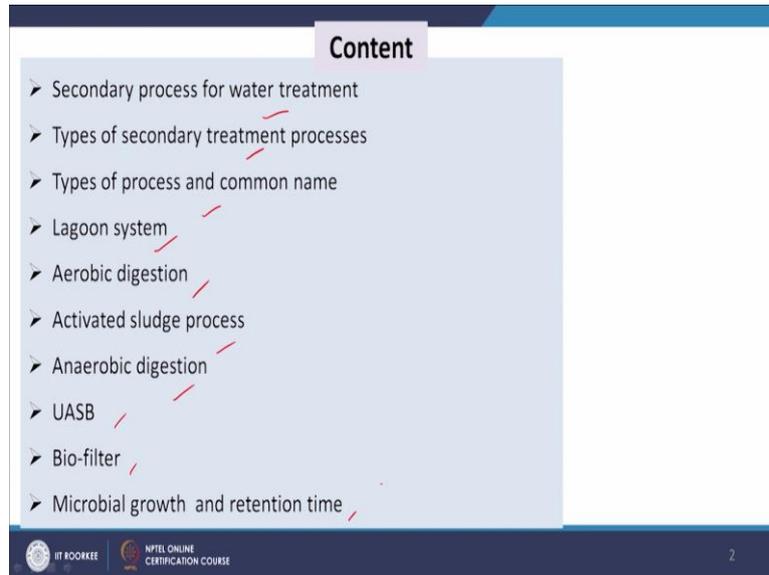


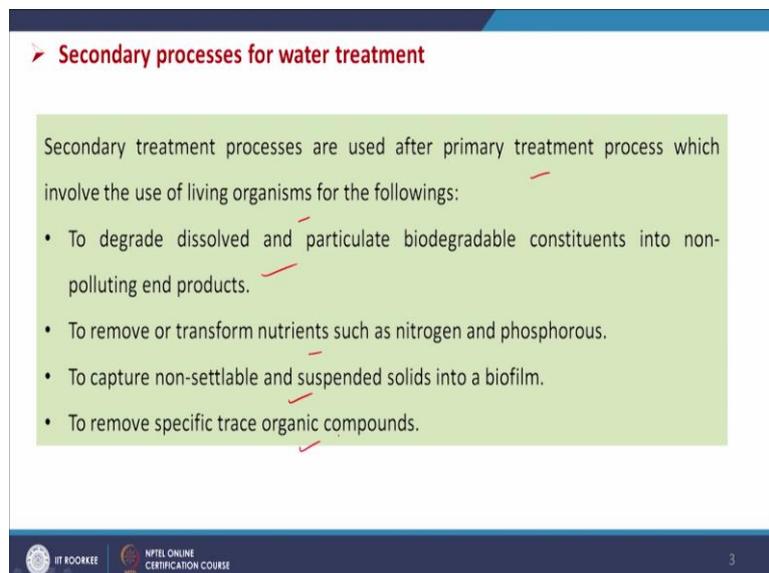
Basic Environmental Engineering and Pollution Abatement
Professor Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology, Roorkee
Lecture: 29
Secondary Treatment Processes

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Hello, everyone. Now, we will discuss on the topic secondary treatment processes. And, we will discuss in this class on secondary process for water treatment, types of secondary treatment processes, types of process and common name, lagoon system, aerobic digestion, activated sludge process, anaerobic digestion, UASB, bio-filter and microbial growth and retention time.

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Now, we will see what its secondary process? Already, we have discussed in the previous class that after primary treatment, the wastewater enters into the aeration chamber and we add microbial biomass, microbial seeds or we add microbes and then we get the conversion of organic compound and those are degraded in this secondary treatment step. And different types of living organisms can be used including bacteria, yeast, etc. Even plants and micro algae's can also be used.

So, secondary treatment processes are used after primary treatment process, which involves the use of living organisms for the following purpose that is to degrade dissolved and particulate biodegradable constituents into non-polluting end products. To remove or transform nutrients such as nitrogen and phosphorus and to capture non-settable and suspended solids into a biofilm and to remove specific trace organic compounds.

So, this is the major objective of the secondary process. And there are a number of types, we can classify this process into different types. So, based on air requirement, this can be aerobic process or anaerobic process.

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The slide is titled "Types of secondary treatment processes" and is divided into a section titled "Types based on air requirement". It lists two types of processes:

- Aerobic Process:** Takes place in the presence of air and utilize aerobic microorganisms, which use molecular/free oxygen to assimilate organic impurities i.e., convert them into carbon dioxide, water and biomass.
- Anaerobic Process:** Take place in the absence of air (molecular/free oxygen) by anaerobic microorganisms which do not require air (molecular/free oxygen) to assimilate organic impurities. The final products of organic assimilation in anaerobic treatment are methane and carbon dioxide gas and biomass.

The slide footer includes the logos for IIT Kharagpur and NPTEL Online Certification Course, along with the number 4.

And in aerobic process, this process takes place in presence of air and utilize aerobic microorganisms, which use molecular or free oxygen to assimilate organic impurities, that is convert them into carbon dioxide, water and biomass. whereas in anaerobic process, this process take place in the absence of air by the anaerobic microorganisms, which do not require air or oxygen to assimilate organic impurities. The final products of organic

assimilation in anaerobic treatment are methane and carbon dioxide gas and biomass. So, these are the basic two types.

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The slide is titled "Types of secondary treatment processes contd..". It is divided into two main sections:

- Types of living organisms used** (green box):
 - Phytoremediation
 - Biological treatment with microbes
 - Type of microbes
 - Bacteria ✓
 - Fungi ✓
 - Algae ✓
 - Yeast ✓

- Microbial growth types** (orange box):
- Suspended growth process
- Attached growth process

Below these sections, a text box states: "Out of these, bacteria has been extensively used either in pure form or mixed with other microorganisms".

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And, if we see the type of living organisms we are using, on that basis, it can be Hydro-remediation, where plant species is used and it can be Phytoremediation, where algae is used or it can be bacterial process. So, biological treatment with microbes like say types of microbes, maybe bacteria, fungi, algae, yeast also.

And when we will be using the microorganisms, because if we use bacteria, it will be more preferable, its performance is better with respect to other methods. So, in that case, the microorganisms may be in suspended form or maybe in attached growth process. It can be attached on some material and that is called attached growth process.

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➤ Types of secondary treatment processes contd..

Conventional treatment options	Advanced treatment options
<ul style="list-style-type: none">• Lagoons ✓• Aerobic digestion ✓• Activated sludge process ✓• Anaerobic digestion ✓• UASB ✓• Bio-filters ✓	<ul style="list-style-type: none">• Granular activated sludge process ✓• Sequential batch reactor ✓• Membrane bioreactor ✓• Phycoremediation ✓• Phytoremediation ✓• Bio-electrochemical system(BES) ✓ /Microbial electrochemical cells(MXCs) ✓

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Now, we will see different conventional methods which are used in wastewater treatment like say, lagoon system, very simple one and then, aerobic digestion, activated sludge process, anaerobic digestion, UASB, up flow, anaerobic sludge blanket reactor and bio filter. So, these are the very commonly used methods as a secondary step for water treatment.

And apart from these, there are some advancement in the secondary processes also, those are granular activated sludge process and sequential batch reactor, these two are the improved versions of the activated sludge process. And then, membrane bioreactor and phytoremediation and phycoremediation and bio-electrochemical systems or microbial electrochemical cells. So, these are the some latest development in the wastewater treatment as a secondary treatment step and we will discuss all these steps in a few classes.

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➤ **Types of process and common name**

Type	Common name
Aerobic processes	
Suspended growth ✓	Activated sludge processes ✓
	Aerated lagoons ✓
	Stabilization ponds ✓
	Aerobic digestion ✓
Attached growth ✓	Trickling filters ✓
	Rotating biological contactors ✓
	Packed bed reactors ✓
Hybrid (suspended + attached growth)	Trickling filters/activated sludge ✓

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Now, we will see types of process and their common names. So, if we go for aerobic process so, that may be suspended or maybe attached growth as you have discussed and for suspended growth different names are activated sludge process, aerated lagoons, stabilization ponds, aerobic digestion.

And in case of attached growth, we may see trickling filters, rotating biological contactors, packed bed reactors. So, they are very common names but the process are basically under these two categories. Then there are some hybrid processes like suspended plus attached growth maybe and trickling filters and activated sludge.

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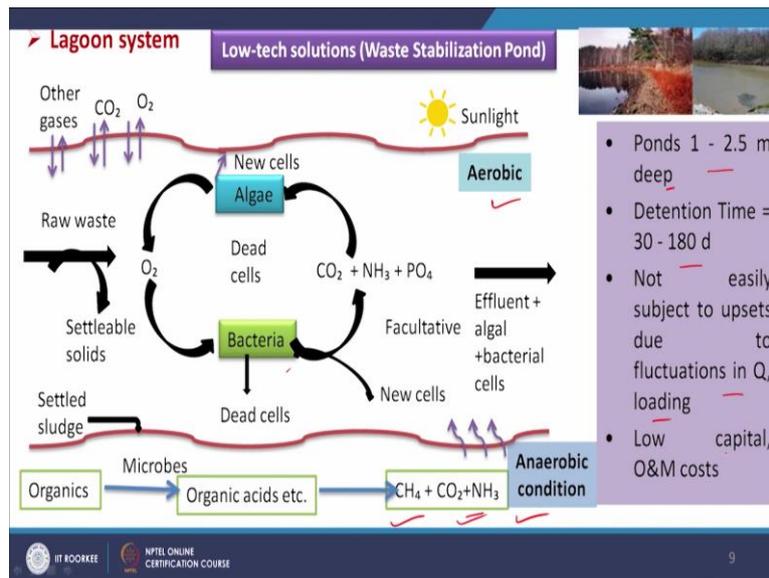
➤ **Types of process and common name contd..**

Type	Common name
Anaerobic Process	
Suspended Growth ✓	Anaerobic contact process ✓
	Anaerobic digestion ✓
Attached Growth ✓	Anaerobic packed or fluidized bed ✓
Sludge Blanket ✓	Upflow Anaerobic sludge blanket ✓
Lagoon Processes	
Aerobic Lagoon	Aerobic lagoon ✓
Maturation Lagoon	Maturation lagoon ✓
Facultative Lagoons	Facultative lagoon ✓
Anaerobic Lagoon	Anaerobic lagoon ✓

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And, anaerobic process maybe again suspended growth or attached growth and sludge blanket type and the common names are anaerobic contact process, anaerobic digestion, anaerobic packed or fluidized bed and upflow anaerobic sludge blanket that is UASB. And, lagoon different processes are also having the same common name like say aerobic lagoon, maturation lagoon, facultative lagoon and anaerobic lagoon. Some lagoons are also aerated in some time, we will discuss that also.

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Now, this is a lagoon system. So, this is a low technology solution and very simple one, in this case, in the water microbes are present, algae are also present. So, algae will take the sunlight and they will produce food and they will produce oxygen. So, oxygen will be available in the water and oxygen also will be diffused from the atmosphere to the water through its surface.

So, there is a two major source of oxygen in it, in the water, one is to the diffusion from air to this water and another is from the algae. So, when algal cell will grow oxygen will be available. So, at the top layer, it will be in aerobic zone and at the bottom layer of the lagoon, then we will see there is no oxygen. So, that will be anaerobic zone completely and in between we will be having oxygen and carbon dioxide both so, that may be termed as a facultative zone.

Now, this is the lagoon system. So, both aerobic, anaerobic and facultative reactions can be possible. And in this case, say microbial cells which are grown at the top layer, so at the bottom layer that will be after their death that will be decomposed also. So, from the bottom

part, methane, carbon dioxide and ammonia will be produced and from the top part oxygen is being produced. So, that way different types of phenomena will be going on and this ammonia and phosphates which are produced here that will also be captured by this algal mass.

So, these type of different types of reactions will be going on in the lagoon system and the organic compounds will be degraded. How this organic compound will be degraded? Because apart from this bacteria will also work on it. Again, some algae are also there, they can take the organic as their food when light is not available. So, in pond systems that is 1 to 2.5 meter deep, we see and detention time is 30 to 180 day and not easily subject to upsets due to fluctuation in flow rate and low capital operation and maintenance costs.

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➤ Lagoon system contd..

Type	Aerated aerobic ✓ (h: 0.4 and 7.5 m)	Aerated facultative	Aerobic facultative (h: 0.6 and 1.5 m)	Aerobic ✓
Description	Aeration of pond accomplished by use of mechanical oxygen diffusers: sedimentation facilities required	Uses only surface aerators: some anaerobic decomposition takes place in sediments at the pond bottom	Oxygen supply provided at surface by algae and surface mixing by wind; some anaerobic activity in bottom sediments	Shallow ponds where algae provide oxygen to maintain aerobic conditions in pond
Advantages	<ul style="list-style-type: none"> • Relatively small volume/land area required • Odor-free • High degree of treatment 	<ul style="list-style-type: none"> • Relatively small volume/land required • Relatively odor-free • High degree of treatment 	<ul style="list-style-type: none"> • Low O & M cost • High degree of treatment 	Low O & M cost

h: average depth

Source: Adapted from National Association of Towns and Townships (1989)

Now, we will see different types of the lagoon system, we can get. One is your aerobic and another is your aerated aerobic. Aerobic means, as I mentioned the lagoon at that top part we are expecting that oxygen will be available. So, it may be possible that oxygen is available by the microalgae available in the water and to the diffusion to the surface of the water body.

So, in that case, we will be terming it as aerobic but when we will be providing some additional oxygen so, that is aerated aerobic, that will be aerobic but additionally some oxygen is provided. So, aeration of pond accomplished by use of mechanical oxygen diffusers so, in that case, we will be terming it as aerated aerobic. And aerated facultative that uses only surface aerators, some anaerobic decomposition takes place in sediments at the pond bottom.

That means, when we are providing additional oxygen that can, it is possible that we are providing the oxygen throughout the depth or it may be possible we are providing oxygen only at the upper layer but not at the bottom layer out. In that case we will be getting a aerated facultative.

Similarly, for aerobic facultative and aerobic both condition will get, when we will not be providing any additional oxygen by mechanical means, but the algae present in the water those will be giving some amount of oxygen to the water as a ledge by natural process air from air oxygen will be diffused to the surface of the water. So, in that case, oxygen supply provided at surface by algae and surface mixing by wind so, some anaerobic activity in bottom sediments.

So, basically four types of situations we are getting and which phenomena is prevailing that will depend upon the depth and if depth is very less suddenly we will get the aerobic conditions, anaerobic area will be less but depth is more than more anaerobic area will be increased.

So, we can get facultative in that case and all these are having some advantages like say relatively small volume, land area required and odor free, high degree of treatment in case of aerated aerobic and for aerobic as oxygen is relatively less with respect to aerated aerobic it is operation and maintenance cost is less.

But performance may be lower and aerobic facultative low operating and maintenance costs, high degree of treatment and for aerated facultative relatively small volume or land required and relatively odor free, high degree of treatment. So, these are some characteristics of this type.

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➤ Lagoon system contd..

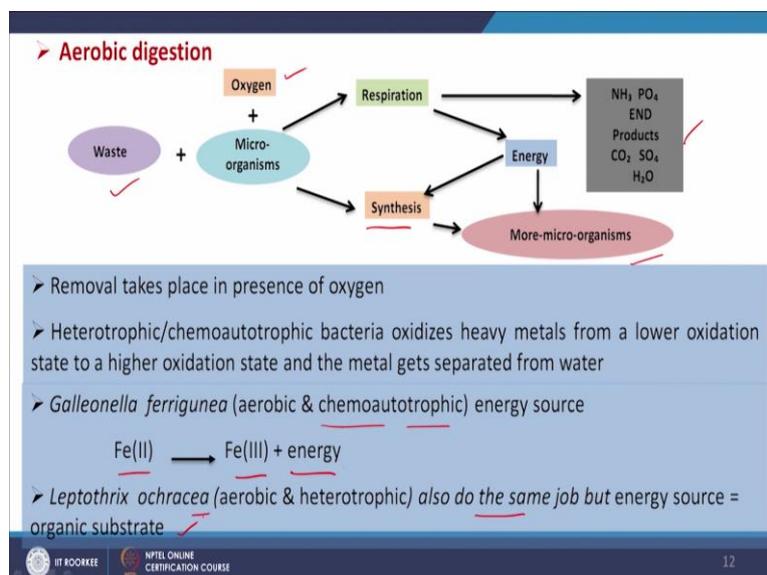
Type	Aerated aerobic (h: 0.4 and 7.5 m)	Aerated facultative	Aerobic facultative (h: 0.6 and 1.5 m)	Aerobic
Disadvantages	High O & M cost of any pond system	Substantial O & M cost	• Large volume and land area required • Possible odors	Large volume and land area required Possible odors
Labor	Maintain aerators: sludge removal	Minimal	Minimal	Minimal
Energy	Moderate	Low (for aerators)	None	None
Degree of complexity	Moderate: limited amounts of skill for equipment maintenance	Simple; no skilled labor required	Simple; no skilled labor required	Simple; no skilled labor required
Residuals	Sludge	Sludge removal once every 10 to 20 years	Sludge removal once every 10 to 20 years	Algae cell

Source: Adapted from National Association of Towns and Townships (1989)

Apart from that, we can get some disadvantages for all these type of systems. As mentioned here, like in case of aerated aerobic, it is high operation and maintenance cost of any pond system. And in case of aerobic it requires large volume and the land area with respect to aerated aerobic.

So, there will be some optimal scope for optimization and labour requirement is also different for different type of lagoon system, energy requirement is also different. So, suddenly, when we are going for aeration, additional aeration, the energy cost will be more and degree of complexity will also be more when we are going to send the compressed air at the bottom of the lagoon and residuals will also be different, as mentioned here for different cases.

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Now, we will discuss aerobic digestion. So, as the term indicates oxygen will be available. So, there will be oxygen and waste, microorganisms will work on it and their biomass will grow synthesis and then those biomass will be grown. So, more microorganisms will be getting and there will be some respirations and through the respiration some other elements will be produced. So, this is a reactions, different types of steps which occurs in case of aerobic digestion.

Now, as you know that in presence of oxygen, some microbes are present, those can oxidize some metals and they can take the energy released through this type of conversion for their growth. So, those are called chemoautotrophic bacteria and *Galleonella ferrigunea*, this is aerobic and chemoautotrophic bacteria.

So, by the presence of these bacteria, Fe (II) oxidized to Fe (III) and energy is released and that energy is consumed by this microorganism further growth. Like similar way *Leptothrix ochracea* they also do the same job but energy source is organic substrate. So, that is heterotrophic bacteria, these are some examples of aerobic digestion. And also, many organic compounds will be oxidized in the presence of microorganisms that is heterotrophic microorganisms.

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➤ Aerobic digestion contd..

Basic Ingredients and method

- High density of microorganisms (keep organisms in system)
- Good contact between organisms and wastes (provide mixing)
- Provide high levels of oxygen (aeration)
- Favorable temperature, pH, nutrients (design and operation)
- No toxic chemicals present (control industrial inputs)

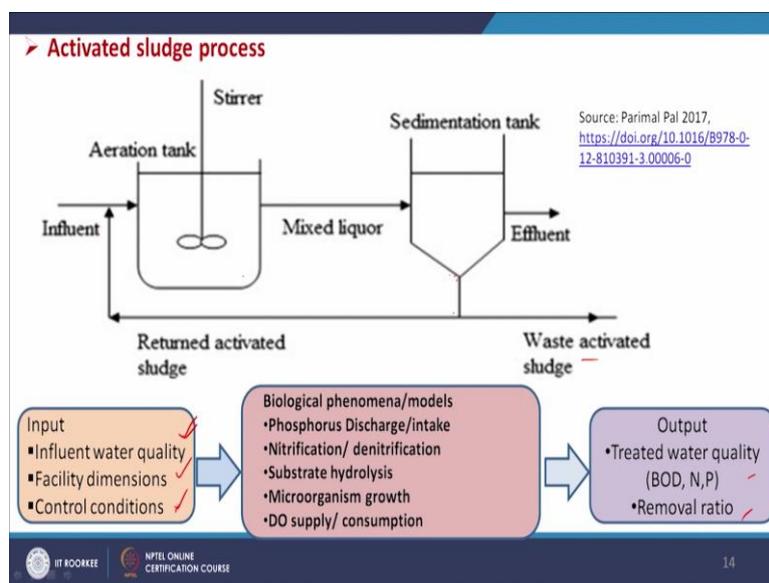
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And, basic ingredients and method which are required for this secondary treatment. So, those are high density of microorganisms, these keep organisms in system to ensure the high efficiency and then, good contact between organisms and wastes. Therefore, some aeration is

provided basically for proper mixing and provide high levels of oxygen, for both the purpose oxygen plays a significant role.

One it provides the oxygen for the reaction, other way it also provides the mixing and good contact between organic compound and the microorganisms. And then, favorable temperature, pH, nutrients, these are essential for the growth of the microorganism, because microorganisms are very susceptible to pH, temperature etc. And no toxic chemicals should be present. If toxic chemicals is present, then the growth of microorganisms will be affected. So, the subsequent oxidations of the organic compounds will also be affected.

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Now, we will see the activated sludge process. So, in activated sludge process our objective is to reduce the organic carbon present in the wastewater. So, our input will be inlet water quality, the facility dimensions and control conditions. So, these are very, very important to get the performance of the system. Let us see in the system what happens?

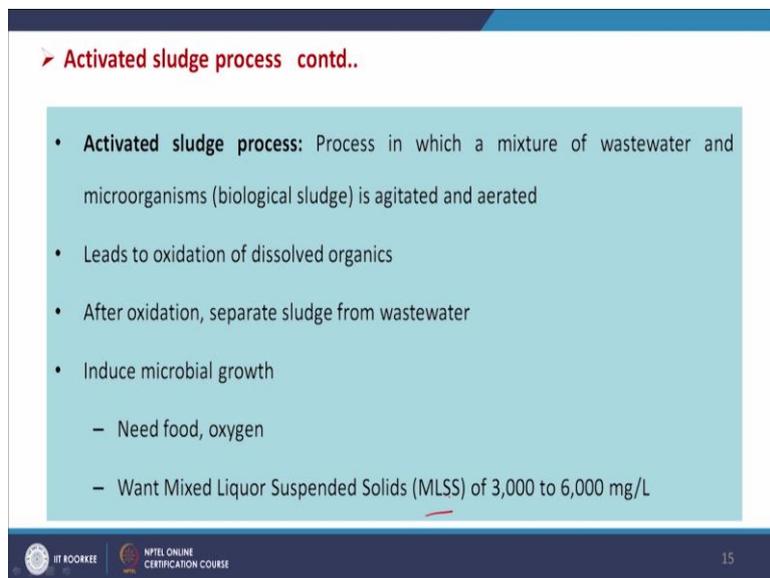
In the system, the wastewater comes after primary treatment to the first tank that is called aeration tank. Then in aeration tank microbes are also present in it so, microbial degradation takes place, then after a certain resident time the overflow goes to the sedimentation tank and then sludge are settled and supernatant goes for the further treatment that is tertiary treatment and the sludge the part of it is recycled, and this is the source of the new microbial cells and some part of the sludge is wasted and it is sent for waste management, sludge management.

So, this is the flow sheet basically and this is the activated sludge process. As the sludge is recycled for the activations or for the growth of the new cells in the aeration chamber this

process is called activated sludge process. And in this activated sludge process, our input is your wastewater after primary treatment and then what is the influent quality and what is the dimensions of this reactor, this sedimentation tank etc.

And what are the conditions we are maintaining, that will give us some quality of the output, that will give us treated water quality and removal ratio. And there will be a number of phenomena which will be going on inside these two reactors. So, there will be say phosphorus discharge intake nitrification, denitrification and substrate hydrolysis, microorganism growth, DO supply and consumption. So, all those phenomena are very, very important for the successful operations of this activated sludge process.

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➤ **Activated sludge process contd..**

- **Activated sludge process:** Process in which a mixture of wastewater and microorganisms (biological sludge) is agitated and aerated
- Leads to oxidation of dissolved organics
- After oxidation, separate sludge from wastewater
- Induce microbial growth
 - Need food, oxygen
 - Want Mixed Liquor Suspended Solids (MLSS) of 3,000 to 6,000 mg/L

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Now, this activated sludge process in which a mixture of wastewater and microorganisms is agitated and aerated leads to oxidation of dissolved organics, after oxidation separates sludge from the wastewater and induce microbial growth. So, need food and oxygen the microbial needs food and oxygen.

So, those are provided also in the aeration chamber and one mixed liquor suspended solids that is equal to 3000 to 6000 mg/L. So, somewhere it is 2500 to 4000 mg/L is also sufficient. So, this MLSS that indicates the presence of microbial biomass in the aeration chamber. So, that is very, very important parameter to ensure the effective conversions of the organic compounds.

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Anaerobic digestion

Upwards flow anaerobic sludge blanket

COD Balance Anaerobic

Anaerobic treatment is a proven and energy-efficient method for treating industrial wastewater. It uses anaerobic bacteria (biomass) to convert organic pollutants or COD (chemical oxygen demand) into biogas in an oxygen-free environment. UASB reactor has widely been used in industry. It is suitable for wastewater stream with high BOD and COD value (Preferably COD more than 4000 ppm).

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Now, we will see anaerobic digestion. So, in this case, oxygen is not needed. So, as shown here influent is coming and then there will be some microbes. So, microbes will work on it in absence of oxygen. So, there will be some anaerobic reactions. So, carbon dioxide and methane will be produced. So, then after a certain time of residence, so gas will be collected here and treated effluent will be going out from the top of this chamber. So, we see this is our sludge bed and this is our effluent collection zone.

And in this case, we see that CODs are converted to basically sludge and methane gas, that is our main objective to get the methane. So, energy recovery is necessary from the anaerobic reaction and then 10 % of the COD is converted to sludge and 90 % of the COD is converted to CH₄, these are some typical values given for this upflow anaerobic sludge blanket reactor UASB. So, in this case, normally higher COD concentration is necessary and at least 4000 mg/L COD concentration is necessary in the influent water then only this process can be used.

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Bio-filter

It is one of the most important separation processes that can be employed to remove organic pollutants from air, water and wastewater. Any type of filter with attached biomass on the filter media can be defined as a bio-filter.

Schematic of the packaging biofiltration system for the treatment of household wastewater.

A schematic cross-section of the contact face of the bed media in a rotating biological contactor (RBC)

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Now, we will see bio filter. So, bio filter as shown here. So, you see, it has some influent here. So, that is pre-treatment and this is bio-filtration and effluent and some clarification. So, these are the different steps in the bio filtration process. And if we concentrate here in the bio filtration, then we see there are some media on which a microbial film is grown.

And in that film, there will be some one side in contact with the bulk water that is organic present in the wastewater and attached to it this disk will be anaerobic zone and oxygen will be available in the water and the microbes will consume the oxygen, the microbes will be attached on the disk media and consume the oxygen available in the water.

So, at the water site, more oxygen will be available, but when we will go towards the disk media, then the oxygen availability will be reduced. So, here aerobic and anaerobic both zones will be available. So, facultative condition will be available. So, it is one of the most important separation processes that can be employed to remove organic pollutants from air, water and wastewater. Any type of filter with attached to biomass on the filter media can be defined as a bio filter.

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➤ Bio-filter contd..

Filter media

Originally bio-filter was developed using rock or slag as filter media, however, at present several types and shapes of plastic media are also used. GAC, anthracite, filter coal, sand, bagasse etc are in use.

Various particle shapes of media

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And, the biomass will be attached on some media. And those different types of media have been used, like say, granular activated carbon, anthracite, filter coal, sand, bagasse etc. and different shapes of the particles can be used as shown here.

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➤ Bio-filter contd..

Mechanism

Bio-film formation

- Attachment of M.O.
 - Transportation of M.O.
 - Initial adhesion
 - Firm attachment
 - Colonization
- Growth of M.O.
- Decay and detachment of M.O.

DLVO : Derjaguin-Landau-Verwey-Overbeek

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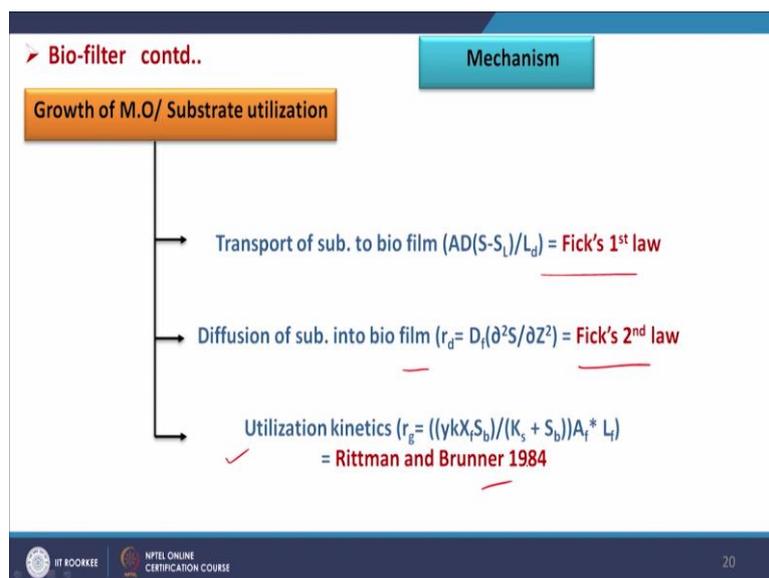
And then, we will see the mechanism, how the bio filtration will work. So, in that case, we see that some biofilm formation is necessary. So, attachment of microorganisms and the media, then growth of microorganisms and then biofilm formations and after a certain time the microbes will be dead and that is decay and detachments of microorganisms. So, these are the major steps or mechanism for the working of the bio filter.

And we see the attachment of microorganisms, for the attachment of microorganism, microorganisms need to be transported from the bulk of the solution to the surface of the filter media. So, that transportation of microorganisms this can be done either by diffusion or by convection or sedimentation or active mobility of microorganisms. So, microorganisms itself can move from the bulk to the surface or diffusion may help or if there is any convection that will help or the sedimentation can also help for the attachment.

So, initial when it is coming, the microorganisms are coming at the surface of the media, then there will be some initial adhesion either some Vander walls or DLVO, Vander walls means attractive force and DLVO basically the repulsive forces. So, the two forces are available at the surface. So, depending upon the predominance, so, initial adhesion will take place and then film attachment. So, microbes have come to the surface that depending upon the surface of the media, the attachment will be influenced.

Like say surface properties each has good surface properties, more heterogeneity and then influent character and the availability of sufficient elements which are favorable for the growth of the microorganisms that will prefer the biofilm production. So, that film attachment and colonization, these two, initially the film attachment, then gradually it will grow, for this surface properties of the media as well as the influent character are both important.

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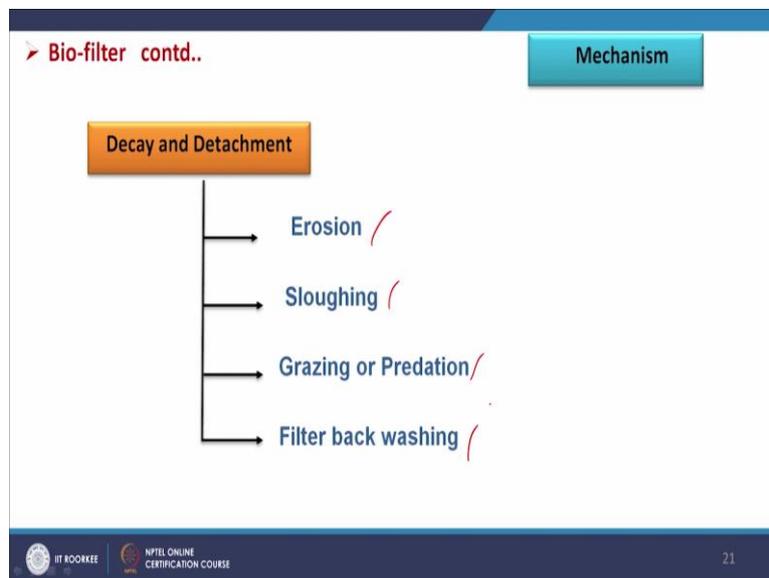


And then growth of microorganism. So, for the growth of microorganism, we need again the transport of substrate to biofilm because microbes need organic compounds for their growth

and those are the organic compounds will be degraded basically. So, from the bulk of the solution to the surface of the filter it has to become and that is by Fick's first law, transportation of the substrate can be possible.

And diffusion of substrate into the biofilm then substrate which is coming from the bulk of the solution to the surface of the filter media then, it will be diffused through the biofilm that is Fick's second law. And then, microbes will also consume the organic compounds and that will be guided by the many utilization kinetics like Monod like equations. So, here it is given Rittman and Brunner expression. So, there are different mechanisms which are followed for the growth of the microorganism.

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And then, decay and detachment. So, after a certain time microbes will be dead and that has to be removed from the filter media and that can be done by erosion, that can be done by sloughing, that can be done by grazing predation or filter back washing. So, we have also seen in the previous class that back washing is necessary to remove the materials which is deposited on the filter media to avoid clogging.

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➤ **Bio-filter contd..** **Types**

- Packed bed ✓
- Fluidized Bed ✓
- Rotating biological contactors (R.B.C) ✓
- Trickling Filters ✓

Trickling filter Source: Gulhane M.L. et al., 2015

Rotating biological contactors (a & b) Source: Amshawee et al., 2020

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Now, there will be different types of bio filters, let us say packed bed, fluidized bed, rotating biological contactors and trickling filters. So, these trickling filters is very common and very primitive one. So, basically we see we have some media and we spray water for long term operation, if we use it for long term operation, so, microbial film will be developed on the surface of the media and biological activity will be started and organic compound will be degraded. So, this is very primitive one.

And then, packed bed and fluidized bed that can be developed by using different packing material and by the attachment of the microbes on the packing material. And, in the rotating biological contactor as shown here, you see this is our media where the microbes are available and organic compounds are also available and this is our disk. So, there are a number of disks out there that is a side view.

So, we are talking about one disk and in this disk from the inside we are having some vacuum. So, water will be passing through this filter. So, microbes will be working on the organic compounds and then organic compounds will be converted to CO_2 and H_2O and this water after treatment, the water will pass through the surface of it and in the surface we have bio layer formation. So, this microbes which will be growing on the surface that will help to decompose the organic compounds. So, this is the mechanism of the rotating biological contactor.

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➤ **Microbial growth and retention time**

GROWTH KINETICS

Monod function $\mu = \hat{\mu} \frac{S}{K_S + S}$

$\frac{dx}{dt} = \mu X - K_d X$

growth decay

$X =$ concentration of biomass (ML^{-3})
 $\mu =$ specific growth rate (t^{-1})
 $K_d =$ specific decay rate (t^{-1})

Specific growth rate, μ

μ_{max}

$\frac{1}{2} \mu_{max}$

K_S

Limiting nutrient concentration, S

$\mu = \hat{\mu} \frac{S}{K_S + S}$

Specific growth rate as a function of the limiting nutrient concentration

Source: Legner et al., 2019

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Now, we will discuss microbial growth and retention time. So, as you know, that when microbes we are using, when we are adding some seeds, microbial seeds, so, those will grow and that growth kinetics can be defined as dx/dt and X is the microbial biomass. So, dx/dt and we know that this is first order kinetics

$$dx/dt = \mu X$$

we also know that after a certain time, some biomass will also be decayed or dead. So, that decay rate is also there. So, overall rate will be

$$dx/dt = \mu X - K_d X$$

So, that is dx/dt that is a overall growth kinetics of microbes in any media or wastewater sample. And, then this μ we can define that is specific growth rate. So, this μ is equal to maximum specific growth rate

$$\mu = \hat{\mu} \left(\frac{S}{K_s + S} \right)$$

That means the specific growth rate will depend upon the availability of the substrate in the media. So, by these expressions we can calculate the μ .

And if we plot the specific growth rate, the value of μ with respect to K_s that is limiting new nutrient concentration with respect to S , if we plot μ with respect to S . So, this is S and this is μ . So, we will be getting this type of first order kinetics. So, maximum growth rate is μ_{max}

and if we take the half value of μ_{max} , then the corresponding S value is our K_s , because in this expression if we put K_s equal to S then

$$\mu = \hat{\mu} \left(\frac{S}{K_s + S} \right) = \hat{\mu} \left(\frac{S}{2S} \right) = \hat{\mu} / 2$$

So, that is the definition of K_s which is used in Monod function. So, by using these expressions we can mathematically calculate the growth rate of the microorganism.

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➤ **Microbial growth and retention time contd..**

Also, solid production rate $\frac{dX}{dt}$ is related to substrate utilization rate $\frac{dS_r}{dt}$

By following relationship:

$$\frac{dX}{dt} = Y \left(\frac{dS_r}{dt} \right)$$

For growth phase only,

$$\frac{dS_r}{dt} = (1/Y) * \frac{dX}{dt} = \frac{\mu}{Y} X = \frac{\mu_{max}}{Y} X \left(\frac{S}{K_s + S} \right)$$

Case 1: $S \gg K_s$

$$\frac{dS_r}{dt} \sim KX \text{ where, } K = \frac{\mu_{max}}{Y}$$

i.e. removal rate is independent of substrate concentration and that the removal rate depends on X only.

Case 2: $S \ll K_s$

$$\frac{dS_r}{dt} = K \frac{SX}{K_s} \sim K'XS \text{ where, } K' = \frac{K}{K_s} = \frac{\mu_{max}}{YK_s}$$

Here, removal rate depends both upon X and S. Where, X is the mass of biomass in the system (usually represented by MLSS i.e. Mixed Liquor Suspended Solid), μ is the specific growth rate constant (time^{-1}).

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➤ **Microbial growth and retention time**

GROWTH KINETICS

Monod function $\mu = \hat{\mu} \frac{S}{K_s + S}$

$\frac{dx}{dt} = \mu X - K_d X$
 growth decay

X = concentration of biomass (ML^{-3})
 μ = specific growth rate (t^{-1})
 K_d = specific decay rate (t^{-1})

Specific growth rate as a function of the limiting nutrient concentration

Source: Legner et al., 2019

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And for solid production rate dx/dt that is related to substrate utilization rate dS_r/dt .

$$\frac{dX}{dt} = Y \left(\frac{dS_r}{dt} \right)$$

Y is the yield coefficient. But if we net production rate, we consider that means if we want to include the decay rate also then

$$\frac{dX}{dt} = Y \left(\frac{ds_r}{dt} \right) - K_d X$$

where K_d is the decay constant and X is the microbial mass concentration. And then, by rearranging this we can get

$$\left(\frac{ds_r}{dt} \right) = \frac{1}{Y} \frac{dX}{dt}$$

$$\left(\frac{ds_r}{dt} \right) = \frac{1}{Y} \frac{dX}{dt} = \frac{\mu}{Y} X = \frac{\mu_{\max}}{Y} X \left(\frac{S}{K_s + S} \right)$$

Now, if this S value, is much, much greater than the K_s then we ignore this one, then we can get

$$\left(\frac{ds_r}{dt} \right) \sim KX$$

But, if S value is much lesser than the K_s , then

$$\left(\frac{ds_r}{dt} \right) = K \frac{SX}{K_s} \sim K'XS$$

Where $K' = K/K_s = \mu_{\max}/YK_s$

So, in this case, we see that dS_r/dt dependent on X as well as S value, but in this case, the dS_r/dt dependent on only X value.

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➤ **Microbial growth and retention time contd..**

Hydraulic detention time, $t_{HRT} = \frac{V}{Q} = \frac{\text{Volume}}{\text{Flowrate}}$

Sludge age or mean residence time, $\theta_c = \frac{\text{Mass of solid in the system}}{\text{Mass of solid leaving system per day}} = \frac{xV}{x'Q} = \frac{x}{x'} t_{HRT}$

Where, $x (=X/V)$ the concentration of microbial solution in the system, x' is the concentration of solids withdrawn.
 For the flow through system, $x = x'$ and
 For the flow system with recycling, $x < x'$ and

Food to microorganism ratio,

$$\frac{F}{M} = \frac{\text{Substrate removal rate}}{\text{Solids (microorganisms) in the system}} = \frac{(S_0 - S)/t}{X} = \frac{(S_0 - S)}{xVt}$$

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Now, hydraulic retention time. So, hydraulic retention time that is the volume by volumetric flow rate for any case this is applicable.

$$t_{HRT} = \frac{V}{Q} = \frac{\text{volume of the tank reactor}}{\text{flowrate}}$$

And sludge age or mean residence time this is defined as

$$\theta_c = \frac{\text{mass of the solid in the system}}{\text{mass of solid leaving system per day}} = \frac{xV}{x'Q} = \frac{x}{x'} t_{HRT}$$

So, in this case if the V is the volume and x is the biomass concentration in it. So, $x*V$ to be the total biomass present in it in the volume. And then if our x' is the biomass leaving from the system and Q is the volumetric flow rate. So, $x*Q$ is the biomass leaving from the system. So, hydraulic retention time*(x/x') is our that is sludge age or mean residence time or cell residence time.

So, another important parameter which is essential for understanding the activated sludge process or secondary process basically.

$$\frac{F}{M} = \frac{\text{Substrate removal rate}}{\text{Solids (microorganisms) in the system}} = \frac{(S_0 - S)/t}{X} = \frac{(S_0 - S)}{xVt}$$

S_0 is the initial substrate concentration, S is the final substrate concentration. X is nothing but small $x*V$ that is a concentration of microbial cell into the volume of the reactor. So, that way you can get the value of F/M . So, up to this in this class. Thank you very much for your patience.