Water and Wastewater Engineering
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Attached Growth Aerobic Process:
Trickling Filters and Rotating Biological contactors
Lecture – 26

Last few lectures we were discussing about the biological treatment of wastewater. We have seen the different process modifications of activated slugs. We have discussed in detail about pond systems and we have also seen that the facultative pond is the one which is most commonly used in wastewater treatment systems. We have also seen in detail on how to design the pond systems. But the most common thing what we have discussed till now is all those processes of suspended growth systems.

Today we will discuss about attached growth systems which are commonly used in waste water treatment that too in aerobic conditions. So coming to the attached growth systems the most commonly used one in wastewater treatment are trickling filters and rotating biological contactors. There are other few systems which is not so commonly used but it is coming up in wastewater treatment processes they are fluidized bed attached systems and submerged systems.

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Attached Growth systems

Aerobic
- Trickling filters
- Rotating biological contactors

Anaerobic
- Anaerobic filters
- Denitrification systems

These two systems are commonly used in aerobic system as well as in anaerobic system. Today we will be concentrating on attached systems which are commonly used in aerobic systems. Coming to the aerobic system as I have already told trickling filters and rotating biological contactors are most commonly used and in anaerobic system anaerobic filters, anaerobic flow rates, the reactors etc are being used. In anoxic process we can go for this denitrification system in attached growth system also. We have discussed nitrification and denitrification in detail in suspended growth systems. First we will discuss what is the biology of the attached growth system. This shows a some what schematic picture of the system biology.

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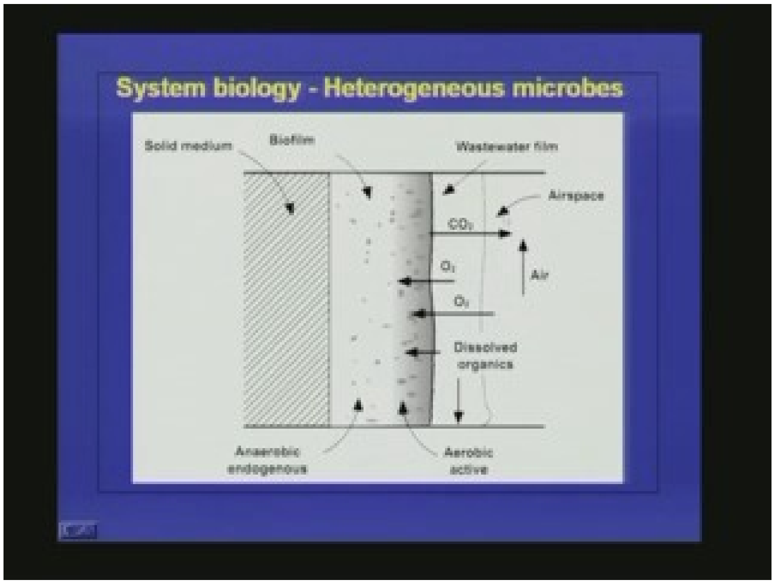

System biology - Heterogeneous microbes

It consists of hydrogenous microorganisms and you have a solid medium on which the microorganisms are growing, this is the solid medium and this is the biofilm and we can see that this is the wastewater film whatever is passing through the trickling filter and this is the air. Air is passing along with the liquid and that is how the reactions are taking place in the bio-technique filter.

The term itself is not giving the actual picture of the treatment system. Though we are calling it as a bio-technique filter the filtration part is very very negligible. The treatment is occurring because of biological action and the waste whatever is present in the water will be penetrating to the liquid filling and from there it will be coming to the biological film and biological action will be taking place. As a result the organic material will be converted into carbon dioxide and water. So because of this organic material conversion more and more cells will be generated. So the biofilm thickness in the solid support will be increasing with respect to time.

Now what will happen to the oxygen diffusion and the substrate diffusion?
Oxygen diffusion and substrate diffusion through the film will be limited so as a result we will be getting an aerobic zone in the beginning or which is in contact with the liquid film and an entropic zone which is in contact with the solid surface.

How it is happening is because the air is available or oxygen is available to the system because of the dissolved oxygen whatever is present in the wastewater. As well as when air goes through the bio-trickling filter it comes in contact with the liquid film and because of that contact some oxygen will be diffusing from the gas ways to the liquid ways so the thickness of the aerobics zone I told you the biofilm will be having an aerobic zone and entropic zone.

The thickness of the aerobic zone depends upon the oxygen transfer as well as the organic concentration of the wastewater and the factors that affect the oxygen transfer. One the overall oxygen transfer coefficient, second one is what is the concentration of oxygen in the solid liquid interface, if the oxygen concentration in the solid liquid interface is very high naturally high concentration gradient will be available between the liquid film as well as the biofilm so naturally more oxygen transfer will be taking place.

The next one is how much is the dissolved oxygen present in the liquid film that is also important which decides what is the amount of oxygen getting transferred to the system. Another factor which affects the aerobic zone or anaerobic zone thickness is the organic matter penetration into the biofilm because if more and more organic matter penetration to the biofilm naturally the micro organism request more oxygen to transfer them. The organic matter penetration also depends upon the fluorite of the wastewater and the organic concentration of or organic loading whatever we are applying to the bio trickling filter if the wastewater is high BOD or high COD naturally the organic matter penetration will be very very high to the system.

The next one is how much is the biodegradability of the organic matter though the organic matter penetration is at a faster rate. If it is not biodegradable then what will happen is the microorganisms may not be able to utilize it in a proper way so naturally the oxygen utilization rate will be less so the aerobic zone thickness will be high.

Another one is the substrate utilization rate or the degradation rate of the organic matter. Whatever is penetrated through the biofilm if the degradation rate or the specific substrate utilization rate is very very high naturally a corresponding amount of oxygen should be available then only the degradation will be taking place. These are the factors which decide the aerobic zone thickness and anaerobic zone thickness.

If the aerobic zone thickness is less naturally the anaerobic zone whatever is present will be having a higher thickness. And usually whenever we talk about attach those systems the thickness of the biofilm varies from 1 to 3 mm because if the thickness is higher there are various problems. One is that the thickness is small the porosity is limited so clocking of the biofilter will be taking place so it will not be allowing the penetration of liquid as well as air through the bio trickling filter.

Another one is because of the flowing of water some shear stress will be developed and it will be shearing the biofilm if the thickness is very very high. Another factor is if the thickness of the biofilm is very very high the penetration of organic matter is limited so the micro organism whichever is present in the extreme end of the bio film or the biomass whatever is very close to the solid medium the food availability will be limited and as the thickness of the biofilm increases more and more food will be available in the biofilm which is in contact with the liquid so there more oxygen more organic matter etc will be available. But as the organic matter penetrates through the biofilm, as it comes to the extreme end or the one which is staying near the solid medium by the time all other microorganisms whatever is present till that will be utilizing the organic matter. As a result the microorganisms whatever is staying near the solid will be deprived of food. So how can they survive?

They will be undergoing endogenous suspiration or auto oxidation. So as a result there will not be any microorganism in the layer which is very close to the solid medium so naturally the biofilm loses its attachment capacity and it will be coming out of the bootlicking filter or the supporting medium. So in the system the thickness of the biomass in the attach medium is control by itself by the diffusivity of the oxygen as well as the organic matter and because of the food limitation endogenous respiration takes place and it will be getting detached from the system. Therefore, stuffing of the biomass will be taking place and this will be coming along with the treated affluent. That is what I have represented here in this picture.

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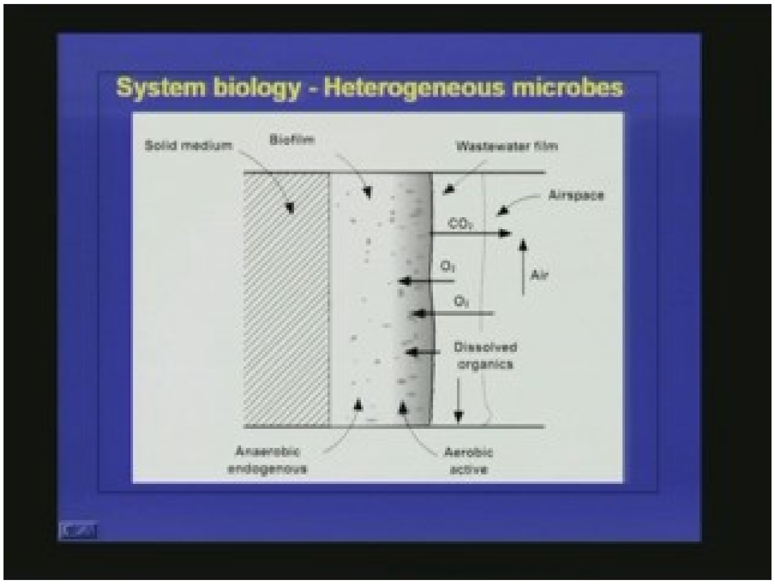

System biology - Heterogeneous microbes

This is the solid medium and this is the biofilm and we can see that this is the wastewater film. Because the biofilm is there the liquid is crossing in this direction so there will be always a film of water attached to the biofilm and this is the airspace and air will be flowing or moving in this direction. So what is happening is whatever dissolved oxygen is present in the wastewater entering into the biofilm we can see that this is the oxygen penetration (Refer Slide Time: 10:21) oxygen penetration can take place both from the wastewater film as well as from the air.

It first enters in the waste water then from this film it will be entering into the biofilm and some dissolved organic as it passes it will be entering into the biofilm so what is happening is here we can see that lot of oxygen is available in this region so this region is working under aerobic conditions. As we go to this side the oxygen availability will be limited because whatever oxygen that is available will be utilized by the microorganism here so as we go here the oxygen availability will be less so this film will be in entropic condition.

If the thickness of this film increases further then the dissolved organic penetration also will be limited so the microorganism here will be utilizing a portion of the organic matter and the concentration of organic mater will be reducing with respect to distance. So microorganisms here may not be getting enough food so as a result it will be undergoing endogenous respiration and once the complete endogenous respiration of the layer takes place the entire biofilm will be pealing of from the supporting medium known as sluffing.

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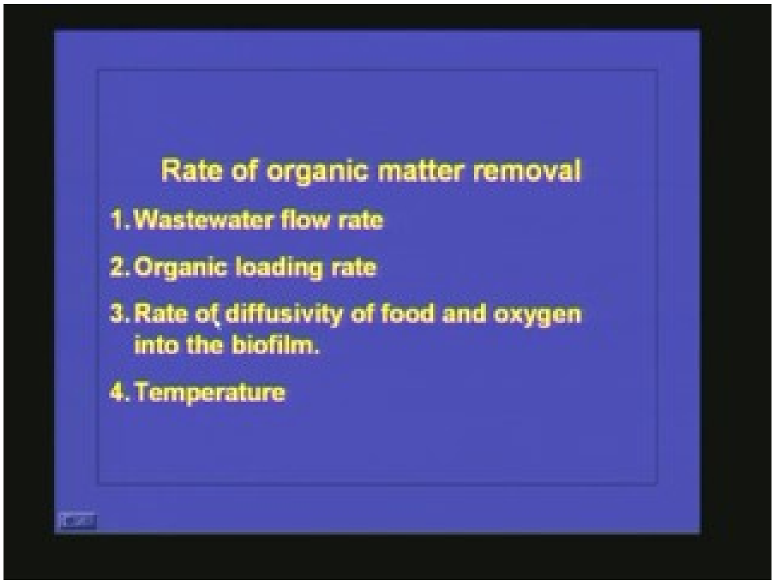

Rate of organic matter removal

1. Wastewater flow rate
2. Organic loading rate
3. Rate of diffusivity of food and oxygen into the biofilm.
4. Temperature

Now we will see how the organic matter is getting removed in the system. The rate of organic matter removal is depending upon the wastewater flow rate and organic loading rate, rate of diffusivity of food and oxygen into the biofilm and the temperature how these parameters are very very important.

As we discussed if the wastewater flow rate and organic loading rate are high then naturally the penetration of organic matter from the liquid film to the biofilm will be very very high. So naturally if the organic mater is available to the microorganism then the removal will be at a faster rate. We have seen how the micro organisms are utilizing the organic matter.

First it has to come and get attached to the microbial cell then it has to enter through the cell wall and go into the cell then only the metabolic activity will be taking place as a result some part will get converted into carbon dioxide and water because of the catabolic activity and some part will be consumed for the creation or generation of new cells which is known as anabolism. So unless the organic matter is available for the microorganism it will not be getting removed that is why if you have a high flow rate and high organic concentration naturally the penetration of the organic matter will be very very high.

Any microbial reaction is temperature dependent. We have already seen that after temperature increases the microbial activity will be increasing and for most of the microbial activity the optimum temperature is around thirty five to thirty five degree centigrade in the mesophilic range.

For every ten degree centigrade rising temperature the microbial activity will be increasing by 100% and similarly if the temperature is degree naturally in the microbial activity will be coming down that’s why the temperature of the system is also very very important. So if we can provide a high temperature that means temperature above twenty five degree throughout the operational period then the efficiency of the system will be much higher compared to a temperature which is lower than 20 degree centigrade.

Now we see in detail the trickling filters. Trickling filter is a reactor in which randomly packed solid forms provide surface for microbial growth and it will have a system for wastewater distribution also. When we select the media for the microbial growth the most important parameters are specific surface area and porosity. Specific surface area is the amount of surface area of the media that is available for bio film growth.

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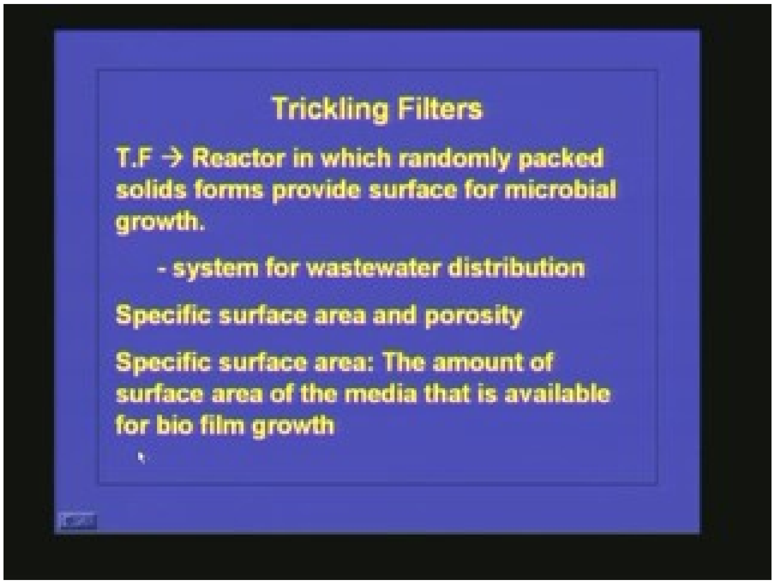

Trickling Filters

T.F → Reactor in which randomly packed solids forms provide surface for microbial growth.

- system for wastewater distribution

Specific surface area and porosity

Specific surface area: The amount of surface area of the media that is available for bio film growth

Porosity is the void space available for passage of wastewater and air. So whenever we select a media for the microbial growth porosity as well as specific surface area is very very important.

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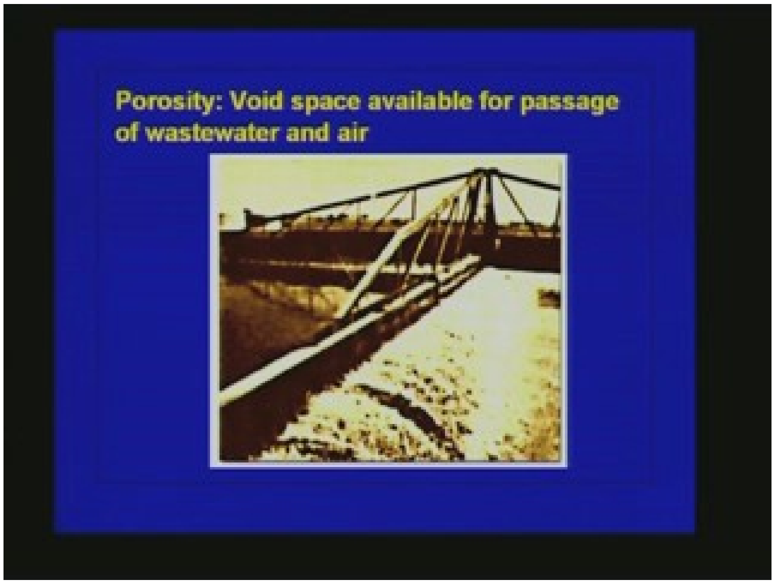

Porosity: Void space available for passage of wastewater and air

The reason is if you have a high specific surface area the amount of surface or the amount of biofilm present in the system will be very very high because the entire surface the microbial film will be growing. Therefore, as the specific surface area increases the biofilm area as well as the total volume of biofilm will be increasing. We all know that in any biological system the workers are microorganisms so naturally if you can provide more microorganisms in the system the system efficiency will be very very high.

Now coming to the porosity, if the porosity is high that is the place which calls the wastewater as well as the air. So if you have a high porosity then you can go for a high hydraulic loading rate where hydraulic loading rate is the volume of wastewater applied to the system per meter cube per day. That means the meter cube of wastewater applied per meter cube of the reactor per day is the hydraulic loading rate. So if the porosity is more then you will have more volume inside the reactor which can hold the wastewater so you can apply more and more water.

In practice the most commonly used solid materials for the bacterial growth especially in trickling filter are crush ton or slack. What will happen is the porosity of this media usually varies from 40 to 50% and specific surface area is around 50 to 60 meter square per meter cube so this media are commonly used in trickling filters which is working under standard condition or standard mode. But there are some other variety of trickling filters known as high rate trickling filter.

As the name indicates high rate trickling filter is the one which can be operated at a very high hydraulic loading rate or organic loading rate. So in high rate trickling filters we go for synthetic supporting media like plastic or some other polymers which is having relatively high specific surface area. The medium is commonly used in bio-towers or high rate trickling filters is having a specific surface area of 200 meter per square per meter cube and a porosity of around 95%. So, from conventional media to this high rate trickling filter media we can see that the specific surface area is increasing around three times and the porosity is almost double so naturally the efficiency of the system will be more or you can treat a large volume of wastewater in a given volume compared to the standard rate trickling filters. This picture shows a trickling filter.

This is the distribution system. It consists of few distributors. So this is one, this is one and here we can see many nozzles so the wastewater will be coming out of the nozzles and it will be sprinkled uniformly over the trickling medium surface. How this distribution system is working in a trickling filter?
It is working because of the hydraulic pressure, hydrostatic pressure available. Here the wastewater will be coming and if it can have a hydrostatic pressure of 1 m of water then the rotating arm will be rotating by itself because of the hydrostatic pressure we don’t have to give any external power and this supply of wastewater will be intermittent. Therefore, as a result what will happen is sometimes the wastewater will be trickling over the trickling filters.

This arm is distributing similarly we can see here also this distributing arm is distributing wastewater. after this distribution we can see that here the medium is exposed to the air for some time so the intermittent distribution of wastewater gives a chance for air it circulates through the medium so enough option will be available for the degradation of the organic matter by the microorganisms and the water will the wastewater will be trickling through the trickling filter and with respect to time the organic matter will be getting converted to carbon dioxide matter and most of the cells will be getting attached to the system and the treated water we have to collect from the bottom of the trickling filter. So we have to provide some collection devices.

These are the collection devices usually used. We can see that this is the concrete material and this is made up of tiles.

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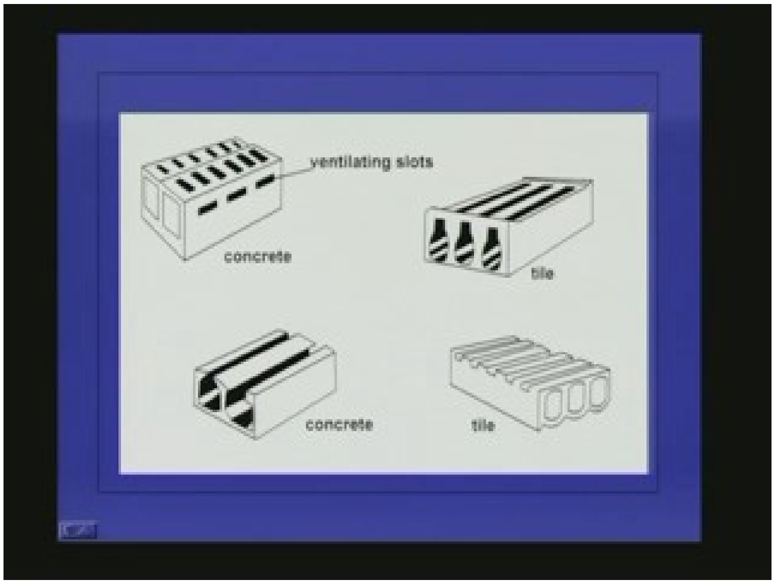

These are different systems here. We can see that here the openings are there and this will be collecting the wastewater whatever is trickling through the trickling filter and from there everything will be collected and going to a secondary treatment system. As I have already explained the trickling filter can be divided into two or three categories low rate filter, standard or intermediate rate filter and high rate filter.

So the classification is based upon the hydraulic loading organic loading rate. In low rate filters or the standard weight filters the hydraulic loading rate is represented as meter cube of wastewater per meter square of filter area per day varying from one to four whereas intermediate rate filter varies from four to ten and in high rate filter it varies from 10 to 40.

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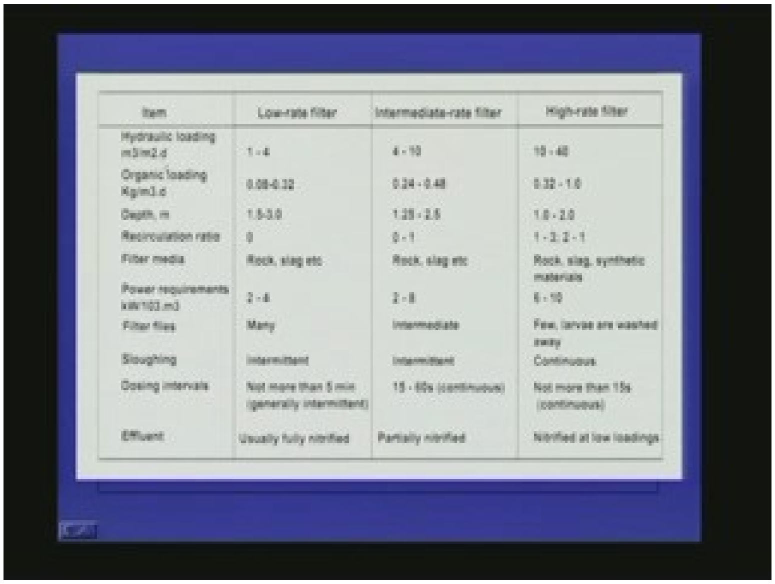

Item	Low-rate filter	Intermediate-rate filter	High-rate filter
Hydraulic loading m3/m2.d	1 - 4	4 - 10	10 - 40
Organic loading Kg/m3.d	0.08-0.32	0.24 - 0.48	0.32 - 1.0
Depth, m	1.5-3.0	1.25 - 2.5	1.0 - 2.0
Recirculation ratio	0	0 - 1	1 - 3: 2 - 1
Filter media	Rock, slag etc	Rock, slag etc	Rock, slag, synthetic materials
Power requirements kW/103.m3	2 - 4	2 - 8	6 - 10
Filter flies	Many	Intermediate	Few, larvae are washed away
Sloughing	Intermittent	Intermittent	Continuous
Dosing intervals	Not more than 5 min (generally intermittent)	15 - 60s (continuous)	Not more than 15s (continuous)
Effluent	Usually fully nitrified	Partially nitrified	Nitrified at low loadings

That means the high rate filter can treat around ten times more wastewater compared to a low rate or a standard rate trickling filter and organic loading rate it is expressed in terms of kilogram per meter cube per day.

Organic loading rate varies from 0.08 to 0.3 in low rate or standard rate trickling filter and for intermediate rate filter it is 0.24 to 0.48 and in high rate it is 0.3 to 1. So we can see that if you go for high rate filter we can increase the hydraulic loading as well as the organic loading rate and the depth of the medium in low rate filter is varying from 1.5 to 3 m, for intermediate it is 1.25 to 2.5 and high rate filter it varies from 1 to 2 m.

Sometimes in bio-tower we can go for a depth of even 10 m and recirculation ratio low rate filter it is 0 and intermediate rate filter it varies from 0 to 1 and high rate filter it varies from 1.1 to 3 or 2 to 3 and filter medium we have already seen in standard rate filter that we usually use crush stores or slack.

in the intermediate filter also the same thing but in high rate filter we use synthetic material usually and the power requirement standard rate filter requests less power because the recirculation is not damaged and intermediate varies from 2 to 8 kW 10 raised to 3 meter cube of water and in high rate it varies from 6 to 10 kW per 10 raised to 3 or 1000 meter cube of water and another one is the new essence is [filter flies…… 22:41].

In low rate filters the filter flies or the chi coda that is the flies usually found, they are many in intermediate rate filters they are in the mediate not many are there but in high rate filter very few flies are seen.

Coming to this sluffings that means how the sludge getting removed from the system low rate filters is intermittent, intermediate rate filters it is intermittent and coming to the high rate filter the sluffing is continuous and dozing intervals for low rate filters it is not more than five minutes and for intermediate rate filter it is 15 to 60 seconds and high rate filter not more than 15 seconds. The effluent here in standard rate or low rate filter is usually fully nitrified. That means it doesn't require any further treatment and intermediate rate filter is partially nitrified.

In high rate filter if the organic loading rate is slow then we get nitrified liquid. But if the loading rate is very very high then we will not be getting nitrified effluents.

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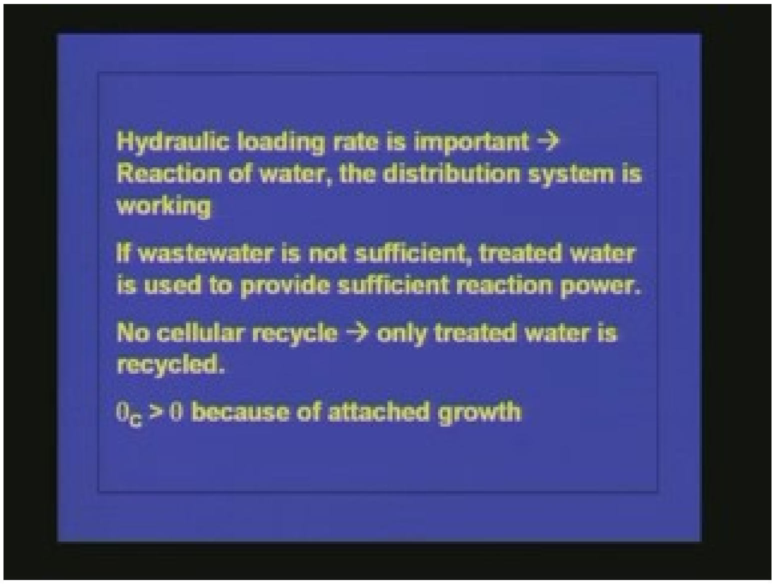

Hydraulic loading rate is important → Reaction of water, the distribution system is working

If wastewater is not sufficient, treated water is used to provide sufficient reaction power.

No cellular recycle → only treated water is recycled.

$0_C > 0$ because of attached growth

In trickling filter we have seen the organic loading rate as well as the hydraulic loading rate. But coming to the hydraulic loading rate in trickling filter the hydraulic loading rate is very very important because I have already discussed how the distribution of wastewater is taking place in a trickling filter. It is because of the hydrostatic pressure available in the distributing arm. So if enough hydraulic loading rate is not practiced then the hydrostatic pressure available will not be sufficient for the movement of the rotating arm so in such cases we have to supply power externally. But if the hydrostatic pressure is sufficient then the pressure itself will be taking care of the wastewater distribution in the trickling filter at specified intervals. So, the hydraulic loading rate is very very important.

In trickling filter also we use recirculation but the recirculation of trickling filter is entirely different from that of activated sludge process. In activated sludge process we are re-circulating to increase the biomass concentration in aeration tank so we re-circulate the settling sludge from the secondary sedimentation time to the aeration time of the activated sludge process so the recirculation is to maintain a high concentration of mix liquid suspended solids in the aeration tank because that will definitely increase the efficiency of the system.

Now coming to the trickling filter we know that the biomass is growing attached to the medium so in the system will be having a high concentration of biomass always so we need not supply biomass to the system. What is the purpose of recirculation in the bio trickling filter?

One is to provide enough hydrostatic pressure to the distributing arm because if the hydraulic loading is not sufficient the distribution system will not be operating properly so to get enough hydrostatic pressure we re-circulate the treated effluent from the secondary sedimentation tank because in trickling filter also we need to have a secondary sedimentation tank the reason is a portion of the biomass whatever is attached to the system it will be sluffing of and coming to the effluent.

Therefore, if we allow the effluent to go just like that then this sluff biomass will be going along with the treated effluent and naturally if the suspended solid concentration as well as the COD of the system will be very very high or the treatment efficiency will not be meeting the required standards. Thus, we have to provide a secondary sedimentation tank. So the recirculation is from the effluent of the secondary sedimentation tank but not from the settled sludge. That is the major difference in recirculation between an activated sludge process and a trickling filter. Here we are re-circling the effluent not the sludge.

One more reason for the recirculation is that with one pass most of the time the COD will not be getting removed completely so if you pass it again and again it will be getting more contact time and at the microorganism will be getting more time to degrade the organic matter so to increase the treatment efficiency also we re-circulate the ways to the system. Recirculation system can be practiced in many different ways either directly before going to that secondary sedimentation tank or after going to the secondary sedimentation tank we can even put many bio trickling filters in series instead of providing a single filter.

If we can provide a series of filters it will increase the efficiency of the system. the reason is the effective depth of the bio trickling filter will be increasing, because of practical problem in a single bio trickling filter we cannot provide a depth more than two to three meters. But if you provide a series of bio trickling filters what will happen is one will be giving a particular efficiency and from that one the effluent is going to a second trickling filter that will be removing a considerable amount of organic matter whatever is present in the system. So as a result the effluent coming out of the series of treatment unit will be having better quality compared to a single unit.

Whatever I have discussed now is written here; the hydraulic loading rate is important because reaction of water based upon that one the distribution system is working. if wastewater is not sufficient treated water is used to provide sufficient reaction power and no cellular recycle is required only treated water is recycled, theta c is always greater than theta, theta is the hydraulic retention time because of attached growth because whatever is the biomass generated in the system most of them is gained in the system itself. So, biological sludge retention time in an attached growth system is always much higher than the hydraulic retention time.

Now we will see how to design a trickling filter. There is no theoretical approach available for the design of trickling filters. Mostly empirical equations are used for the design of trickling filter. That means in the field many bio trickling filter or pilot trickling filters will be available based upon the performance and based upon the volume flow rate etc and we know what the influent is BOD or COD and what are the effluents BOD COD so based upon that one the design criteria is developed.

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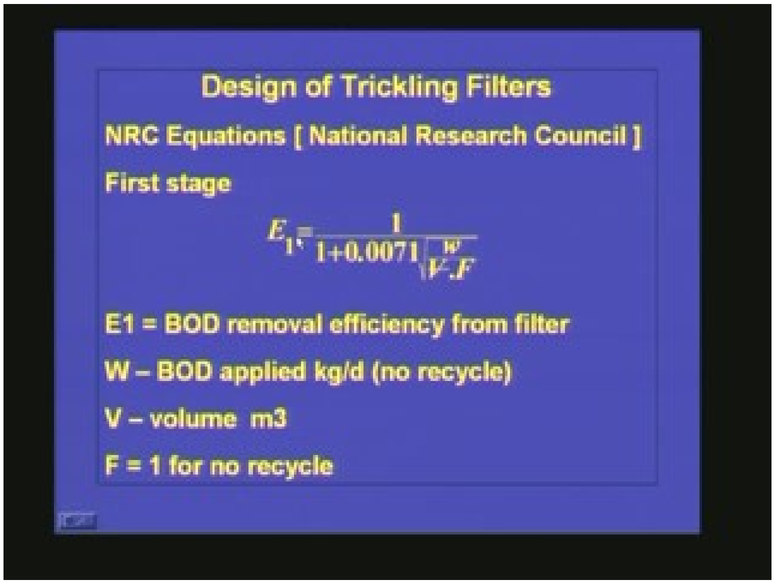

Design of Trickling Filters

NRC Equations [National Research Council]

First stage

$$E_1 = \frac{1}{1+0.0071\sqrt{\frac{W}{V.F}}}$$

E1 = BOD removal efficiency from filter

W – BOD applied kg/d (no recycle)

V – volume m3

F = 1 for no recycle

So the most commonly used approach for the design of trickling filter is the NRC equation that means the National Research Council equations. this is the formula; if you want to design the first stage of a trickling filter we can use E1 is equal to the efficiency of the first stage is equal to 1 by 1 plus 0.007 into square root of w by V into F where E1 is the BOD removal efficiency from the filter in the first filter and w is BOD applied.

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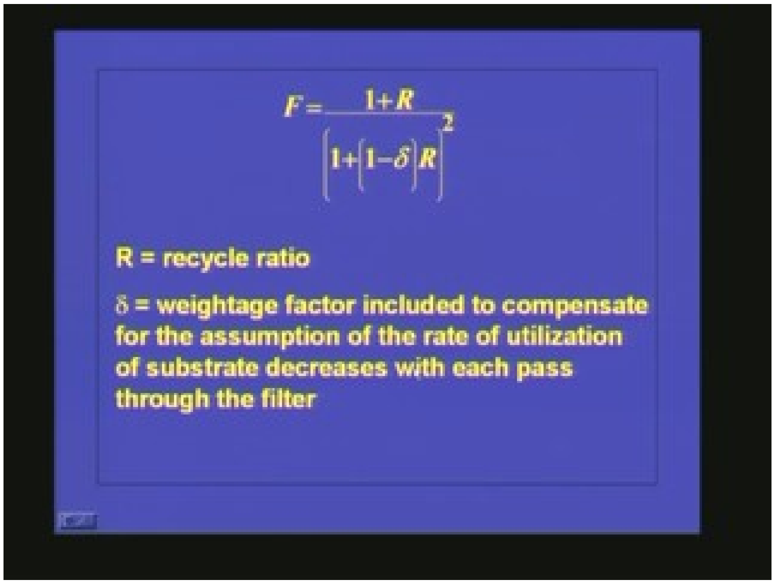

$$F = \frac{1+R}{\left(1+\left(1-\delta\right)R\right)^2}$$

R = recycle ratio

δ = weightage factor included to compensate for the assumption of the rate of utilization of substrate decreases with each pass through the filter

That means kilogram per day without any recycle and V is the volume of the filter in meter cube and F is equal to 1 for no recycle. Hence, if we know the BOD applied per day to the bio filter or bio technique filter and the volume of the filter then we can find out the efficiency of the system.

If the recirculation is there that means in the system we are re-circulating the wastewater F equal to one plus R divided by one plus one minus delta into R whole square where R is the recirculation ratio we can see here one term delta is coming so delta is nothing but the weightage factor included to compensate for the assumption of the rate of utilization of substrate that decreases with each pass through the bio filter, so what does this delta mean. This means the first cycle of the wastewater flow.

The organic matter will be penetrating through the biofilm and microorganisms will be utilizing the organic matter but the utilization rate will be depending upon the biodegradability of the waste. So naturally in the first cycle or the first pass itself the highly biodegradable organic matter will be getting removed from the system and the wastewater whatever is less degradable will be coming out of the bio filter and it is again getting re-circulated through the bio trickling filter. So what will happen is definitely in the second cycle the removal efficiency will not be so high. The reason is highly bio degradable organic matter is removed in the first cycle and in the second cycle less biodegradable organic matter is present. Hence, even though we are keeping the same organic matter loading rate and same volume of the filter in the second cycle the efficiency will be less because of the less biodegradable material present in the system.

If you want to take care of that one we have to include some factors so that is what this delta is doing. Delta will take care of the decrease in substrate utilization rate because of the recirculation. This is how in a trickling filter we re-circulate the water. We will be having a primary sedimentation tank the reason is that the wastewater will be having some in such suspended solids so if you don't remove the suspended solids it will be going to the trickling filter and will get accumulated in the pass of the trickling filter which may result in clogging of the trickling filter.

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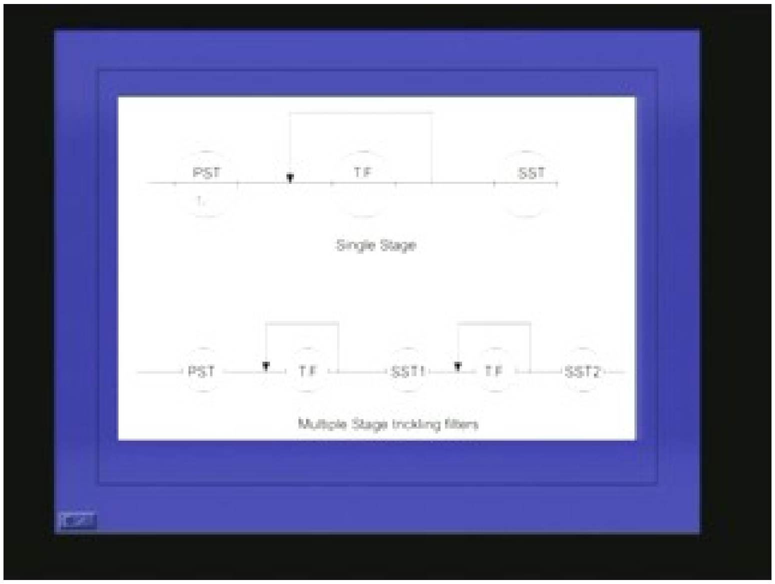

Single Stage

Multiple Stage trickling filters

That's why it is always advisable to have a primary sedimentation tank for the trickling filter. here what is happening is the trickling filter is here and whatever effluent is coming out is not even going to the secondary sedimentation tank but before that it is getting recycled and a portion is going to the secondary sedimentation tank. And after the sludge settling the treated effluent is going out and this is the multiple stage trickling filter primary sedimentation tank and this is the trickling filter recirculation. This recirculation can either be from here or we can have the recirculation like this.

This (Refer Slide Time: 33:55) is the second trickling filter and recirculation and this is the secondary sedimentation tank and here also instead of re-circulating from here we can re-circulate from here also. But many studies how shown that either we re-circulate from here or after secondary sedimentation if you re-circulate also there is not much change in the efficiency of the system so after re-circulation we can reduce the volume of the secondary sedimentation time so now we will see what is the removal efficiency if you go for a series of bio trickling filter so first filter we have seen how to find out the efficiency.

So if you want find out efficiency of the second filter we can use this formula E_2 is equal to 1 by 1 +0.0071 divided by 1 – E_1 into W_2 by V_2 into F. So E_1 is nothing but the efficiency of the first bio trickling filter and W_2 is the BOD applied to the second stage given in kilogram per day and V_2 is the volume of second stage in meter cube and F is the factor which we have already seen, if recirculation is there what is the F value and if recirculation is not there then what would be the F value.

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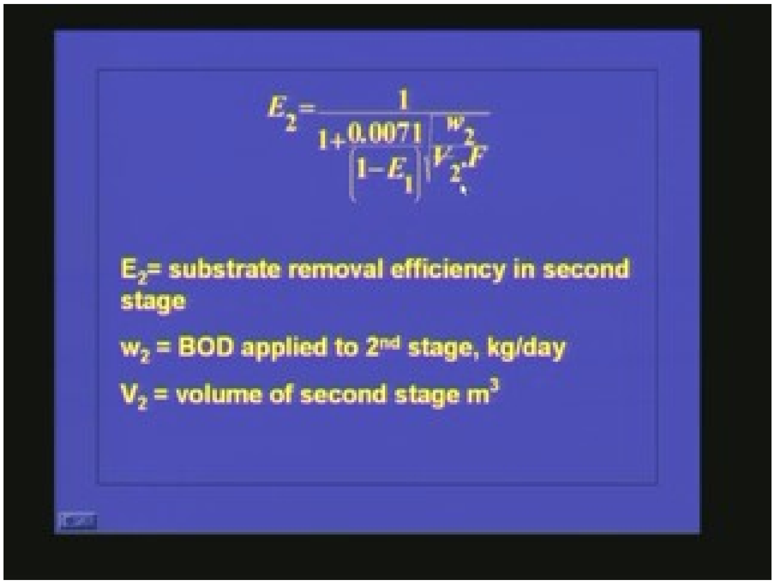

$$E_2 = \frac{1}{1 + \frac{0.0071}{(1-E_1)}\sqrt{\frac{w_2}{V_2 F}}}$$

E_2= substrate removal efficiency in second stage

w_2 = BOD applied to 2nd stage, kg/day

V_2 = volume of second stage m^3

So if we have a series of bio trickling filters we can find out E_1 E_2 E_3 like that and the total removal we can find out which will be the sum of the efficiency of 1, 2, 3 etc. The thing is we cannot just add of the efficiencies because the first one will be removing 80% so the concentration coming to the second system will be only 20% of the initial concentration and from that 20 of the initial 80% will be removed in the second one. So based upon that one we can find out what is the total efficiency. So depending upon what is the effluent quality requirement we can design whether we can go for a single stage bio trickling filter or we have to go for a series of bio trickling filter.

Nowadays people are not going for the standard rate bio trickling filter because the organic loading is limited and the hydraulic loading rate is limited. So if you want to reduce the volume of the bio trickling unit we have to have a very high hydraulic loading rate and an organic loading rate. So nowadays the bio-towers are coming up.

Bio-towers are nothing but deep trickling filters and here the attached medium whatever we are using is light weight modular media so we can go up to 12 m in height so bio-towers are nothing but a high rate bio-trickling filter with a height of 10 to 12 m.

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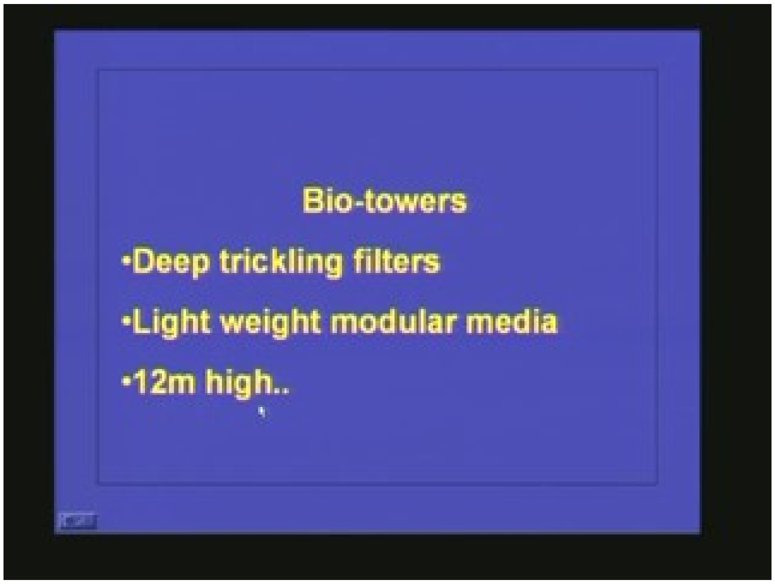

Bio-towers

- Deep trickling filters
- Light weight modular media
- 12m high..

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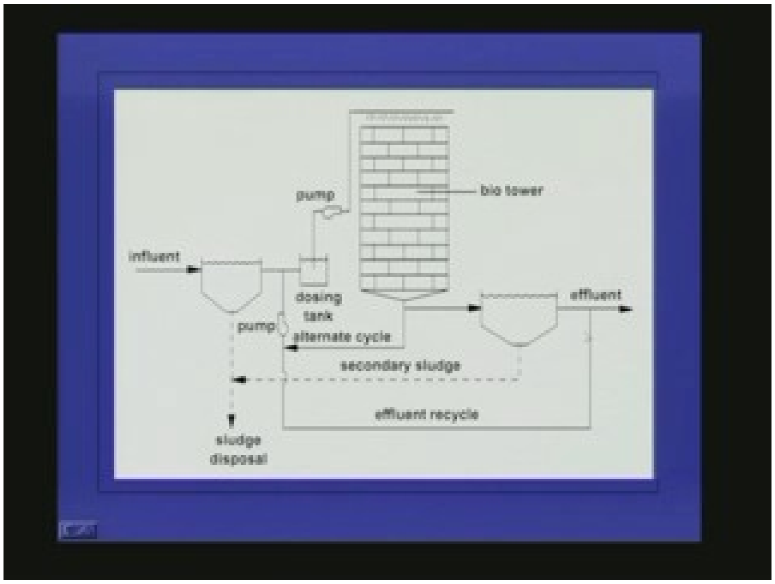

This shows a bio tower. Here we can see the influent coming and this is the primary clarifier so here all the suspended solids from the wastewater is being removed and here whatever wastewater is coming from the primary clarifier is pumped into the bio-tower. This is the bio tower so the treated water is collected here it is going to the secondary clarifier and the effluent is going out after the treatment. So we can have the recycling either from here so we can see the effluent recycling and here whatever is the sludge in the secondary clarifier that is collected along with the sludge from the primary clarifier and it is going for further treatment and if you don't want to have this type of a recycling

we can even have a recycling from here itself. Instead of increasing the secondary sedimentation time volume we can even have an alternative recycling from here.
All these depend on how we want to operate the system. But either this recycling or this recycling is not going to affect the performance of the system drastically.

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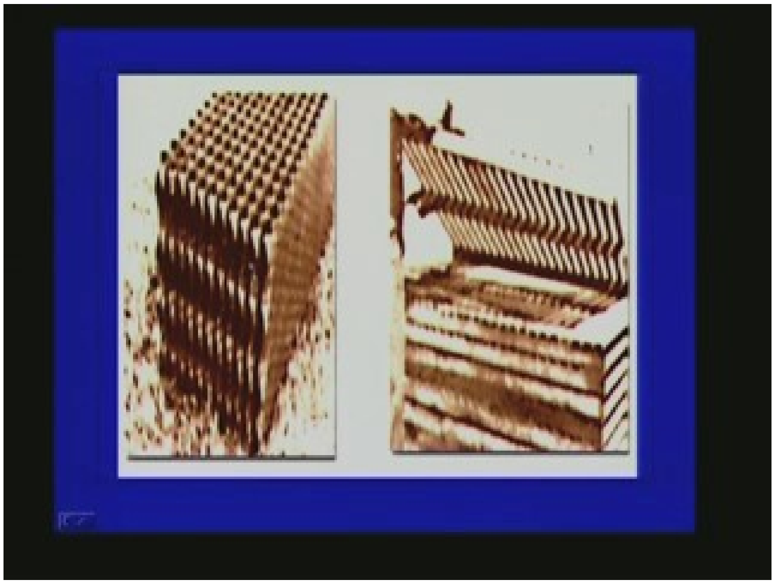

This figure shows the typically used synthetic medium which is serving after support media. Here you can see that it is a synthetic medium it is having lot of surface area for the growth of the microorganism. Here are the pores and it is running through the media. So the porosity of this medium will be around 90 to 95% of the total volume and the specific surface area is around 200 meter square per meter cube so you can imagine how much biomass this type of supporting media can hold.

Now we will see how to design these bio-towers. Usually it is being designed based upon Eckenfelder equation. So if you know what is the effluent quality we have to get from the bio-tower that means Se so this is depending upon the effluent discharge standard.

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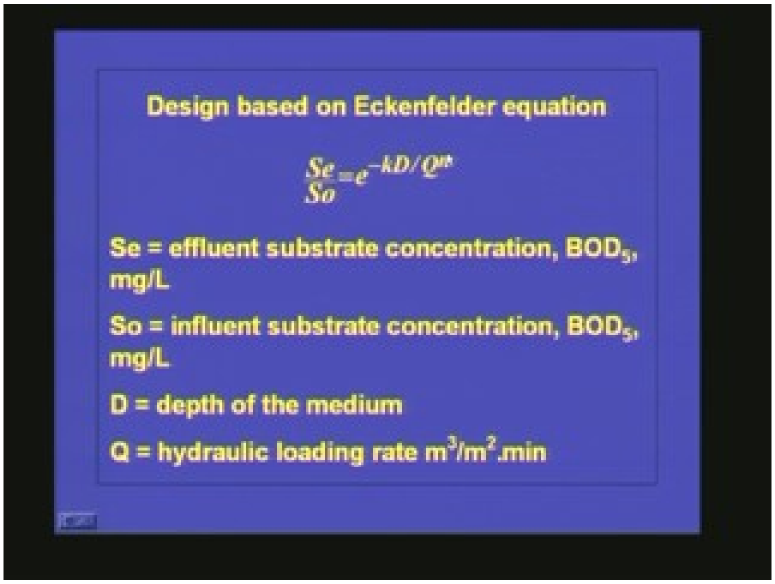

Design based on Eckenfelder equation

$$\frac{Se}{So} = e^{-kD/Q^n}$$

Se = effluent substrate concentration, BOD_5, mg/L

So = influent substrate concentration, BOD_5, mg/L

D = depth of the medium

Q = hydraulic loading rate m^3/m^2.min

And S0 is the ultimate BOD of the wastewater whatever is coming to the system so Se by S0 is nothing but e raised to minus K into D by Q raised to n where Se is the effluent substrate concentration either BOD5 or BODu in milligram per liter and S0 is the influent substrate concentration or BOD five in milligram per liter and D is the depth of the medium, Q is noting but the hydraulic loading rate that means meter cube per meter square per minute or you can put it in terms of days also depending upon the unit of this K value and K is nothing but treatability constant relating to the wastewater and the medium characteristics.

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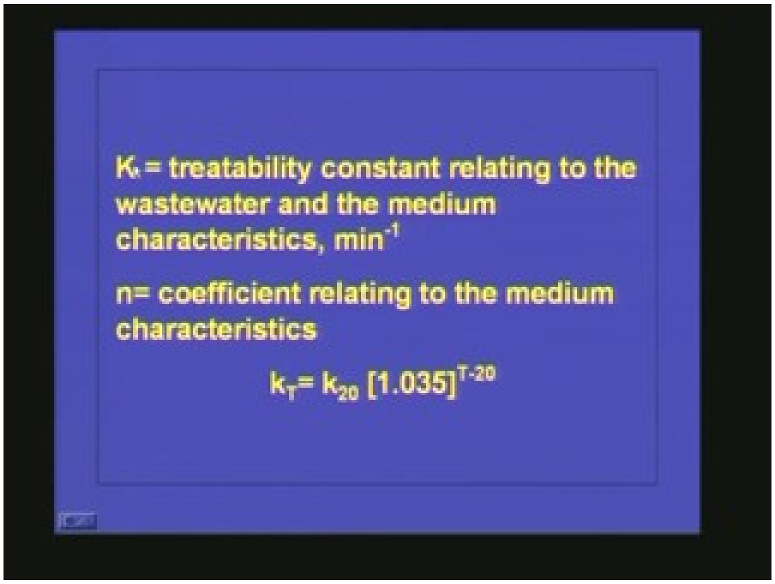

K_t = treatability constant relating to the wastewater and the medium characteristics, min^{-1}

n= coefficient relating to the medium characteristics

$$k_T = k_{20}\,[1.035]^{T-20}$$

Hence, this K will be taking care of the biomass concentration in the media as well as how efficient the biomass is to remove the organic matter present in the system. Or it will be taking care of the biomass concentration as well as the specific substrate utilization rate and ‘n’ is a coefficient related to the medium characteristics and this K value. That means the rate of substrate utilization is a function of temperature. So as the temperature increases this value also will be varying or as the temperature in this K value also will be increasing so we can find out KT at any temperature if you know the K value at 20 degree centigrade using this formula k 20 into 1.035 raised to T – 20 where T is the temperature or the operating condition temperature.

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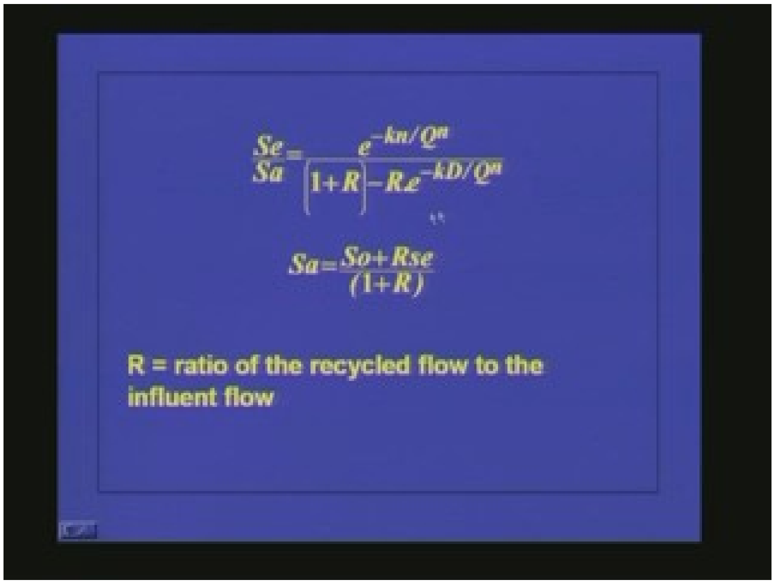

$$\frac{Se}{Sa} = \frac{e^{-kn/Q^n}}{\left(1+R\right) - Re^{-kD/Q^n}}$$

$$Sa = \frac{So + Rse}{(1+R)}$$

R = ratio of the recycled flow to the influent flow

And if we have a multiple unit or recirculation then we can find out what is the Se by Sa value. The first one is without recirculation and this is with recirculation (Refer Slide Time: 41:05) stating how the efficiency is that is equal to e raised to minus Kilo Newton per meter by Q raised to n divided by 1 plus R minus R into e raised to minus K into D by Q raised n. So this will be taking care of the recirculation, because of the recirculation what is the dilution coming into picture as well as how the biodegradability is reducing with each pass of the wastewater. And here Sa is nothing but S0 plus R into Se by 1 plus R because the loading are the total concentration of BOD going to the system will be different from whatever is coming in the based water because from sort of dilution will be taking place, that is what we are calculating here; Sa is, what is the applied BOD that is equal to S0 plus R into s e by 1 plus R where R is the ratio of the recycle flow to the influent flow.

Till now we were discussing about trickling filter. There are other attached flow systems also which is commonly used in wastewater treatment. Another one is rotating biological contactors.

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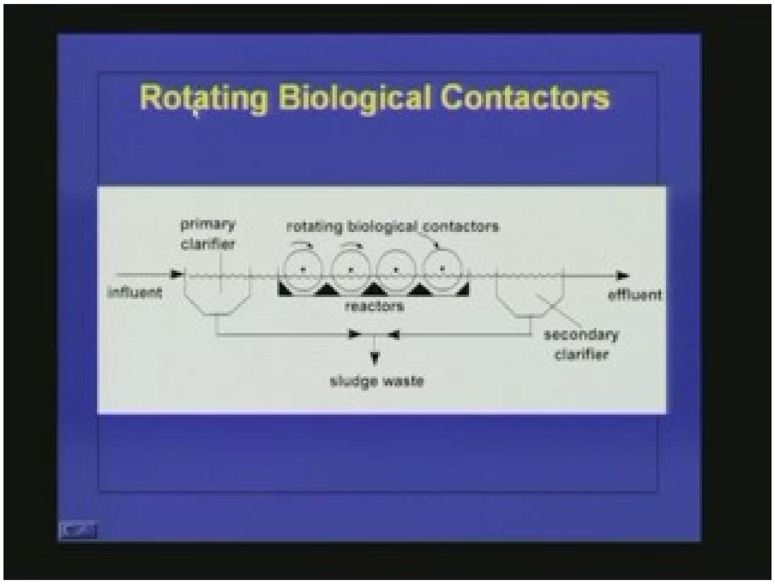

Rotating Biological Contactors

Here we will be having a series of this partially inversed in the wastewater and it will be rotating at a speed of 1 to 2 RPM because all the disks will be connected to a shaft and it will be rotating at a particular speed so with respect to time different portions of the disk will be getting exposed to air so oxygen will be available for the microorganisms for the removal of organic matter. This is the influent coming (Refer Slide Time: 42:56) and you have a primary clarifier, the wastewater from the primary clarifier is entering in the rotating biological contactors so a series of disks are arranged in a shaft. We can have a single shaft or we can provide a series of shafts also.

This is a four unit system, the wastewater will be flowing in this direction and this will be rotating in this direction and this is the water level so in this disk the microorganisms will be growing so only a portion of the disk will be exposed to the wastewater at a time and the remaining portion of the disk with biomass will be getting exposed to the atmosphere so there will be oxygen transfer so enough oxygen will be getting transferred to the microorganism for the degradation of the organic matter. Here also some biomass will be coming out so there is a secondary clarifier which removes the biomass whatever is coming along with the treated effluent and this is the treated effluent. This shows the clear photograph.

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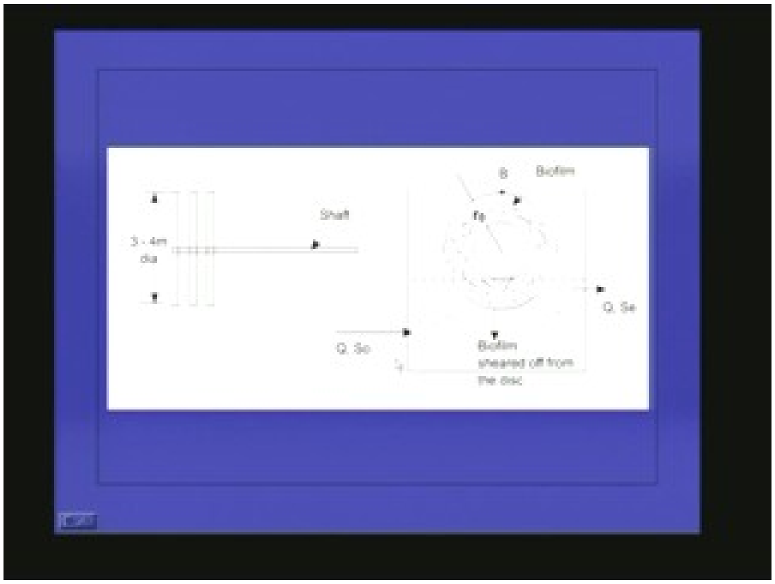

Now we will go into the details of the process. Thus, if you take a shaft so it is something like that and you will be having many disks attached to the shaft so there will be some spacing between these disks so a series of disks will be arranged like that. Usually the disk diameter will be varying from 3 to 4 m depending upon the wastewater flow rate and what is the capacity we need to design or if you want to take the other view we will get like this (Refer Slide Time: 44:36) this is the unit and the wastewater will be there up to this level that means around 40% of the disk will be immersed in the wastewater so a flow rate of Q is coming and S0 is the initial BOD of the wastewater and this is the center of the disk and this much portion will be immersed in the wastewater so naturally the biomass will be growing in this circle so this portion is not getting exposed to the wastewater so there will not be any growth of biomass so you will be getting a wing shaped biomass curve.

Here (Refer Slide Time: 45:20) also this is the wastewater so definitely because the option is getting transferred from the atmosphere to this wastewater some growth will be taking place in the suspended system also but the BOD removal or the organic matter removal in this suspended system will be much much negligible or much much less compared to the organic matter removal by the attached film. The reason is here we give very little residence time in the order of 20 to 30 minutes so the biomass will not be getting enough time for the removal of organic matter and finally the treated effluent is coming out Q into Sc. Here this B represents the biofilm. So, if you want to find out what is happening in the system ADC is the adsorption of substrate on biofilm.

Which is the ADC portion?
If you put here (Refer Slide Time: 46:18) this is B so we can put like this from here to here so the adsorption of the organic matter will be talking place in the biofilm because this portion is immersed in the wastewater.

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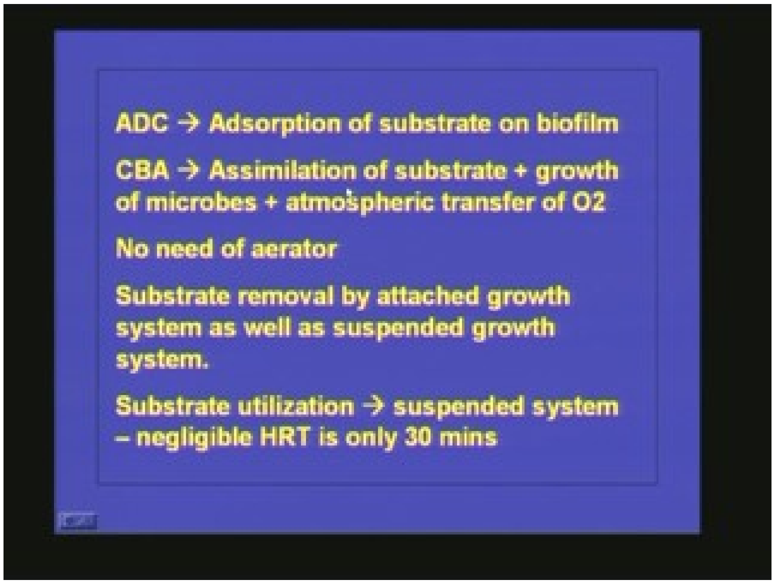

ADC → Adsorption of substrate on biofilm

CBA → Assimilation of substrate + growth of microbes + atmospheric transfer of O2

No need of aerator

Substrate removal by attached growth system as well as suspended growth system.

Substrate utilization → suspended system – negligible HRT is only 30 mins

CBA: CBA is this portion CBA so this is CBA (Refer Slide Time: 46:42) this is A, this is B and this is C so CBA the assimilation of the microorganism will be taking place as well as the oxygen transfer will be taking place here. So, ADC is adsorption of substrate on biofilm and CBA assimilation of substrate plus growth of microorganism plus atmospheric transfer of oxygen. So like that the biofilm will be growing and it will be removing the organic matter as well as more and more cells will be generated. Because of this process there is no need of any aeration.

Substrate removal by attached growth system as well as suspended growth system is taking place and substrate utilization by the suspended system is negligible, HRT is only 20 to 30 minutes.

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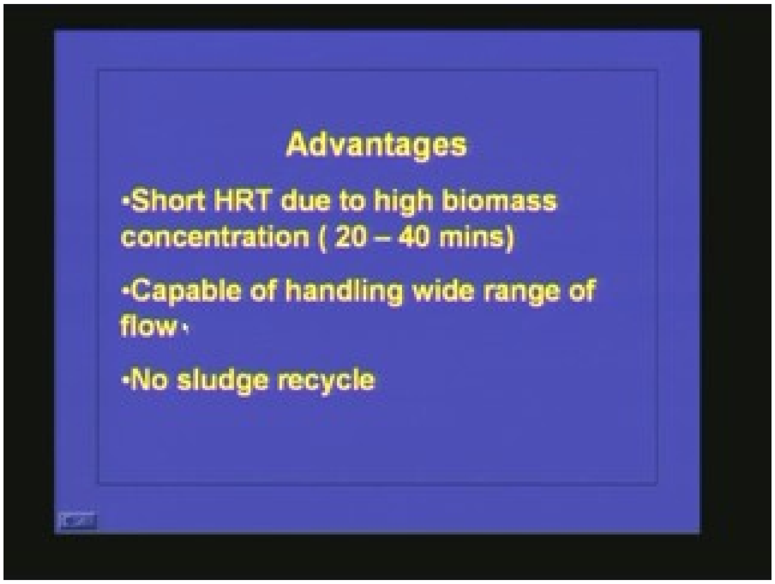

Advantages

- Short HRT due to high biomass concentration (20 – 40 mins)
- Capable of handling wide range of flow
- No sludge recycle

The advantages of this system are;

- Short HRT due to high biomass concentration 20 to 40 minutes and Capable of handling wide range of flow
- No sludge recycling is required and
- It is able to handle different types of loading

Now we will see how to do the design. This is the typical disk.

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Design Relationships

So you have seen that the biomass is growing only in this area and this Q is the flow rate, S0 is the initial BOD, Se is the effluent BOD and this is the biomass growing area. So if you want to make the mass balance how can we do it?
Net range of change in amount of substrate within the reactor is equal to rate at which the substrate enters the reactor minus rate at which substrate disappears from the reactor.

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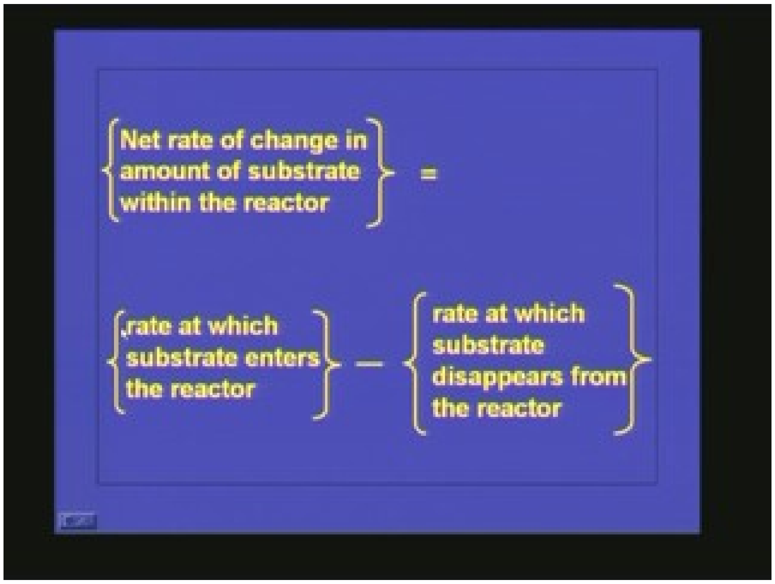

$$\left\{\begin{matrix}\text{Net rate of change in}\\ \text{amount of substrate}\\ \text{within the reactor}\end{matrix}\right\} =$$

$$\left\{\begin{matrix}\text{rate at which}\\ \text{substrate enters}\\ \text{the reactor}\end{matrix}\right\} - \left\{\begin{matrix}\text{rate at which}\\ \text{substrate}\\ \text{disappears from}\\ \text{the reactor}\end{matrix}\right\}$$

So how can we find out the rate at which the substrate is entering into the system and rate at which the substrate is being removed from the system. The rate at which substrate is entering in the system is nothing but Q into S0 where Q is the flow rate and S0 is the initial BOD of the wastewater and how the substrate is getting removed from the system is equal to ds by dt uA into VA plus ds dt us into Vs plus Q into Se.

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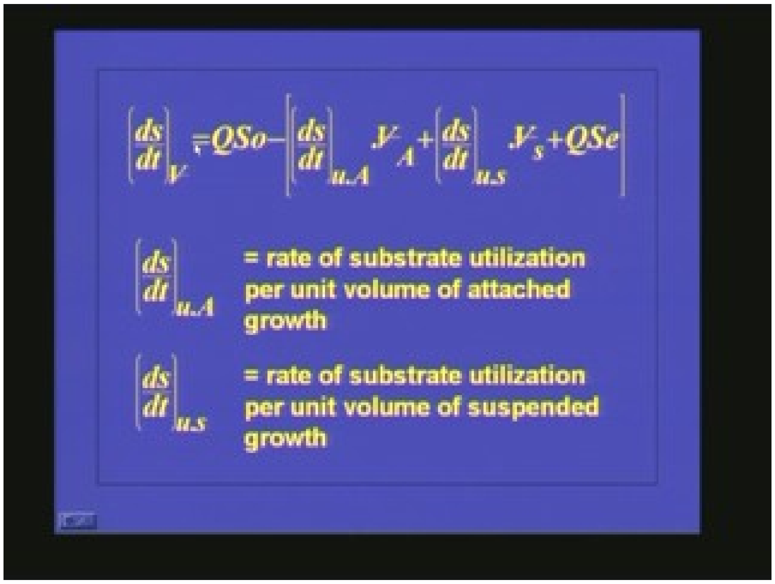

$$\left(\frac{ds}{dt}\right)_V = QSo - \left[\left(\frac{ds}{dt}\right)_{u.A} V_A + \left(\frac{ds}{dt}\right)_{u.s} V_s + QSe\right]$$

$\left(\frac{ds}{dt}\right)_{u.A}$ = rate of substrate utilization per unit volume of attached growth

$\left(\frac{ds}{dt}\right)_{u.s}$ = rate of substrate utilization per unit volume of suspended growth

So this is the substrate utilized by the attached growth microorganism so it is the organic matter whatever is removed by the attached growth system and this is the biomass, this is the substrate whatever is utilized by the suspended growth system and Vs is the volume of the suspended growing system, VA is the volume of the attached growing system and Q into Se Q is the flow rate S is the effluent BOD. That is what I have given here above; ds by dt uA rate of substrate utilization per unit volume of attached growth and ds by dt u S rate of substrate utilization per unit volume of suspended growth and VA volume of active attached biological growth, Vs liquid volume of reactor, S_0 influent substrate concentration and Se effluent substrate concentration.

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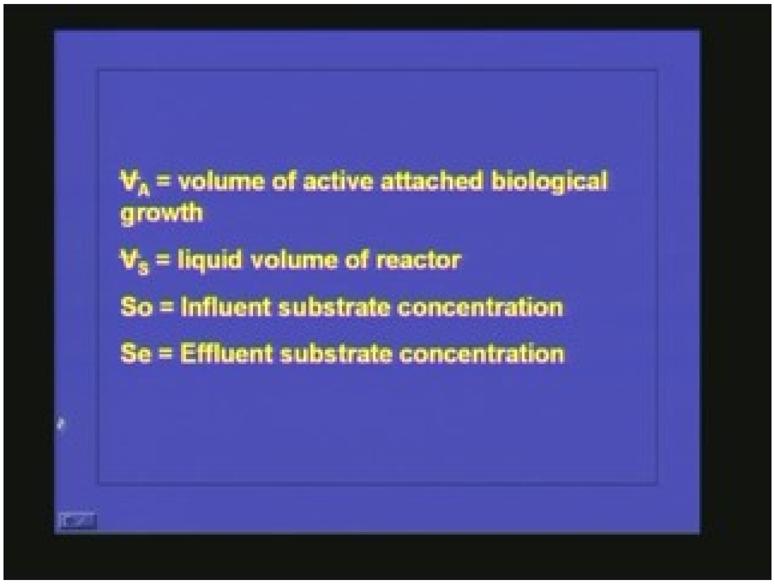

V_A = volume of active attached biological growth

V_S = liquid volume of reactor

So = Influent substrate concentration

Se = Effluent substrate concentration

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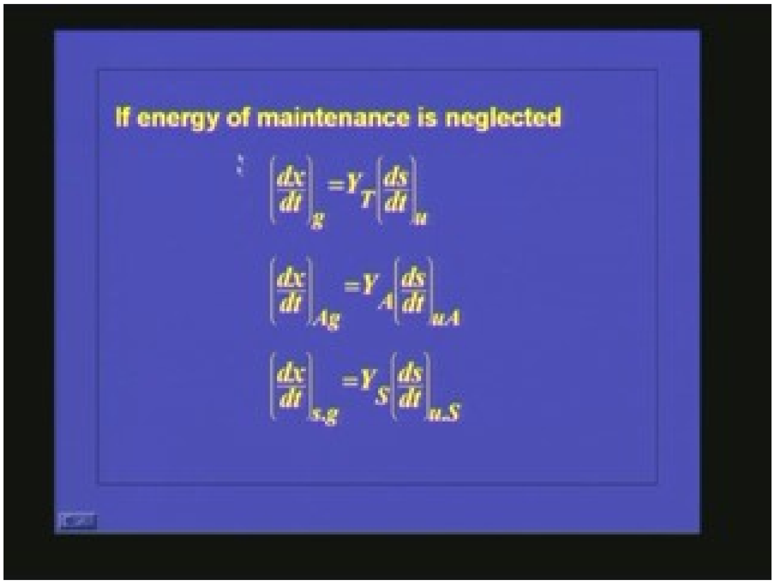

If energy of maintenance is neglected

$$\left(\frac{dx}{dt}\right)_g = Y_T\left(\frac{ds}{dt}\right)_u$$

$$\left(\frac{dx}{dt}\right)_{Ag} = Y_A\left(\frac{ds}{dt}\right)_{uA}$$

$$\left(\frac{dx}{dt}\right)_{s.g} = Y_S\left(\frac{ds}{dt}\right)_{u.S}$$

And if energy of maintenance is neglected so we are assuming that no energy is used for the maintenance then we can write like this dx by dt. That means the rate of change in biomass concentration is equal to Y_T into ds by dt u that means yield coefficient into rate of change of substrate concentration so we can find out what is the rate of change of biomass in attached growth system and what is the rate of change of substrate in suspended growth system. One is Y_A into ds by dt uA and Y_S into ds by dt uS and we have seen that dx by dt is absolute growth rate of attached biomass and Y_A is theoretical yield coefficient.

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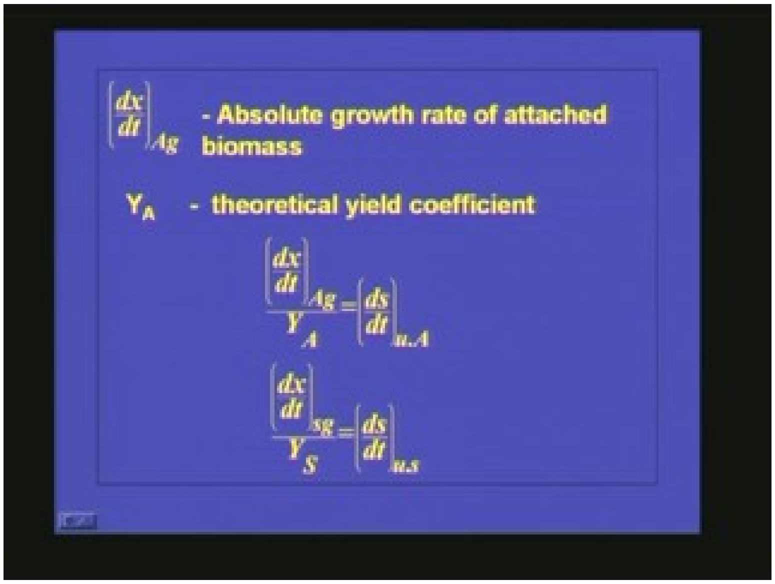

$\left(\frac{dx}{dt}\right)_{Ag}$ **- Absolute growth rate of attached biomass**

Y_A - theoretical yield coefficient

$$\frac{\left(\frac{dx}{dt}\right)_{Ag}}{Y_A} = \left(\frac{ds}{dt}\right)_{u.A}$$

$$\frac{\left(\frac{dx}{dt}\right)_{sg}}{Y_S} = \left(\frac{ds}{dt}\right)_{u.s}$$

Now we can write like this; dx by dt by Y_A is ds by dt uA and dx by dt sg by Y_S equal to ds by dt us it is just readjusting the equation. And if you divide both by X_f that means biomass concentration in the fixed film dx by dt into X_f by X_f by Y_A this term d_X by dt by X_f we have already seen that we can replace specific growth rate by mu A and this X_f will be coming here by Y_A which is nothing but dx by dt, we are rearranging the terms. Similarly here also if we divide by Xs and multiply by X_s we will be getting mu s into X_s by Y_s which is equal to ds by dt into us where X_f is the active biomass per unit volume of attached growth and X_s is active biomass per unit volume of suspended growth system.

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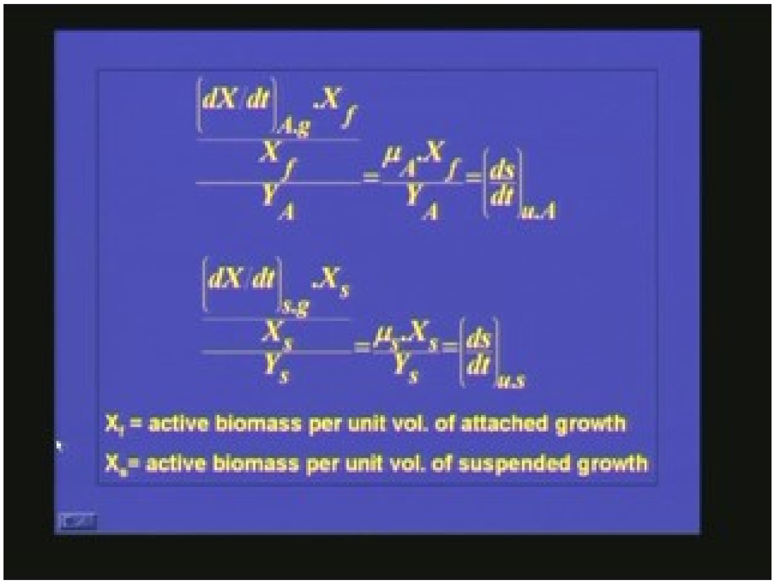

$$\frac{\dfrac{\left(dX/dt\right)_{A.g} . X_f}{X_f}}{Y_A} = \frac{\mu_A . X_f}{Y_A} = \left(\frac{ds}{dt}\right)_{u.A}$$

$$\frac{\dfrac{\left(dX/dt\right)_{s.g} . X_s}{X_s}}{Y_s} = \frac{\mu_s . X_s}{Y_s} = \left(\frac{ds}{dt}\right)_{u.s}$$

X_f = active biomass per unit vol. of attached growth

X_s = active biomass per unit vol. of suspended growth

So your final equation will come like this; ds by dt in the total reactor is equal to Q into S0 that is coming in minus Q into Se this is going out minus mu A into X_f by Y_A into V_A – mu s into X_s by Y_s into V_s so this is the substrate utilized by the attached growth system and the substrate utilized by the suspend growth system.

Now we will find out what V_A is. How can we find out the V_A?

We have to find out the area on which the biomass is growing, A is nothing but 2 into N, N is the number of disk into pi into r_0 square minus r_u square where this r_u is the area which is not exposed to the wastewater, that is what I have written here; N is number of disks, r_0 is the total disk radius, r_u is the un-submerged disk radius so you will be getting total area on which the biomass is growing.

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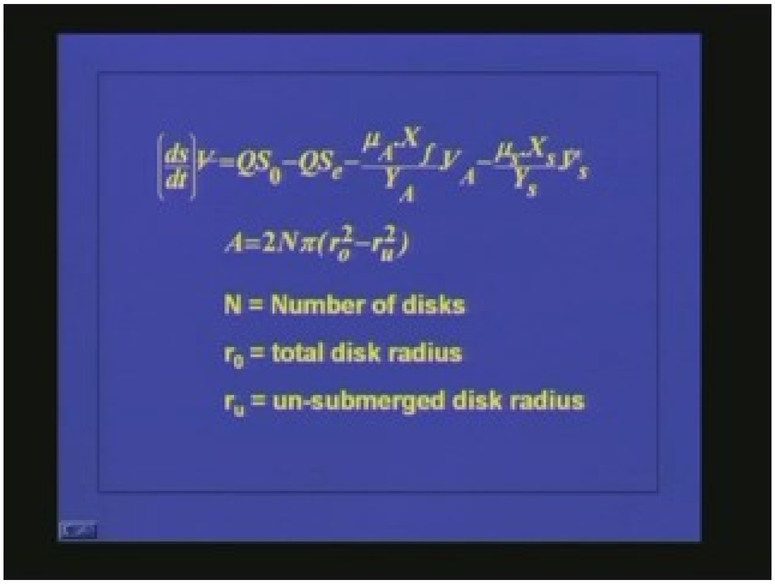

$$\left(\frac{ds}{dt}\right)V = QS_0 - QS_e - \frac{\mu_A.X}{Y_A} f V_A - \frac{\mu_s.X_s}{Y_s} V_s$$

$$A = 2N\pi(r_o^2 - r_u^2)$$

N = Number of disks

r_0 = total disk radius

r_u = un-submerged disk radius

If you know the thickness of the biomass we will be getting the volume which is what I have written here and at steady state the net change of biomass concentration of sustained concentration is zero. So we can write like this; this is the steady state condition Q into S0 minus Q into Se minus mu A into X into Y_A into this is D the thickness of the biomass into total area minus this is the biomass concentration or the substrate removal because of the attached growth where V is the liquid volume of the reactor and we also know that mu is equal to mu max S by Ks plus S.

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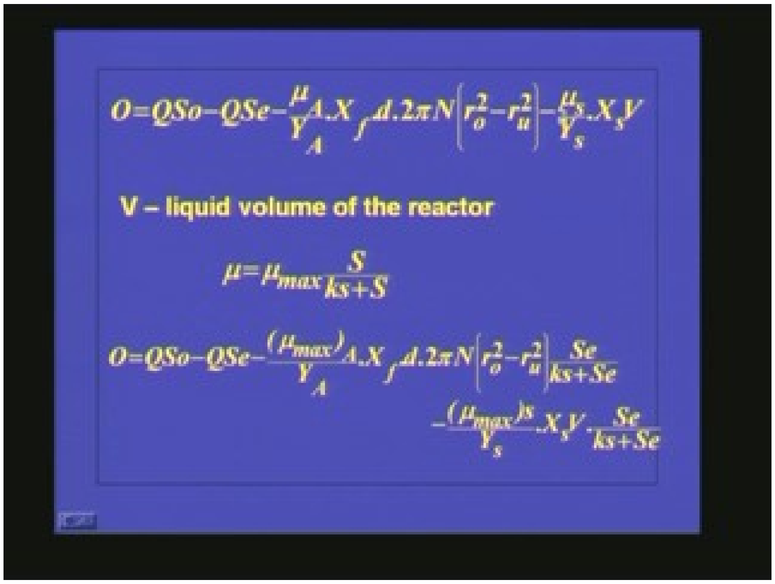

$$O = QSo - QSe - \frac{\mu_A}{Y_A}.X_f.d.2\pi N\left(r_o^2 - r_u^2\right) - \frac{\mu_s}{Y_s}.X_s V$$

V – liquid volume of the reactor

$$\mu = \mu_{max}\frac{S}{ks+S}$$

$$O = QSo - QSe - \frac{(\mu_{max})_A}{Y_A}.X_f.d.2\pi N\left(r_o^2 - r_u^2\right)\frac{Se}{ks+Se} - \frac{(\mu_{max})_s}{Y_s}.X_s V.\frac{Se}{ks+Se}$$

S is nothing but Se as written Q into S0 minus Q into Se into mu max A X_f d 2piN into r_0 square minus r_u squared into Se by Kx plus Se and we are leaving the other term as it is. So here we are neglecting the contribution by the suspended growth system because we have already seen that, in the suspended growth system the time available is very very less so the removal will be very very less.

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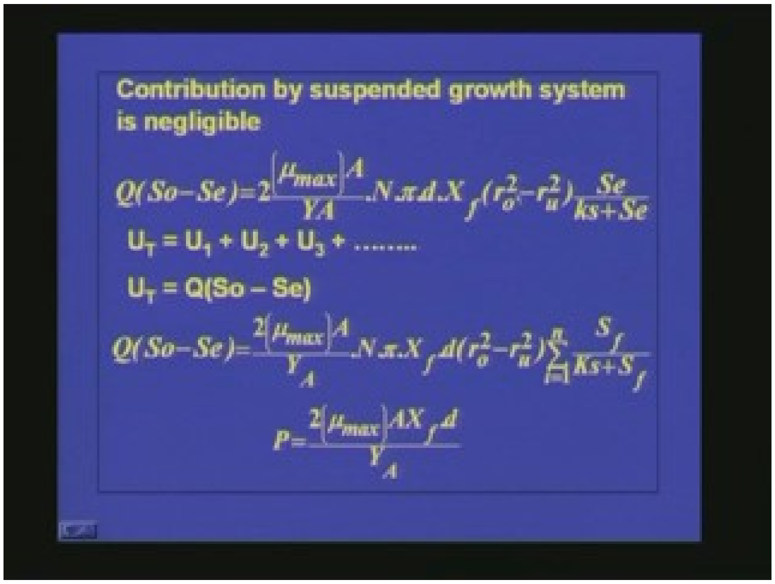

Contribution by suspended growth system is negligible

$$Q(So-Se)=2\frac{(\mu_{max})A}{YA}.N.\pi.d.X_f(r_o^2-r_u^2)\frac{Se}{ks+Se}$$

$$U_T = U_1 + U_2 + U_3 + \ldots\ldots$$

$$U_T = Q(So - Se)$$

$$Q(So-Se)=\frac{2(\mu_{max})A}{Y_A}.N.\pi.X_f.d(r_o^2-r_u^2)\sum_{i=1}^{n}\frac{S_f}{Ks+S_f}$$

$$P=\frac{2(\mu_{max})AX_f d}{Y_A}$$

So, if you want to find out what is the BOD removed that is equal to Q into S0 minus Se that will be equal to 2 into mu max into area by Y_A into N into pi into dX S_f r_0 square minus r_u square into Se by Ks plus Se. And you know that this Se is very very negligible so you will be getting the equation like this and we can replace this entire term with a constant P which is equal to 2 into mu max A into X_f into d by Y_A. So this will be depending upon the rotating bio filter and this will be a parameter decided by the system. So if you replace all these parameters with a factor P it will be taking care of total area on which the biomass is growing, the thickness then Y_A and mu max are the constants.

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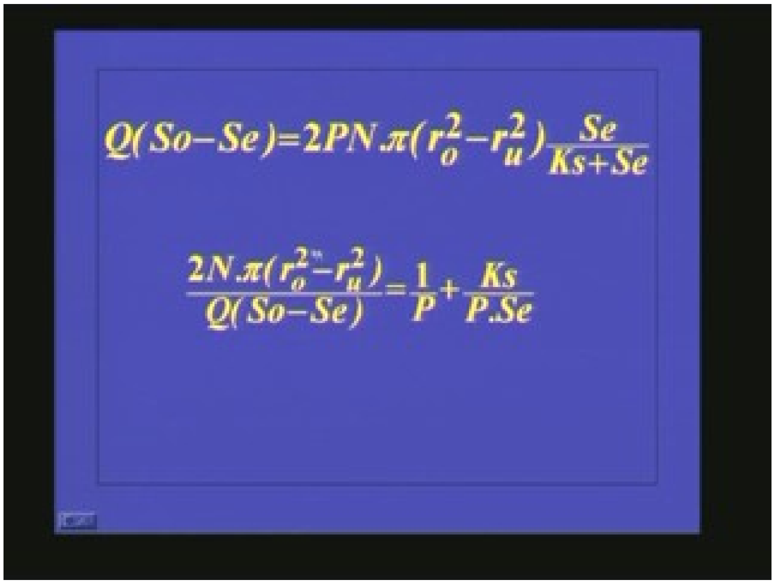
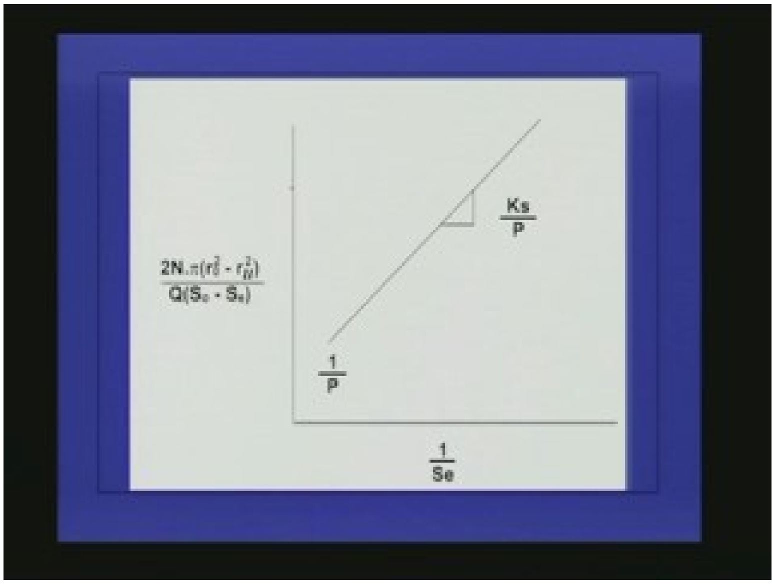


$$Q(So-Se)=2PN.\pi(r_o^2-r_u^2)\frac{Se}{Ks+Se}$$

$$\frac{2N.\pi(r_o^2-r_u^2)}{Q(So-Se)}=\frac{1}{P}+\frac{Ks}{P.Se}$$

Then we will be getting the equation like this; Q into S0 minus Se that means the total organic matter removed from the system is equal to Q into P into N into pi into r square r_0 square minus r_u square into Se by Ks plus Se or we can write like this (Refer Slide Time: 55:15) take this term this side and take the inverse then 1 by P plus KS P into Se is equal to 2N into pi r_0 square minus r_u square by Q into S0 minus Se.

(Refer Slide Time: 55:39 min)



So if you want to find out the P value for a system we can do some large experiments in the law and we can find out this is 1 by Se and this term is equal to 2 into N number of disks into pi into r_0 square minus Re square into Q into S0 minus Se all these terms are known to us. Then if you flow this one we will be getting a line like this so this one will be giving you 1 by P and this one will give you Ks by P so from this one we can find out what is the half saturation constant and what the P value of the system is. This is the way we usually design the rotating biological contactors. So we will know the biokinetic parameters so using the biokinetic parameters we can find out what is the BOD removal the system can have so based upon that one we can find out the number of disks we can provide so either you provide the disk in a series or provide a series of disks so that is the rotating biological filter. Nowadays active bio filters are also being used that is the combination of RBC plus activated sludge process that will be improving the efficiency considerably.

Therefore, we have talked about attached growth systems which is commonly used in wastewater treatment processes, one is trickling filter and in trickling filter itself we can go for high rate trickling filters and standard rate trickling filters and RBC we have seen how to design and nowadays activated RBCs are being used, it is a combination of rotating biological filters as well as activated sludge process. In the next class we will discuss about anaerobic process.