludge and the concentration of biomass in the aeration tank.

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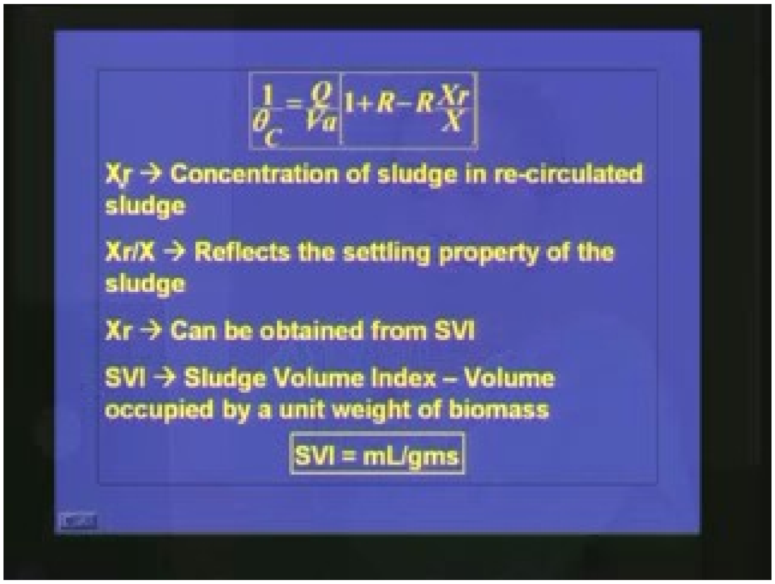

So here Xr is the concentration of sludge in the re-circulated sludge, Xr by x reflects the settling property of the sludge that means how the sludge settling is taking place in the secondary sedimentation tank that is very very important for the proper functioning of an activated sludge process. If the secondary sedimentation tank of an activated sludge process is perfectly fine the entire process will be working perfectly all right but if it is the other way the process will not be having the required efficiency.

How can we find out this Xr?
Xr can be obtained from SVI, this term is also important. This is nothing but sludge volume index. Sludge volume index is nothing but the volume occupied by a unit of weight of biomass and usually SVI is represented in terms of milliliter per grams. That means if this much ml of biomass is there what is the rate of that biomass or what is the volume occupied by a unit mass of biomass that is SVI. How can we find out the SVI?
Before that one we will see how this SVI is important for activated sludge process.

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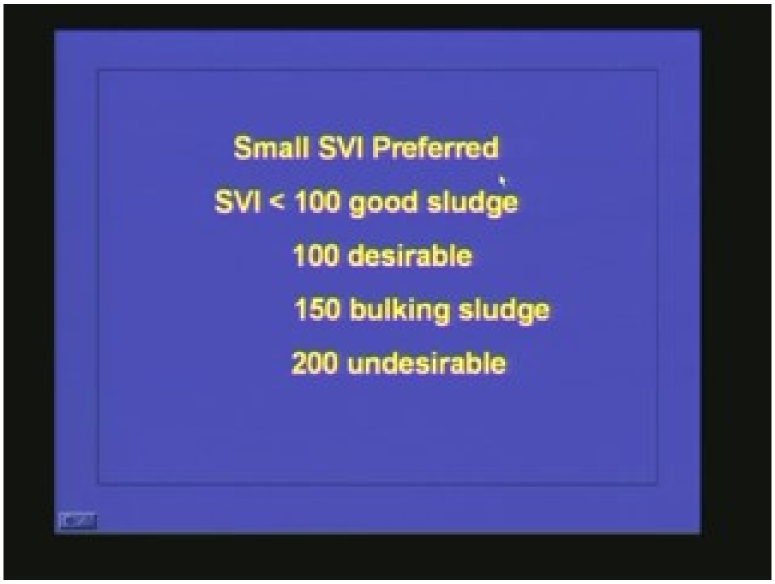

Small SVI is preferred. If SVI is less than 100 it is a good sludge, if it is hundred it is desirable, if it is greater than one fifty it is bulking sludge and if it is greater than 200 it is not at all desirable. So how can we find out the SVI of the system? What we have to do is take a graduated cylinder and take one liter of the mixed liquid suspended solids in that one and allow it to settle for 30 minutes. After 30 minutes we can find out the volume because it is a graduated cylinder so we can find out what is the volume occupied by the sludge and afterwards we find out the MLSS concentration is for milligrams or grams per liter and from that one we can find out the sludge volume index. And sludge volume index is very important for the proper functioning of activated sludge process.

Now we will see what are the things we discussed today. We have seen that biological processes are suitable for either water or wastewater depending upon the pollutant nature. Coming to the wastewater what is happening is most of the solids are highly biodegradable so biological process is the most desirable treatment process for secondary treatment of wastewater especially domestic wastewater.

The biological process is depending upon the microorganisms for their efficiency. It is essential to provide sufficient nutrients, environmental conditions for the microbial growth and depending upon the nutrient requirement we can classify the microorganisms into different categories like autotrophs, heterotrophs, phototrophs, chemotrophs etc and depending upon the electron donor we can classify the process into aerobic, anoxic or anaerobic.

We were also discussing about activated sludge process as to what is happening there. We are providing aeration so the dissolved form of organic matter is getting converted to fresher cells in the colloidal form. And since more and more cells in the colloidal form is present a solid liquid present process is essential so secondary sedimentation tank is an essential part of activated sludge process.

How the sludge settling is taking place in the secondary sedimentation tank?
It is with the help of some bio polymers which is excreted by the biomass themselves. Then we have seen the two parameters; one is hydraulic retention time and another one is biological sludge retention time. For any biological treatment system the design parameter is $theta_C$ not the HRT. $Theta_C$ is nothing but it shows how much time the sludge is remaining in the system and we have seen the mass balance of biomass and the substrate of BOD in the entire system.

We also discussed how to find out the biomass concentration the volume of the aeration tank or the efficiency of the treatment unit using the bio kinetic parameters of the microbial population present in the system and another parameter we have discussed is sludge volume index. This shows the settling characteristic of the sludge and this is also very very important.