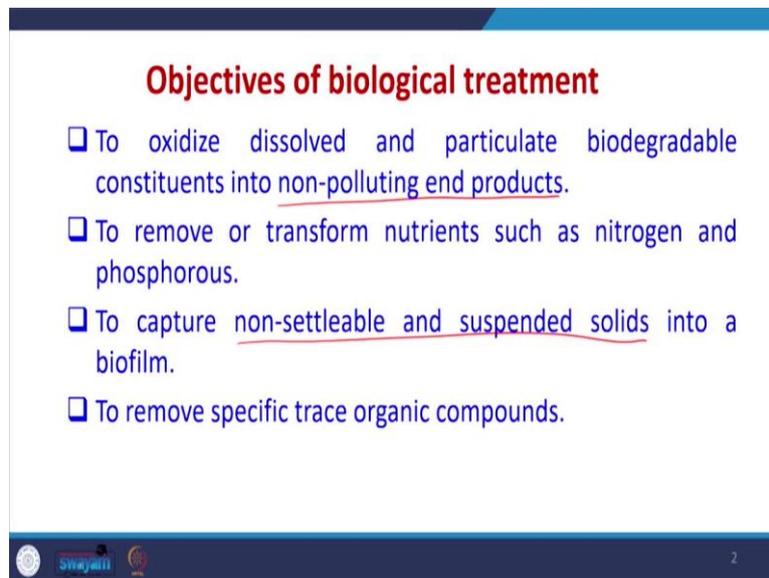


Biological Process Design for Wastewater Treatment
Professor Vimal Chandra Srivastava
Department of Chemical Engineering
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Lecture 21
Lagoon

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. In the last few lectures, we started studying the wastewater treatment in detail. In the last two lectures, we have studied sedimentation, flocculation, coagulation in detail. Before that we studied regarding the flow equalization and aeration. So, till now we have concentrated mostly on physicochemical method of treatment. So, today we are going to start with the biological wastewater treatment sections.

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Objectives of biological treatment

- ❑ To oxidize dissolved and particulate biodegradable constituents into non-polluting end products.
- ❑ To remove or transform nutrients such as nitrogen and phosphorous.
- ❑ To capture non-settleable and suspended solids into a biofilm.
- ❑ To remove specific trace organic compounds.

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We will start with general understanding of that, what are the objectives of biological treatment. So, the basic idea of biological treatment is to oxidize the dissolved and particulate biodegradable constituents which are present in the wastewater into nonpolluting end products. That means, converting them into CO₂, H₂O, etcetera.

Also, it is desired to remove or transform nutrients such as nitrogen and phosphorus during the biological treatment. Also, it is desired to capture non settleable label and suspended solids into a biofilm and to remove the specific trace organic compounds which are present in the wastewater. So, there are multiple facets of biological treatment, the main objective is to oxidize the dissolved and particulate biodegradable constituents into CO₂, H₂O etc. So, this is the main objective of biological treatment.

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Classification of treatment processes

- ❑ Processes According to Microbial Maintenance in the System
 - ❖ **Suspended growth processes:** Here, the microorganisms are maintained as a suspension in the reactor by an appropriate mixing method. E.g. activated sludge systems, oxidation ditch, aerated lagoon, etc.
 - ❖ **Attached growth or fixed film processes:** Here, the microorganisms in the reactor remain attached to some inert packing material or medium. E.g. trickling filter, rotating biological contactor, etc.

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Now, there are different classification of the biological treatment processes. So, according to microbial maintenance in the system, they may be suspended growth processes, they may be attached growth processes, the suspended growth processes, here the microorganisms are maintained as a suspension in the reactor by appropriate mixing methods. The examples include activated sludge systems, oxidation ditches, aerated lagoons etc.

So, we are going to learn the lagoon today in greater detail also further the attached growth or fixed film processes in this case, the microorganisms in the reactor remains attached to some inert packing material or medium and these type of treatment processes are examples include the trickling filter, the rotating biological contactor, etc. So, according to how the microbes are maintained inside the system, the overall the systems may be classified as suspended or attached growth.

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Processes According to Operational conditions

Aerobic process: This process essentially requires the presence of molecular oxygen for the metabolic activity of microorganisms.

- Aerobes use molecular/free oxygen to assimilate organic impurities i.e. convert them into carbon dioxide, water and biomass
- The source of oxygen in the reactor can be natural (e.g. in a trickling filter, aerobic stabilization ponds) or artificial (e.g. in activated sludge process, aerated lagoons). It fails in the absence of oxygen.



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Now, according to operational conditions, whether oxygen is supplied or not. So, the processes may be classified as aerobic, anaerobic facultative etc. In the aerobic process, at least, they require the presence of molecular oxygen for maintaining the metabolic activity or microorganisms, aerobes use molecular or free oxygen to assimilate organic impurities that is convert them into carbon dioxide water and biomass.

The source of oxygen in the reactor can be natural example in the trickling filter and aerobic stabilization ponds or artificial where oxygen is supplied for outside example, in the activated sludge process, aerated lagoons etc. And these aerobic processes they fail in the absence of oxygen.

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Anaerobic process: This process operates in the absence of molecular oxygen in the reactor for the growth of microbes.

- ❖ Anaerobes assimilate organic impurities and the final products of organic assimilation in anaerobic treatment are methane and carbon dioxide gas and biomass
- ❖ E.g., anaerobic sludge digester, anaerobic up-flow filters



Figure 1. Mechanism of aerobic and anaerobic processes

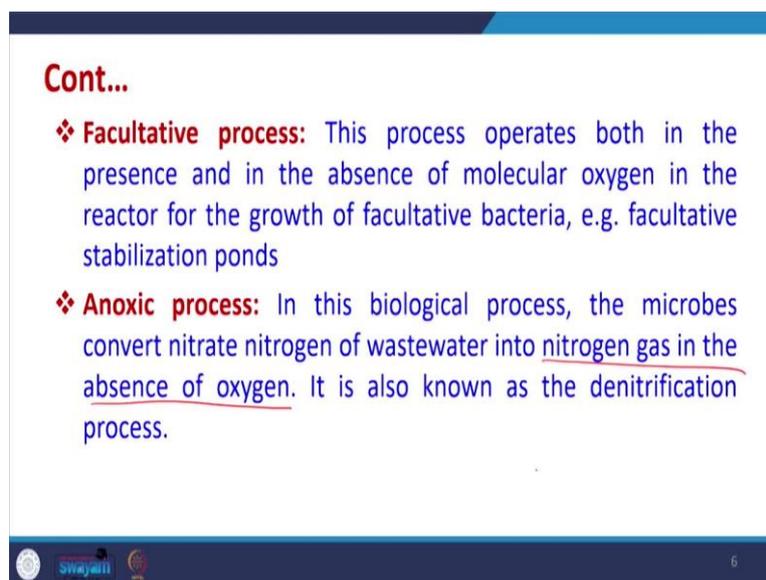


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Then we have anaerobic process. This process operates in the absence of molecular oxygen in the reactor for the growth of microbes. Anaerobes assimilate the organic impurities and the final products of organic assimilation in the in aerobic treatment or like methane, carbon dioxide, gas, biomass etc. The examples of anaerobic treatment include anaerobic sludge digesters, anaerobic up-flow, filters, etc., USB reactors etc.

Now, that difference in the mechanism of aerobic and anaerobic processes is given here. In the case of aerobes, the organic contaminants in the presence of oxygen and nutrients are converted into carbon dioxide and water. And these aerobes also generate excess cell mass in the case of anaerobic bacteria, the organic and dominance in the presence of nutrients are converted into methane and carbon dioxide and certainly some amount of excess cell mass is again generated. So, this is the difference.

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- ❖ **Facultative process:** This process operates both in the presence and in the absence of molecular oxygen in the reactor for the growth of facultative bacteria, e.g. facultative stabilization ponds
- ❖ **Anoxic process:** In this biological process, the microbes convert nitrate nitrogen of wastewater into nitrogen gas in the absence of oxygen. It is also known as the denitrification process.

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Then we have the third method which is called facultative process. This process operates both in the presence and in the absence of molecular oxygen in the reactor for the growth of facultative bacteria. Examples include facultative stabilization pond, so, where no oxygen is supplied if oxygen is available okay, if it is not available, then also the system will operate.

Then we have anoxic process in this biological process the microbes convert the nitrate nitrogen of wastewater into nitrogen gas in the absence of oxygen and this process is known as denitrification. So, this is an anoxic process.

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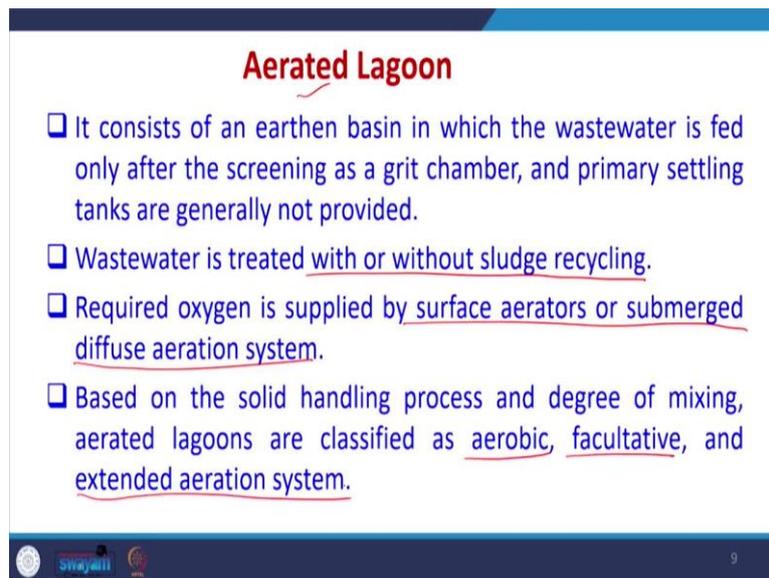
Comparison of aerobic and anaerobic processes	
Aerobic	Anaerobic
Advantages	
<ul style="list-style-type: none"> 50% carbon is converted into carbon di-oxide 40%-50% of carbon is converted into biomass 60% of energy is stored in biomass. Rest removed as process heat High energy input for aeration Nutrient addition requirement is substantial Process requires large area 	<ul style="list-style-type: none"> 94% of carbon is converted into biogas 5% of carbon is converted into biomass 90% of energy is retained as ^{CH₄, CO₂} 3%-5% is wasted as heat and rest is converted to biomass. No external energy input Low nutrient requirement Process area required is less
Disadvantages	
<ul style="list-style-type: none"> Small start time is required Technology is well established 	<ul style="list-style-type: none"> Large start-up time is required Under development with research in progress

The comparison between aerobic and anaerobic processes given here in the aerobic process, the advantage is that 50 percent of the carbon is converted into carbon dioxide and rest is converted into biomass in the case of anaerobic 94 percent of the carbon is converted into biogas and rest is converted into biomass. So, here biogas may contain majority of methane, but certainly carbon dioxide etc., also.

Now, in the aerobic case the 60 percent of the energy stored in the biomass and rest is removed as process heat. Whereas, in the anaerobic case 90 percent of the energy is retained as the biogas and rest to 3 to 5 percent is wasted as heat and rest is converted into biomass, then, for aerobic case, we require high energy input for aeration which is actually a disadvantage and also nutrient addition is requirement and the process may require large surface area.

For anaerobic case there is no external energy input is required because methane is formed and there is a low nutrient requirement also as compared to aerobic case, the process area requirement is also less. The disadvantage is that with respect to anaerobic cases that larger startup time is required, and the wastewater which has to be treated should contain very high amount of carbon, otherwise, an aerobic process may not work. And so, that is why a lot of the research is still in process. For aerobic case, a small startup time is required, which is the benefits and the technology is well established this is there.

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Aerated Lagoon

- ❑ It consists of an earthen basin in which the wastewater is fed only after the screening as a grit chamber, and primary settling tanks are generally not provided.
- ❑ Wastewater is treated with or without sludge recycling.
- ❑ Required oxygen is supplied by surface aerators or submerged diffuse aeration system.
- ❑ Based on the solid handling process and degree of mixing, aerated lagoons are classified as aerobic, facultative, and extended aeration system.

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Now, we will study one of the first biological treatment method which is used very commonly, and which is called as lagoon. So there could be different types of lagoon, aerated lagoon, non-aerated, one anaerobic one facultative, one etc., So, aerated lagoon will try to or lagoon in general will try to learn regarding this.

So, it consists of an earthen basin in which the wastewater is fed only after a screening as a grit chamber and the primary settling tanks are generally not provided. That means, we have a pond or a lagoon in which water is fed after only screening and this type of system are most commonly used in the small industries.

Wastewater is treated with or without sludge recycling. So, this is possible, required oxygen is supplied by surface aerators are submerged diffused aeration system, it is possible that no oxygen may also be given. But for aerated lagoon, this required oxygen has to be supplied. Based upon the solid handling process and degree of mixing aerated lagoons can be classified as aerobic facultative, extended aeration systems etc. this is there.

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The key features of aerated-lagoon treatment are:

- ❑ **A large detention time**
 - ❖ Since aerated lagoons do not have sludge recycling, the solids retention time (SRT) is approximately equal to the liquid detention time.
 - ❖ Typical SRTs of 5 d for heterotrophic BOD removal or 25 d for nitrification require liquid detention times in the order of 5 and 25 d, respectively.
 - ❖ A consequence of the large liquid detention is a small volumetric loading, often less than 0.01 kg BOD₅/m³d.

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Now, the key features of aerated lagoon treatment systems are that they have very large detention time, which is not good in fact, because the larger detention time means that larger area will be required. Since aerated lagoons do not have flush recycling, the solid detention time is approximately equal to the liquid detention time itself. Typical SRTs of 5 days for heterotrophic BOD removal at 25 days for nitrification requires liquid retention times in the order of 5 to 25 days respectively.

A consequence of large detention time is a small volumetric loading often less than 0.1 kg BOD₅ per meter cube per day, because we have large detention time the volumetric loading is smaller.

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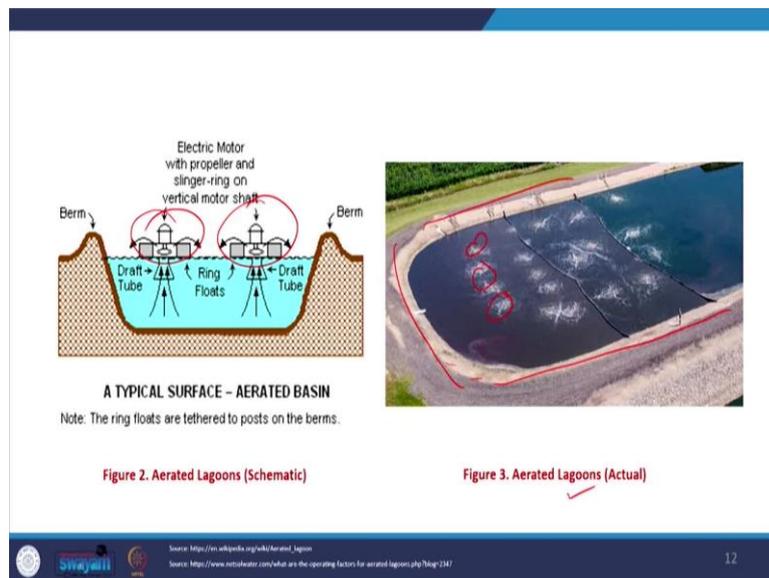
- ❑ **A shallow depth and a large plan-view surface area**
 - ❖ The typical depths of aerated lagoons range from 1 to 3 m (3 to 10 ft)
 - ❖ These relatively shallow depths maximize the ratio of plan-view surface area to liquid volume
- ❑ **A shallow depth and a large plan-view surface area**
 - ❖ Most aerated lagoons use high-speed surface aerators
 - ❖ It provides a high surface area with a low-capital cost of high-speed surface aerators, and flexibility in locating high-speed surface aerators to maintain good solids mixing

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Then we have a shallow depth that means, the depth is small and a large plan view surface area is more. So, there this is the typical depths of aerated lagoon range from 1 to 3 meter they relatively shallow depths maximize the ratio of maximum planned surface area to liquid volume.

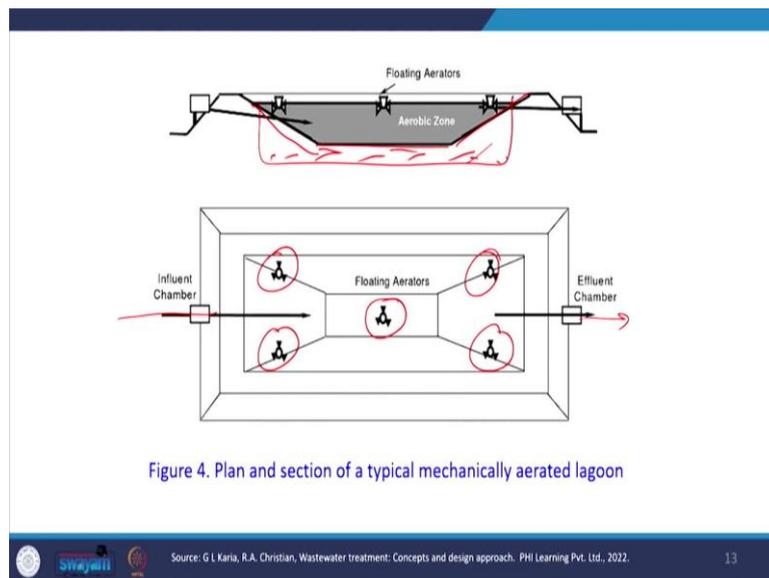
Most aerated lagoons use high speed surface aerators it provides high surface area with low capital cost of high speed surface aerators and flexibility in locating the surface aerator to maintain the good solid mixing.

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So, this is like aerated lagoon, which is actually you can see is this length is very huge and this dimensions are huge and their area is very huge. And these aerators maybe use for providing the mixing as well as the oxygen required for this and these aerators actually float on the surface of the bumps. So, this is there, you can see the bumps, so, they are like they will float on the surface. You can see here some of the aerators which may be there.

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Also, this is the planning section we have typically mechanically aerated lagoon, you can see the floating aerators one is here one is kept here, one is kept here to move. So, here we have inlet chamber after the screening water will come and after large detention type of treatment the water will go out from here. So, the overall the system may look like this, below this we may have a sludge zone where the sludge is getting settled, this is there.

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Facultative system

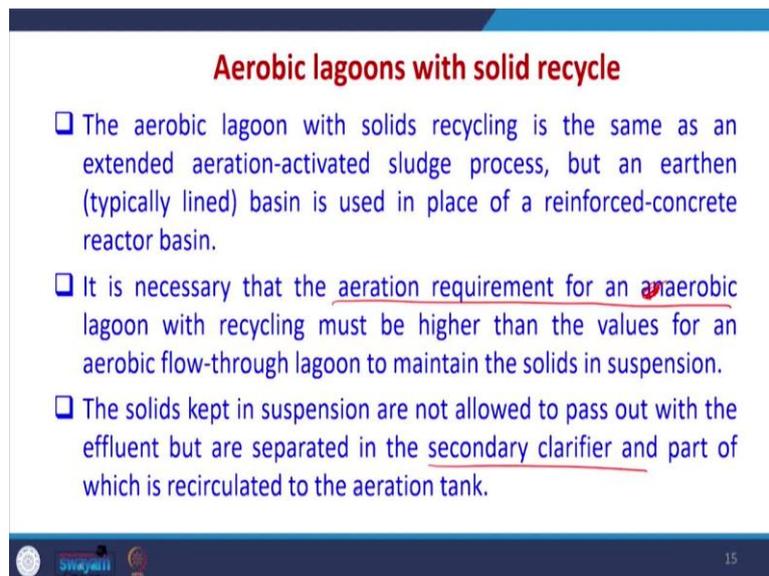
- ❑ The design is similar to the aerobic system except that both aerobic and anaerobic conditions prevail in the lagoon.
- ❑ It is normally designed at a low F/M ratio.
- ❑ The power supply is just sufficient to supply the required oxygen and, therefore, all the solids in the influent do not remain suspended.
- ❑ The particulate solids are degraded aerobically while settled solids are decomposed anaerobically at the bottom of the tank.

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Now, in the facultative lagoons. That design is similar to the aerobic system except that the both aerobic and anaerobic conditions prevail in the lagoon and it is normally designed at low F by M food to microorganism ratio. The power supply is just sufficient to supply the required oxygen and therefore all the solids in the effluent do not remain suspended.

The particulate solids are degraded aerobically while settled solids are decomposed anaerobically. So that means the particles which are at the top which are not being settled, they are actually aerobic degradation happens. Whereas the particles which are bigger which actually settle down very quickly to the bottom, they decompose anaerobically at the bottom of the tank. So both systems are operating simultaneously.

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Aerobic lagoons with solid recycle

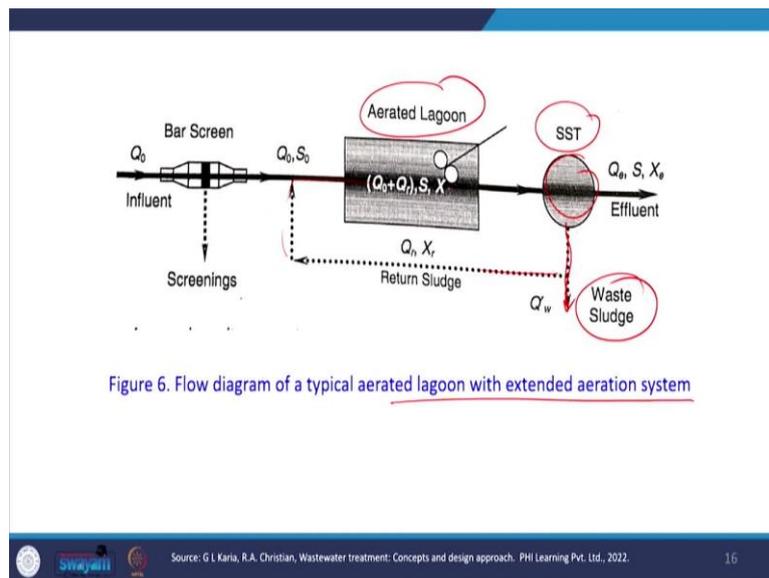
- ❑ The aerobic lagoon with solids recycling is the same as an extended aeration-activated sludge process, but an earthen (typically lined) basin is used in place of a reinforced-concrete reactor basin.
- ❑ It is necessary that the aeration requirement for an aerobic lagoon with recycling must be higher than the values for an aerobic flow-through lagoon to maintain the solids in suspension.
- ❑ The solids kept in suspension are not allowed to pass out with the effluent but are separated in the secondary clarifier and part of which is recirculated to the aeration tank.

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Then there are aerobic lagoons with solids recycling. The aerobic lagoon with solid recycling is the same as an extended aerated activated sludge process but an earthen typically lined basin is use in place of reinforced concrete reactor basin. It is necessary that the aeration requirements for an aerobic lagoon with recycling must be higher than the values for an aerobic flow through lagoon to maintain the solids in the suspension.

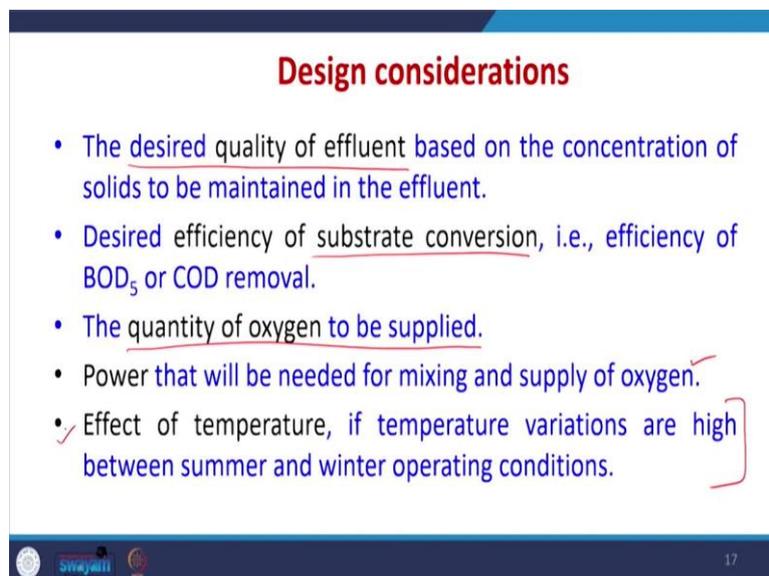
So, here the requirement of aeration is more the solids kept in the suspension are not allowed to pass out with the effluent but are separated in the secondary clarifier and part of which is recirculated to the aeration tank itself.

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So, it may be looking like this, it is similar to activator sludge system only thing is that we have a settling secondary settling which is happening and then the solids which are coming out part of the solids are recycled killed back into the system and others are wasted. So, this is the typical aerated lagoon with extended aeration system. So, here the aeration will be more as compared to a pass through aerated lagoon.

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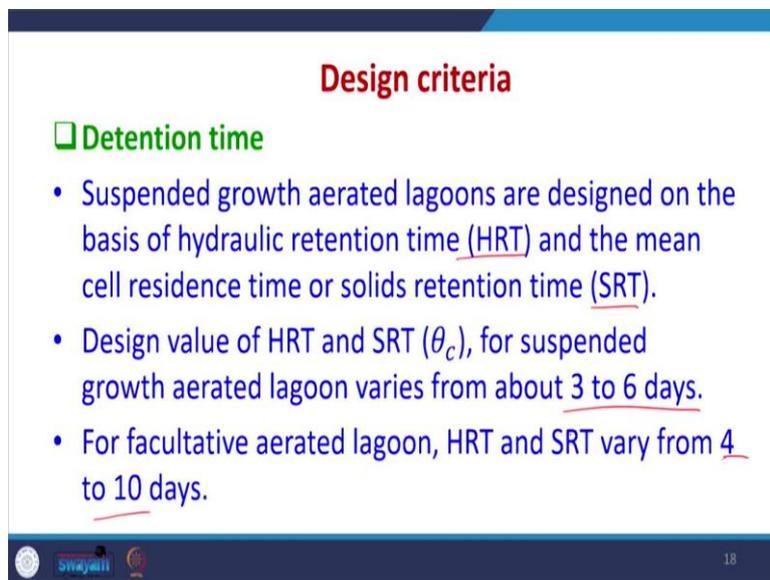


Now, what are the design considerations in the lagoon that desired quality of effluent based upon the concentration of solids to be maintained in the effluent? So, this is very important factor the what is the faulty of effluent which is desired. Based upon this we have to see that what amount of solids have to be maintained in the basin and in the effluent.

Desired efficiency of sustained conversion what is the efficiency of conversion we desire?
What is the BOD and COD removal what is the quantity of oxygen which has to be supplied
This has also to be determined? Then once this is known then we have to know that power
that will be needed for mixing and supply of oxygen. So, this power has to be calculated.

Effect of temperature if temperature variations are high between summer and winter
operating conditions, it is possible that the lagoon is in a place where the difference in the
temperature between summer and winter season is very high. So, the effect of temperature
has also to be considered.

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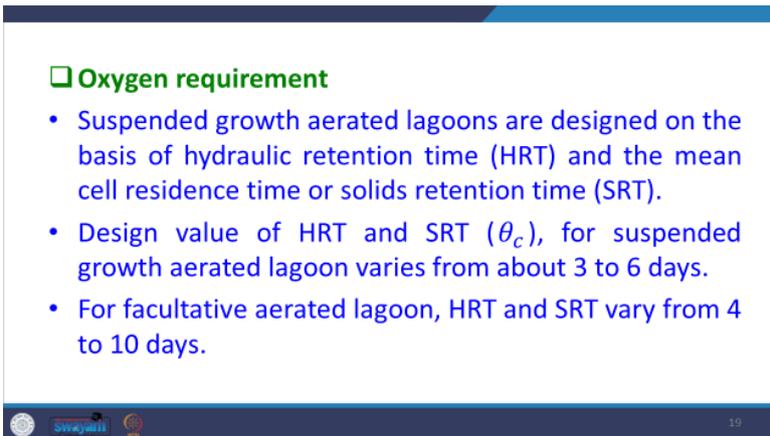


Design criteria

Detention time

- Suspended growth aerated lagoons are designed on the basis of hydraulic retention time (HRT) and the mean cell residence time or solids retention time (SRT).
- Design value of HRT and SRT (θ_c), for suspended growth aerated lagoon varies from about 3 to 6 days.
- For facultative aerated lagoon, HRT and SRT vary from 4 to 10 days.

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Oxygen requirement

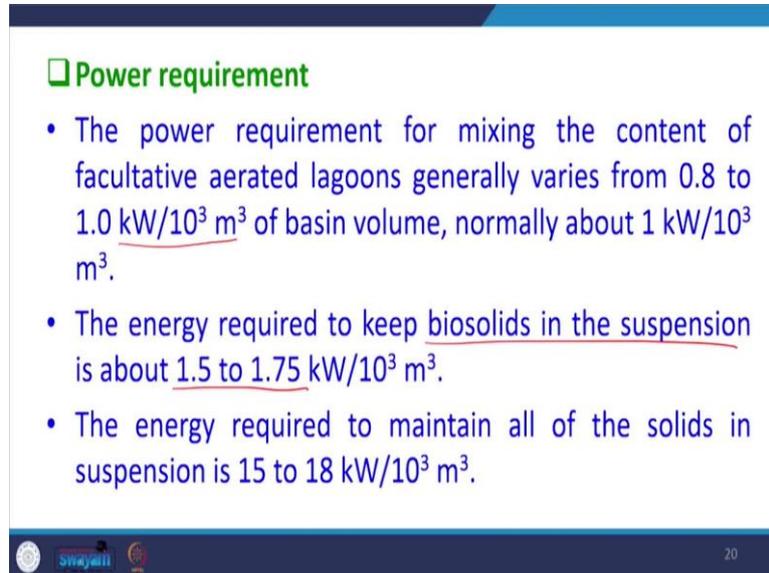
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Now, design criteria detention time suspended growth aerated lagoons are designed on the basis of hydraulic retention time and the mean cell residence time are solid retention time SRT. They are dependent upon HRT and SRT, that design value of HRT and SRT for suspended growth aerated lagoon varies from 3 to 6 days.

And for facultative aerated lagoon, HRT and SRT vary from 4 to 10 days. So, for aerated lagoon, it is lesser for facultative aerated and lagoon it is much higher.

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Power requirement

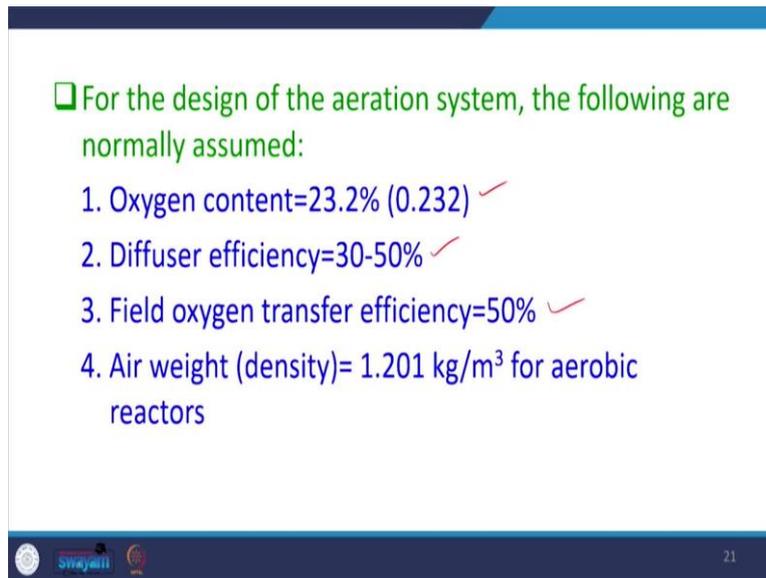
- The power requirement for mixing the content of facultative aerated lagoons generally varies from 0.8 to 1.0 kW/10³ m³ of basin volume, normally about 1 kW/10³ m³.
- The energy required to keep biosolids in the suspension is about 1.5 to 1.75 kW/10³ m³.
- The energy required to maintain all of the solids in suspension is 15 to 18 kW/10³ m³.

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Now, the power requirement for mixing the content of facultative aerated lagoon generally varies from 0.8 to 1 kilo watt per 10 raised to 3-meter cube of based in volume. Normally about 1 kilo watt per 1000-meter cube, the energy required to keep the bio-solids in the suspension is about 1.5 to 1.75 kilo watt per 10 raised to 3-meter cube.

The energy required to maintain all the solids in the suspension is about 15 to 18 kilowatt per 1000-meter cube. So, the energy requirements are different depending upon the whether we want to keep mainly bio-solids in the suspension or we want to keep all the solids in the suspension. So, it will depend upon that and power requirement for mixing is also varies depending upon whether we have aerated lagoon or facultative lagoon.

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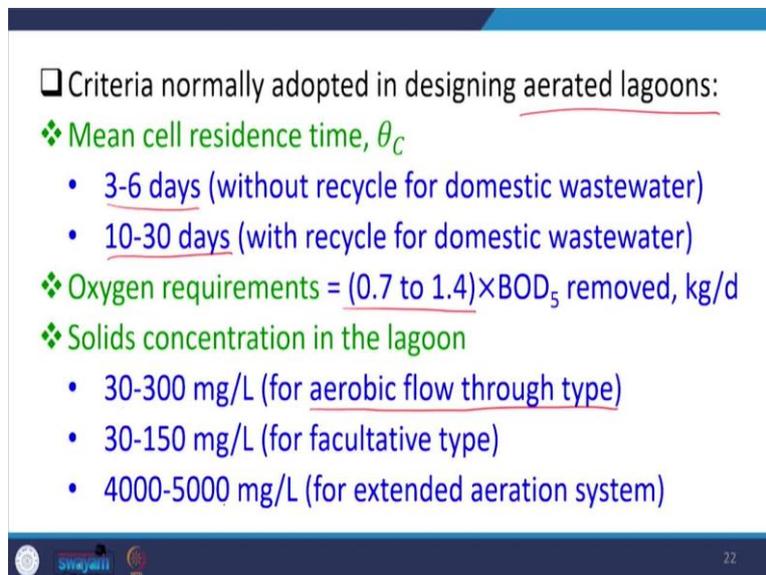
□ For the design of the aeration system, the following are normally assumed:

1. Oxygen content=23.2% (0.232) ✓
2. Diffuser efficiency=30-50% ✓
3. Field oxygen transfer efficiency=50% ✓
4. Air weight (density)= 1.201 kg/m³ for aerobic reactors

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But the design of aerated system the following are normally assumed the oxygen content is assumed to be around 23.2 percent or so, that diffuser efficiency is 30 to 50 percent. The field oxygen transfer efficiency is around 50 percent. Air weight density around 1.2 kg per meter cube for aerobic reactors.

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□ Criteria normally adopted in designing aerated lagoons:

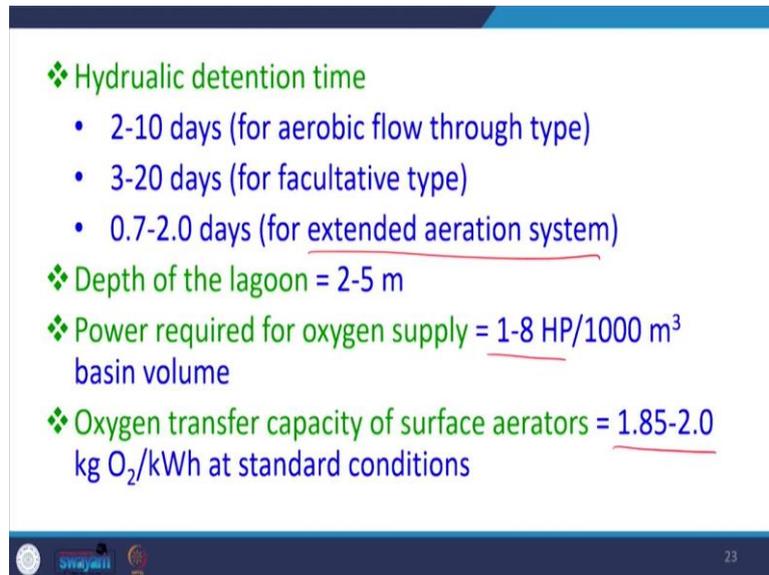
- ❖ Mean cell residence time, θ_c
 - 3-6 days (without recycle for domestic wastewater)
 - 10-30 days (with recycle for domestic wastewater)
- ❖ Oxygen requirements = (0.7 to 1.4) × BOD₅ removed, kg/d
- ❖ Solids concentration in the lagoon
 - 30-300 mg/L (for aerobic flow through type)
 - 30-150 mg/L (for facultative type)
 - 4000-5000 mg/L (for extended aeration system)

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That criteria normally adapted in designing the aerated lagoons are that the mean cell residence time theta is 2 to 6 days I will let us discuss without recycle for domestic wastewater and with recycled for domestic wastewater it is 10 to 30 days. Oxygen requirement is between 0.7 to 1.4 per into the amount of BOD removed in kg per day. So, it will be can take tentatively around one value.

So, then the solid concentration in the lagoon have to be maintained depending upon the type of operation for aerobic flow through type system it is 30 to 300 for facultative in the range of 30 to 150 milligram per liter whereas for extended aeration system it is much higher 4000 to 5000 milligram per liter.

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❖ Hydraulic detention time

- 2-10 days (for aerobic flow through type)
- 3-20 days (for facultative type)
- 0.7-2.0 days (for extended aeration system)

❖ Depth of the lagoon = 2-5 m

❖ Power required for oxygen supply = 1-8 HP/1000 m³
basin volume

❖ Oxygen transfer capacity of surface aerators = 1.85-2.0
kg O₂/kWh at standard conditions

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The HRT values are between 2 to 10 days for aerobic flows through system 3 to 20 days for facultative type and 0.7 to 2 days for extended aeration system. The depth may vary from 2 to 5 meter, the power requirement for oxygen supply may vary from 1 to 8 horsepower per 1000-meter cube based in volume and the oxygen transfer capacity for surface aerator is around 2 kg oxygen per kilowatt hour at the condition. These are the typical values which are assumed in the lagoon design. Now we can do some modeling and understand that design of Lagoon by simple equations.

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Design of Lagoons

Applying mass balance on lagoon given in the figure:

$$BOD_{in} = BOD_{out} + BOD_{consumed}$$

$$QS_0 = QS + V(kS)$$

$$\frac{S}{S_0} = \frac{1}{1 + k(V/Q)} = \frac{1}{1 + k\theta}$$

Where, S/S_0 = fraction of soluble BOD remaining,

- ✓ k = reaction rate coefficient (d^{-1})
- ✓ θ = hydraulic detention time (d^{-1})
- ✓ V = reactor volume (m^3), and
- ✓ Q = flow rate (m^3/d)

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$$BOD_{in} = BOD_{out} + BOD_{consumed}$$

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Where, S/S_0 = fraction of soluble BOD remaining,

k = reaction rate coefficient (d^{-1})

θ = hydraulic detention time (d^{-1})

V = reactor volume (m^3), and

Q = flow rate (m^3/d)

So if you suppose there is a aerobic so this is a lagoon and here in this zone the aerobic treatment will happen and because the oxygen may not be available in this zone so here anaerobic treatment and in the sludge zone also an aerobic treatment may happen. This is the typical lagoon. Now we have the lagoon which is having a flow rate of water at Q and the initial concentration of solids is as S_0 and after treatment the flow rate remains the same and the solid this the concentration of the organic comes down to S .

So applying mass balance in the lagoon. So BOD in will be equal to BOD out plus BOD consumed. Now, the BOD actually in is Q into S_0 . So, S_0 is the initial concentration in terms of BOD, then the BOD out is Q into S . And we are assuming that the rate or conjunction of

BOD is given by first order reaction rate constant k , which is reaction rate coefficient is the term.

So, this is V into ks , s is the concentration inside the reactor and V is the volume. Now, if we actually use this equation, we can easily formulate this formula which is given here. So, S by S_0 is equal to 1 upon $1 + kV/Q$, where V/Q can be considered as θ which is the hydraulic detention time.

And S by S_0 is the fraction of soluble BOD remaining after the treatment. So, and V is the reactor volume Q is the flow rate. So, this is the simple equation we can find out for the lagoon.

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If several reactors are arranged in series, the effluent of one pond becomes the influent to the next. A substrate balance written across a series of n reactors results in:

$$\frac{S_n}{S_0} = \frac{1}{(1 + k(V/Q))^n}$$

A wide range of values for k is available in the literature. Although many variables relating to both the reactor and wastewater affect the value of k , water temperature affects it most significantly. k value at any temperature can be found out by following equation:

$$k_T = k_{20} \phi^{T-20}$$

Where, k_{20} = reaction rate constant at 20°C (ranges from 0.2 to 1.0) and ϕ = temperature coefficient ranges from 1.03 to 1.12.

A substrate balance written across a series of n reactors results in:

$$\frac{S_n}{S_0} = \frac{1}{(1 + k(V/Q))^n}$$

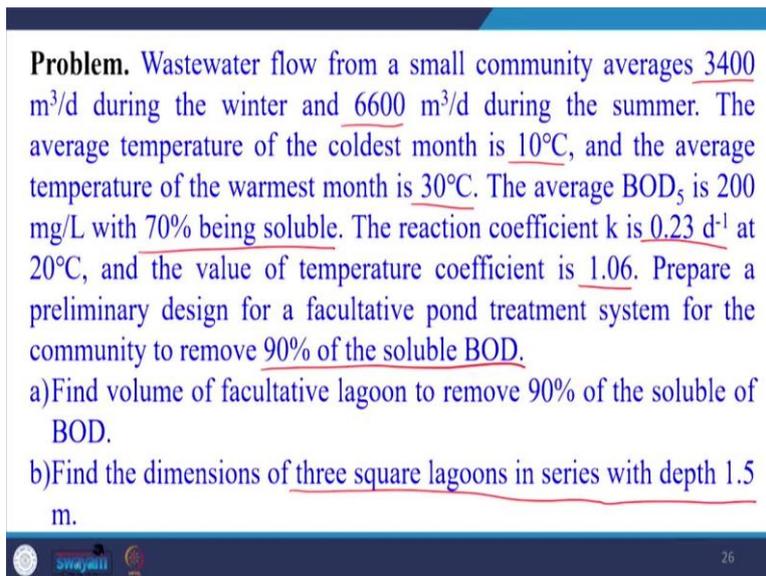
k value at any temperature can be found out by following equation:

$$k_T = k_{20} \phi^{T-20}$$

And if several reactors suppose one lagoon is followed by second lagoon etc., if several reactors are arranged in series, the effluent of one pond becomes the influence to the next and a sustained balance written across a series of N reactor results in the following formula the S_n upon S_0 equal to 1 upon $1 + kV/Q$ raised to n , where n is the number of reactors in series wide range of values of k are available in the literature.

So, we should know the value of k although many variables relating to both the reactor and wastewater affect the value of k , the water temperature affects it most significantly. So, k value at any other temperature can be found out using this formula k at 20 is known. So, k reaction rate constant at 20 degrees centigrade it may range from 0.2 to 1 and θ is the temperature coefficient which its value may also vary in the range of 1.03 to 1.12. This is there. So, this formula can be used for reactors or lagoons in series.

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Problem. Wastewater flow from a small community averages 3400 m³/d during the winter and 6600 m³/d during the summer. The average temperature of the coldest month is 10°C, and the average temperature of the warmest month is 30°C. The average BOD₅ is 200 mg/L with 70% being soluble. The reaction coefficient k is 0.23 d⁻¹ at 20°C, and the value of temperature coefficient is 1.06. Prepare a preliminary design for a facultative pond treatment system for the community to remove 90% of the soluble BOD.

a) Find volume of facultative lagoon to remove 90% of the soluble of BOD.

b) Find the dimensions of three square lagoons in series with depth 1.5 m.

Now, we will try to solve one problem before ending today's lecture. So, a wastewater flow from a small community averages around 3400-meter cube per day during the winter. Whereas, it is 6600-meter cube per day during the summer. This there is a lot of variation in the community with respect to wastewater generation per day. The average temperature of the coldest month is 10 degrees centigrade, whereas the average temperature of the warmest month is 30 degrees centigrade.

The average BOD 5 is 200 milligrams per liter, with 70 percent being soluble, and the reaction coefficient k is given to be 0.23 per day at 23 degrees centigrade, the value of temperature coefficient is given to be 1.06.

Now, we have to prepare a preliminary design of a facultative pond treatment system for the committee to review 90 percent of the soluble BOD, find the volume of the facultative lagoon to remove 90 percent of the soluble BOD, find the dimension of the 3 square lagoons in series with depth to 1.5 meter if we are using them to problems are given. Now we will go ahead

and solve for both the conditions summer as well as winter and in both the cases the average BOD same around 200 milligrams per liter with 70 percent soluble BOD.

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Problem. Wastewater flow from a small community averages 3400 m³/d during the winter and 6600 m³/d during the summer. The average temperature of the coldest month is 10°C, and the average temperature of the warmest month is 30°C. The average BOD₅ is 200 mg/L with 70% being soluble. The reaction coefficient k is 0.23 d⁻¹ at 20°C, and the value of temperature coefficient is 1.06. Prepare a preliminary design for a facultative pond treatment system for the community to remove 90% of the soluble BOD.

a) Find volume of facultative lagoon to remove 90% of the soluble of BOD.

b) Find the dimensions of three square lagoons in series with depth 1.5 m.

Solution:

(a) Estimation of rate constants at given temperature

Summer: $k_{25} = 0.23(1.06)^{30-20} = 0.411 \text{ d}^{-1}$

Winter: $k_{10} = 0.23(1.06)^{10-20} = 0.128 \text{ d}^{-1}$

(b) Estimation of volume of lagoon

Summer: $\frac{S}{S_0} = \frac{1}{1+k(V/Q)} \Rightarrow \frac{20}{200} = \frac{1}{1+0.411(V/6600)}$ $V = 144525.5 \text{ m}^3$

Winter: $\frac{20}{200} = \frac{1}{1+0.128(V/3400)}$ $V = 239062 \text{ m}^3$

(a) Estimation of rate constants at given temperature:

Summer: $k_{25} = 0.23(1.06)^{30-20} = 0.411 \text{ d}^{-1}$

Winter: $k_{10} = 0.23(1.06)^{10-20} = 0.128 \text{ d}^{-1}$

(b) Estimation of volume of lagoon:

Summer: $\frac{S}{S_0} = \frac{1}{1+k(V/Q)} \Rightarrow \frac{20}{200} = \frac{1}{1+0.411(V/6600)}$

$$\frac{20}{200} = \frac{1}{1 + 0.128 \left(\frac{V}{3400} \right)}$$

Winter:

Now, estimation of rate constant because the k value is given here is at 20 degrees centigrade and it is 0.23 per day. So, this is given in the question 0.23 per day at 23 degrees centigrade. So, we tried to find out the k value add different conditions. So this is k at 30 degrees centigrade is 0.23 1.0 30 minus 20 this is there and at in the winter season because the temperature is 10 so 10 minus 20 so 0.128 per day. So this condition there.

Then estimation of volume of lagoon in the first case, so, the formula which is used for single lagoon is this. Now, a put all the values, so, 90 percent have to be removed remember, we have to remove the 90 percent of the soluble. So, we are assuming that 20 by 200 or 0.9 we can assume this. So, under this condition, this is the formula. So, k value is already known for summer condition 0.411 and 6600 is the flow rate whereas, 3400 is the flow rate in the during the winter season, where the k value is 0.128.

So, in the both the conditions the volume is coming out 144525 whereas, 239062 that means, the volume which is required in the winter season for treatment is much higher as compared to during the summer season.

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(c) Estimation of dimensions of three square lagoons in series

$$\frac{S_n}{S_0} = \frac{1}{\left(1 + k \left(\frac{V_i}{n \times Q} \right) \right)^n}$$

Summer: $\frac{200}{20} = \left(1 + \frac{0.411 \times V_i}{3 \times 6600} \right)^3 \quad V_i = 55607.13 \text{ m}^3$

Winter: $\frac{200}{20} = \left(1 + \frac{0.128 \times V_i}{3 \times 3400} \right)^3 \quad V_i = 91980.8 \text{ m}^3$

Summer:

$$\frac{200}{20} = \left(1 + \frac{0.411 \times V_i}{3 \times 6600} \right)^3$$

Winter:

$$\frac{200}{20} = \left(1 + \frac{0.128 \times V_i}{3 \times 3400}\right)^3$$

Now, if suppose we are going to use 3 volumes in series, so, we have 1 reactor, 2 reactors, and 3 reactors and want to remove the 90 percent of the soluble BOD. Now, the equation for this case will become S_n by S_0 this is that means S_3 by S_0 is equal to 1 upon $1 + k V_i$, V_i means the volume of each and by n into Q . So, this is there.

So, if you solve so, it is coming out V_i is equal to 55,607 for summer season and 91,980 for winter season. So, again we have more volume which is required for treatment during winter season.

This is how we can design the reactors based upon the data available for lagoon for a simple community like village community or a very small community in any of the town and thus we can foresee that how much amount of lagoon area or volume will be required that depending upon that depth we can assume the initial conditions and then just we can treat the water which is generated in the community. So we are going thank you very much. We will learn the activated sludge system in detail in the next lecture. Thank you very much.