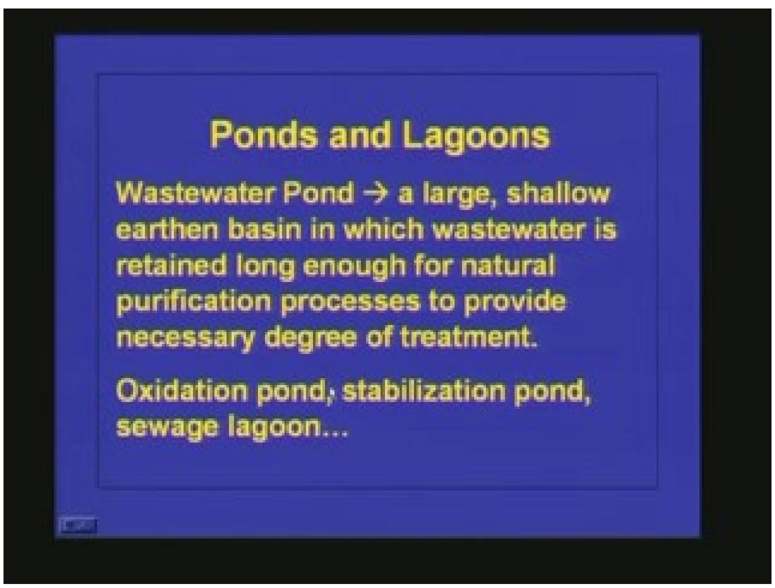
Water and Wastewater Engineering
Dr. Ligy Philip
Department of Civil Engineering
Indian Institute of Technology, Madras
Natural Wastewater Treatment Systems
Lecture - 25

Last class we were discussing about various design parameters of activated sludge process. We have seen in detail the design criteria of aerators, how we can select aerators and how many aerators we have to provide and so on. Also, we started seeing what are these ponds and lagoons, we have discussed about various type of ponds namely; aerobic ponds, facultative ponds, anaerobic ponds then we also talked about aerated lagoons and pollution ponds.

What is a pond?
A pond is nothing but a large earthen basin in which wastewater is retained enough for natural purification process to provide necessary degree of treatment. here we are not giving any extra treatment but whatever is happening by the natural process we are allowing enough time for the wastewater to stay there so that the natural process will take care of the pollutant whatever is presented in the wastewater and with respect to time everything will be purified and the water will be of discharged quality. This is known as a pond.

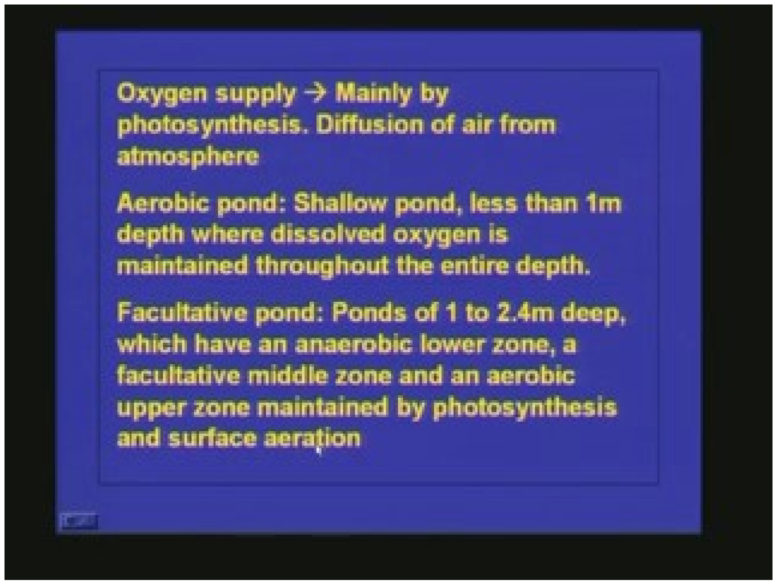
We are utilizing the natural phenomena for the treatment of the wastewater and we have seen that pond usually is called by different names such as oxidation pond, stabilization pond, sewage, lagoons etc.

(Refer Slide Time: 1:52)



And here the oxygen supply is because of photosynthesis, that is one way how the pond is getting oxygen and another way is the natural replenishment because whatever oxygen present in the wastewater will be consumed by the microorganisms when they utilize the food or it is the biochemical oxygen demand that will be consumed by the microorganisms so naturally the dissolved oxygen concentration in the wastewater will be coming down.

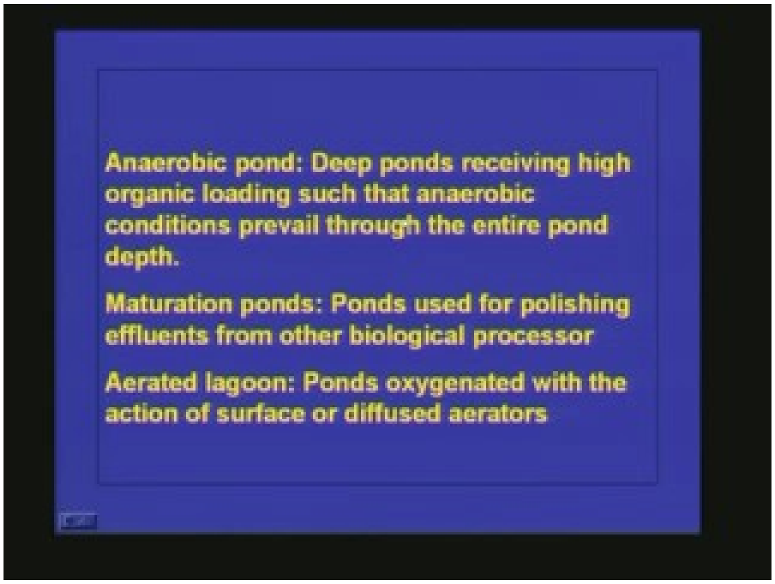
(Refer Slide Time: 2:29)



And if you see the saturation concentration of oxygen in water varies from 8 to 9 point within the available temperature. What I mean is if the temperature is between 20 and 30 degree centigrade that is the usual temperature we experience in our country, especially in the southern part of our country so during this period we allow the oxygen concentration to get saturated. We will be getting a value in between 8 to 9.2 mg per liter but when organic matter is there and microorganisms utilizing oxygen will be consumed at a faster rate and dissolved oxygen concentration in the wastewater will be almost nil or it will be in the range of 102 mg per liter so there exists a great concentration gradient because there is a drastic difference between the saturation concentration and the concentration existing in the wastewater. This concentration gradient drives more oxygen to get dissolved in the wastewater. That is the way how the oxygen concentration is increasing in the ponds.

We have already discussed what an aerobic pond is. It is a shallow pond less than 1 m in depth where dissolved oxygen is maintained throughout the depth of the tank it is an aerobic pond.

(Refer Slide Time: 6:14)



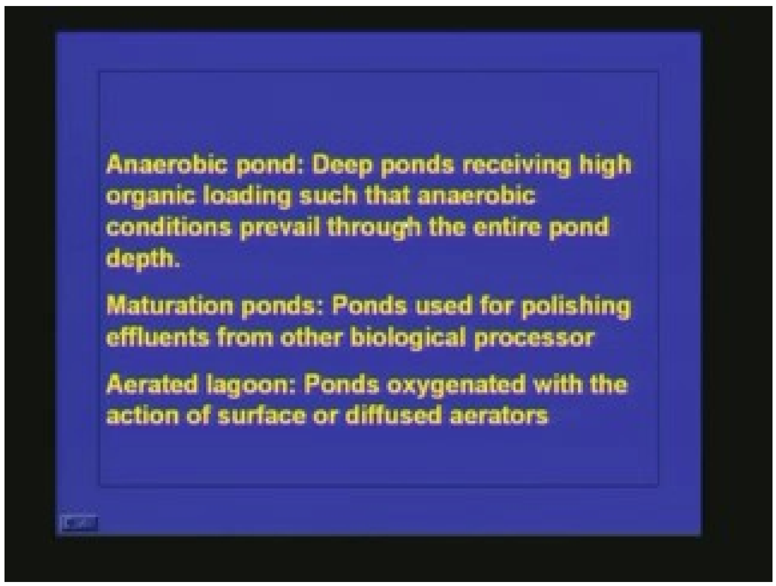
Facultative pond also we have discussed. Here the pond depth varies from 1 to 2.5 m so we will be having an aerobic zone, then a facultative zone and anaerobic zone. So, in anaerobic zone the entire sludge will be settling down and it will undergo anaerobic degradation because since oxygen is not available there anaerobic bacteria will be growing at a faster rate in that region so they will be converting this sludge organic sludge whatever is settled in the bottom of the tank and as a result the biogas that means methane and carbon dioxide will be generated.

Sometimes because of the presence of inorganic substances like sulphate, nitrate etc in the waste it will be getting reduced to sulphide and ammonia so we may get nitrogen sulphide and ammonia also from the bottom layer. So once it comes up in the facultative layer it will be having both aerobic and anaerobic bacteria. The facultative bacteria are those which can survive in aerobic condition as well as anaerobic condition. So the middle layer will be in facultative condition and the top layer will be completely in aerobic condition, there the photosynthesis will be providing enough oxygen photosynthesis and the natural replenishment will be giving enough oxygen for the microorganisms. therefore because of that one the organic matter will be getting oxidized and whatever is the inorganic compounds coming in the reduced form that also will be getting oxidized in that zone because of the availability of oxygen.

Anaerobic pond is the one which is very deep and throughout the length of the tank anaerobic condition will be prevailing. So this type of ponds is used to treat high organic clot wastewater. For example, if you take distillery wastewater the COD varies from 30000 to 1 lakh or few lakhs depending upon the process. So, if you want treat them aerobically you can imagine what is the amount of oxygen we have to supply because we have seen that for 1 kg COD destructions or 1 kg BOD destruction we have to supply for 1 to 2 kg of oxygen depending upon the process whether it is a conventional activated sludge process or an extended aeration process.

If the COD is so high how can we transfer that much of oxygen that is one problem, another one is to transfer that much of oxygen what is the power required that is also too high and the economics or the operational cost involved in such a system will be very very high. What usually is practiced in the treatment of high organic clot wastewater is first go for anaerobic treatment because anaerobic process will be taking care of a major portion of the organic matter and it will be getting converted to methane and carbon dioxide apart from new cells so the COD or the BOD will be getting reduced to around 50 to 60% in the anaerobic reactors or the anaerobic pond and afterwards it will be coming to facultative pond or aerobic pond and it will be getting treated to the required degree. So we can eliminate or we can avoid the extra or excessive oxygen requirement which will not be available by the natural replenishment process that is why we prefer anaerobic pond for high strength wastewater.

(Refer Slide Time: 12:50)



Now coming to the maturation ponds this I have discussed earlier in the previous class. Maturation ponds are the ponds used for polishing effluent from other biological processes. For example, if you go for conventional activated sludge process or anaerobic process nowadays the flow anaerobic sludge blanket is coming and many municipalities are employing that type of process for the wastewater treatment. But the disadvantage of such process is that the destruction of microorganism whatever is present in the wastewater is very very low the destruction of pathogens or the disease causing microorganisms whatever is present in the system after passing through such treatment unit is only one or two log.

That means if you have 10 raised to 7 no of microorganisms per ml that is the usual average concentration of microorganisms present in the domestic wastewater and after treating it in a anaerobic process and effluent if you check for the microbial concentration you will be finding around 10 raised to 4 to 10 raised 5 or sometimes even 10 raised to 6 number of organisms per ml and if you want to discharge this water to existing water bodies it is not advisable and the standards will not allow you to discharge sludge wastewater to the inlet water bodies. So in such cases what we have to do is we have to destruct the microbial concentration.

We have discussed that in water treatment we can destroy the microorganisms using disinfection process but it is advisable to go for disinfection. In case of wastewater the answer will be no because the amount of chlorine required for the destruction of microorganisms as well as the non biodegradable organic matter whatever is presented in the wastewater will be very very high so the costs involved in the process will be extremely so it is not advisable to go for the chlorination after the secondary treatment.

Moreover there will be many organic compounds so what will happen is this chlorine will be reacting with these organic compounds and it will be forming organochlorine compounds and most of the organochlorine compounds are cosonic in nature and they are very difficult to degrade. So if you treat it with chlorine and whatever is the treated effluent if you discharge into the inlet water bodies that water may be used by somebody as a source or raw water source for the water supply. So naturally all these organocholrine compounds will be presented there and for most of the treatment 100% removal of organocholrine compounds may not take place so it is not advisable.

The solutions for such problem is to go for polishing ponds. In polishing ponds what we are doing is allow the water to stay for long time and as we have seen in aerobic ponds throughout the depth of the pond aerobic conditions will be prevailing or dissolved oxygen will be available throughout the depth of the tank so the tank or the pond will be exposed to sunlight. And in sunlight there is so much of UV radiation so because of this UV radiation and adverse environmental conditions most of the pathogens will be destructed.

Therefore whatever effluent we are getting from the oxidation pond or the polishing pond will be meeting the effluent discharge standard in case of pathogens or the microbial concentration or with respect to most probable number as well as the organic matter because we are providing such a long detention time with the polishing unit or the polishing pond so what will happen is definitely there will be microorganism present in the system.

Oxygen is available continuously so these microorganisms will be utilizing the left over organic matter whatever has come out of the secondary treatment and they will be converting it into carbon dioxide and fresh cells so your effluent whatever is coming from the polishing units will be much better compared to the ones coming out of the secondary treatment unit. That is the purpose of maturation ponds or a polishing pond.

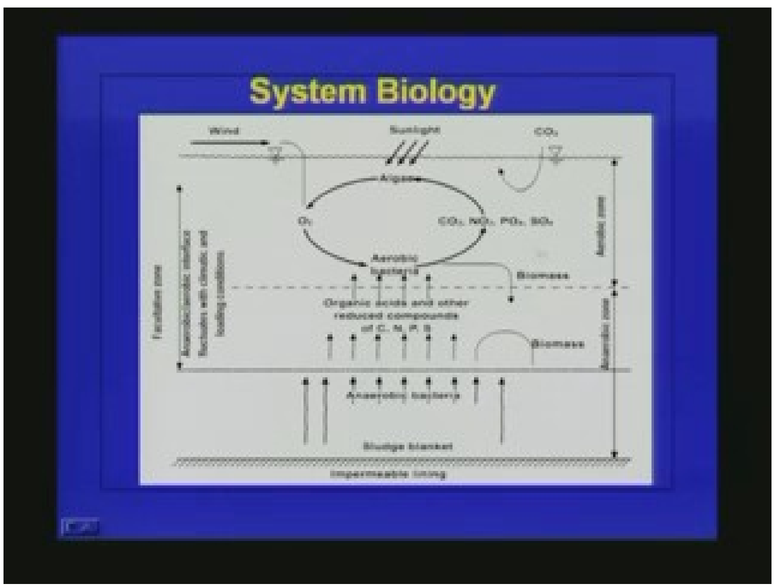
Now we will see aerated lagoons. This also I have explained in the last class. In aerated lagoons what we are doing is most of the time the oxygen is transferred by natural replenishment or because of the re-aeration process from the atmosphere oxygen is getting into the pond system. But if the wastewater strength is very high, most of the time this oxygen transfer will not be sufficient to give enough oxygen for the microorganisms for the oxidation of the organic matter in such cases we supply air by mechanical means by using surface aerator or diffused aerators.

In a pond if you use artificial aeration then that is known as lagoons. Lagoons also can be classified into aerated lagoons and facultative lagoons. In aerobic lagoons all the suspended solids whatever is present in the wastewater will be in suspension, complete mixing will be taking place. This is known as aerobic lagoons.

In facultative lagoons what happens is it will be having just like facultative pond anaerobic zone and a facultative zone and anaerobic zone. So in the anaerobic zone the sludge will be there that means some amount or a certain amount of sludge will be settling down in the bottom of the tank. Or the sludge whatever is present in the wastewater or all the suspended solids whatever is present in the wastewater will not be available in suspended form. This is known as facultative lagoons.

Anaerobic degradation will be taking place and all other treatment is exactly similar to a facultative pond but the only thing is we are providing aeration artificially or by mechanical means. Now we will see what exactly is happening in a pond. We will discuss the system biology in detail.

(Refer Slide Time: 15:40)



This is a facultative pond. Why I am discussing about the facultative pond is in most of the cases especially for municipal wastewater treatment we go for a facultative pond because maintaining aerobic pond will be very very difficult and the area required for such ponds will be tremendous so the land cost will be so high. So it is practiced that most of the time for domestic wastewater treatment or municipal wastewater treatment facultative ponds are usually used. So the facultative ponds are having three distinguish layers; this is the anaerobic layer and this is the facultative zone and this is the aerobic zone.

What is happening in the anaerobic zone is here the microbial anaerobic bacteria will be present and after that because of the anaerobic bacterial degradation volatile organic acids are produced and that will be coming into the top layers and biogas will be produced. That means methane and carbon dioxide will be produced here which will be coming up from the system and we will be getting reduced compounds of nitrogen, phosphorus and sulphur and here the top layer we have the aerobic layer. So in aerobic layer what happens is the symbiotic action of aerobic bacteria and algae is taking place.

What is this symbiotic action? Symbiotic action is the action by two groups of microorganisms or two groups of microorganisms or groups in such a way that the activity of one group helps the other groups and vice versa. That means both the groups are interdependent. This is the symbiotic action. How the symbiotic action is taking place in an oxidation pond? What happens if the organic matter is present? The microorganisms will be utilizing the organic matter and they will be converted into carbon dioxide and water and as a result more new cells will be produced.

But what will happen when algae is present? Algae will not be using any organic matter whatever is present in the wastewater because we know that algae can generate or produce organic matter by using carbon dioxide and this organic matter thus produced by photosynthesis is used for the cytoplasm formation. So the carbon dioxide whatever is released by microorganisms will be utilized by algae and that carbon dioxide will be used by them in photosynthesis process and it will be getting converted into cytoplasm or other organic material and that will be released to the system.

In the process of photosynthesis what will happen is the water will be getting oxidized and oxygen will be released so during photosynthesis more and more oxygen will be available to the microorganisms which can utilize the organic matter and convert the organic matter into carbon dioxide and water so this carbon dioxide will be utilized by the algae.

Algae will be producing oxygen that is being used by microorganisms or bacteria and bacteria will be utilizing the organic matter and producing carbon dioxide that will be utilized by the algae that is why we call it as a symbiotic relationship. Because of this photosynthesis as well as the re-aeration more and more oxygen will be available in the pond but what will happen in night time whether the algae will be able to produce oxygen because photosynthesis required sunlight so at night time algae will not be able to produce any oxygen and moreover for their respiration they need oxygen so if you see the dissolved oxygen concentration in a pond will be varying diagonally. That means there will be a strategic change in dissolved oxygen concentration.

If you see between day time and night time during the night time definitely the dissolved oxygen concentration will be less compared to day time because day time oxygen is entering in the system because of photosynthesis and during night time whatever oxygen is entering in the system due to re-aeration from the atmosphere by natural process it will be consumed by both bacteria and algae.

What will be the condition of ph in the system, whether the ph will remain a constant throughout the day, it is not because what is happening is because of the microbial degradation carbon dioxide will be produced in the system and we know that if carbon dioxide gets dissolved in water it will be forming carbonic acid and carbonic acid will bring down the pH of the system. But in day time what is happening in oxidation pond is whatever carbon dioxide is released by the microorganisms will be immediately consumed by the algae for the photosynthesis. So the carbon dioxide concentration will be less or the dissolved carbon dioxide concentration in the pond will be less so because of that one naturally the ph of the system will be high.

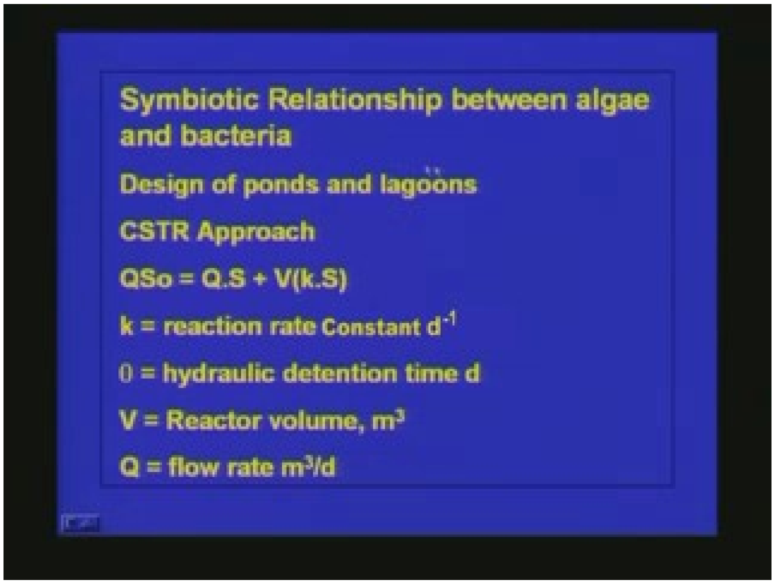
But what will happen in night time the algae will be doing the respiration and bacteria will be doing their respiration so as a result carbon dioxide will be produced by both the organisms and all the carbon dioxide whatever is produced in the system will be remaining in the system because algae will not be able to do any photosynthesis during night time so the concentration of carbon dioxide will be very very high in night time because of that one the ph of the system will be coming down.

If you see the day time and night time there will be a strategic variation or a measurable variation of dissolved concentration as well as pH in the system. This is the working principle of oxidation pond.

The major one is symbiotic relationship between the algae and bacteria because of this symbiotic relationship it is very very difficult to model the pond system and we have seen already that the major contribute of the COD removal or the organic matter removal is bacteria because algae utilized only carbon dioxide for their cell synthesis but it is reported that certain algae can use the organic matter in a heterotrophic pathway and generate more and more algae cells.

But the contribution by those types of algae is very very significant compared to the bacterial contribution. So, as far as the COD removal is concerned bacteria or the major contributors but to maintain a high dissolved oxygen concentration. Algae play a significance role so that is what we have seen the symbiotic relationship between algae and bacteria that is what is taking place in a pond system.

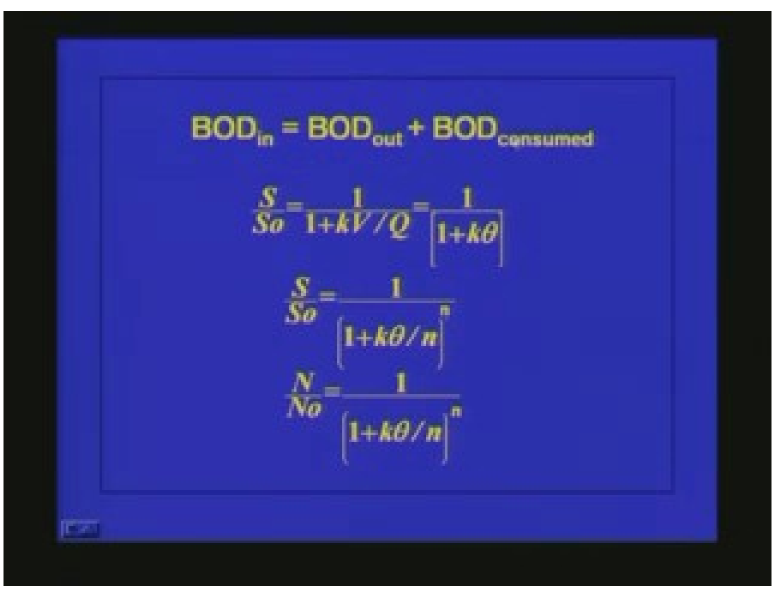
(Refer Slide Time: 20:50)



This is the most important thing. If you have more algae in the system definitely the dissolved oxygen concentration in the system will be high. Now we will see how we can design a pond or a lagoon. Either we can go for a CSTR approach or we can go for a plug flow approach so if you want to go for a CSTR approach we can use this equation.

What is the BOD in mass balance? If you take, that is equal to BOD out plus BOD consumed because mass cannot be destructed so it will be appearing in some other way. Whatever is the BOD coming into the system is equal to BOD out plus BOD consumed by the microorganism whatever is present in the system so we can write like this;

(Refer Slide Time: 22: 50)

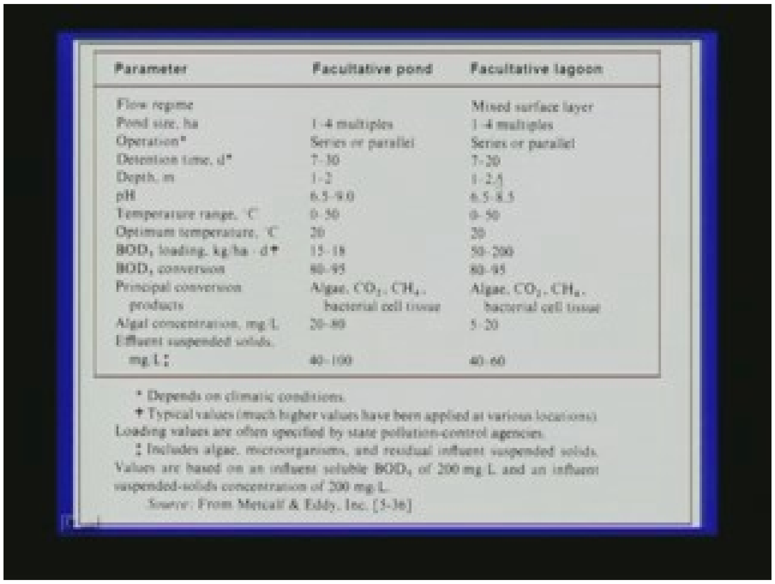


What is the total BOD coming to the system? That is nothing but flow rate into the BOD concentration that is Q into S0 that is equal to Q into S that is the BOD present in the outlet Q into S plus V into k into S. This is the reaction whatever is taking place in the system or this is the rate at which the organic matter is getting removed from the system where k is the reaction rate constant per day and S we have seen is the BOD of the outlet water because it is the CSTR reactor as soon as S0 enters in the system because of the complete mixing it will be instantaneously changing to S that is why we are using V into k into S and theta we have already seen, this is the hydraulic detention time that means what is the amount of time the water is staying in the treatment system and V is the reactor volume and Q is the flow rate.

Thus, if you want to write an equation we can write like this S by S0 is equal to 1 by 1 plus k into V by Q because the earlier equation was; Q into S0 is equal to Q S plus V into k S so from that one we will be getting this equation S by S0 is equal to 1 by 1 plus k into V by Q and we know that volume by flow rate is nothing but the hydraulic retention time so the equation can be modified like this; S by S0 is equal to 1 by 1 plus k theta so this is the treatment efficiency in a single pond. But if you have end number of ponds what will be the outlet concentration?
We can write like this; S by S0 is equal to 1 by 1 plus k theta by n because this is the detention time in each pond because theta is the total detention time. So if you have n tanks then theta by n will be the hydraulic retention time in each tank and it will be raised to n. So, S by S0 is equal to 1 by 1 plus k theta by n raised to n or if you are talking about the microorganisms because the ponds can be utilized as the polishing unit also in that case if you want to find out what is the outlet microbial concentration we can use this formula; n by n0 where n0 is the initial microbial concentration that is equal to 1 by 1 plus k theta by n raised to n.

These are some design parameters of a facultative pond and facultative lagoons. So detention time of facultative pond varies from 7 to 30 days. In facultative lagoons it is 7 to 20 days because we are giving aeration artificially and depth varies from 1 to 2 m and here it can be 1 to 2.5 m and BOD loading kilogram per hectare here it can vary from 15 to 18 kg BOD per hectare.

(Refer Slide Time: 26:00)



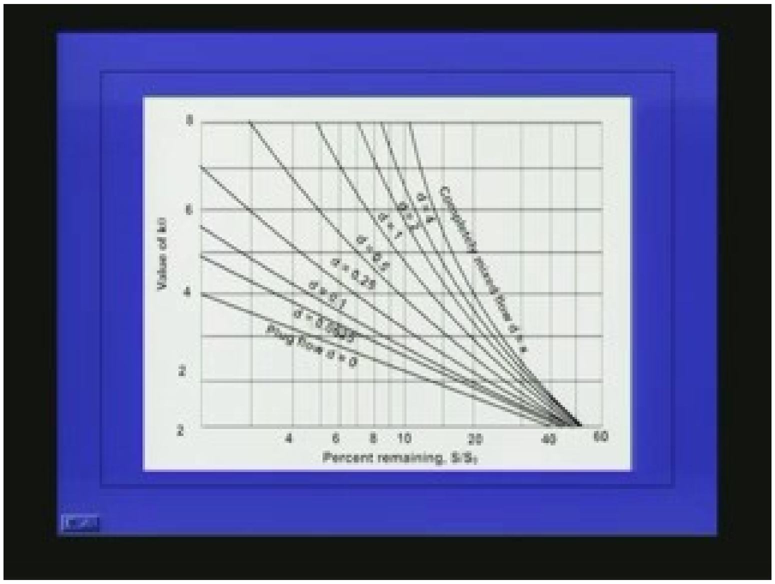
Parameter	Facultative pond	Facultative lagoon
Flow regime		Mixed surface layer
Pond size, ha	1-4 multiples	1-4 multiples
Operation*	Series or parallel	Series or parallel
Detention time, d*	7-30	7-20
Depth, m	1-2	1-2.5
pH	6.5-9.0	6.5-8.5
Temperature range, °C	0-50	0-50
Optimum temperature, °C	20	20
BOD_5 loading, kg/ha · d†	15-18	50-200
BOD_5 conversion	80-95	80-95
Principal conversion products	Algae, CO_2, CH_4, bacterial cell tissue	Algae, CO_2, CH_4, bacterial cell tissue
Algal concentration, mg/L	20-80	5-20
Effluent suspended solids, mg/L‡	40-100	40-60

* Depends on climatic conditions.
† Typical values (much higher values have been applied at various locations). Loading values are often specified by state pollution-control agencies.
‡ Includes algae, microorganisms, and residual influent suspended solids. Values are based on an influent soluble BOD_5 of 200 mg/L and an influent suspended-solids concentration of 200 mg/L.
Source: From Metcalf & Eddy, Inc. [5-36]

In facultative lagoons we can go up to 50 to 200 kg per hectare because we are supplying air externally and BOD conversion or the treatment efficiency is 80 to 95 in both the systems and effluent suspended solids if you see in facultative pond will be in the range of 400 to 4200 mg per liter whereas in facultative lagoons it is 40 to 50 mg per liter.

Therefore, if you supply air externally we can improve the efficiency and we can reduce the land or the area requirement and we have seen the design of a facultative pond based upon CSTR concept. But we know that there is no complete mixing taking place in any pond system and we know that it is not completely plug flow reactor because the turbulence will be reduced because of the temperature gradient and because the wind will be blowing and since this is such a vast area open to the atmosphere there will be turbulence. So in most of the cases the ponds whatever we are considering they are neither plug flow nor CSTR. So it will come between and CSTR.

(Refer Slide Time: 27:30)



If you know where it stands then depending upon the efficiency required we can find out what is the detention time we have to give in the ponds. This family of curve is available and here the x axis gives the remaining percentage. That means S by S0 if S0 is the initial concentration and S is the effluent concentration then this is the percentage BOD remaining in the system. So if you know what is the efficiency you want to achieve by the pond system then you will be knowing what is the percentage remaining so corresponding to that one depending upon the flow regime or mixing regime we can find out what is the k theta value we have to provide. Theta is nothing but the HRT and k is the degradation constant. This is available for oxidation pond. It will be varying with various parameters.

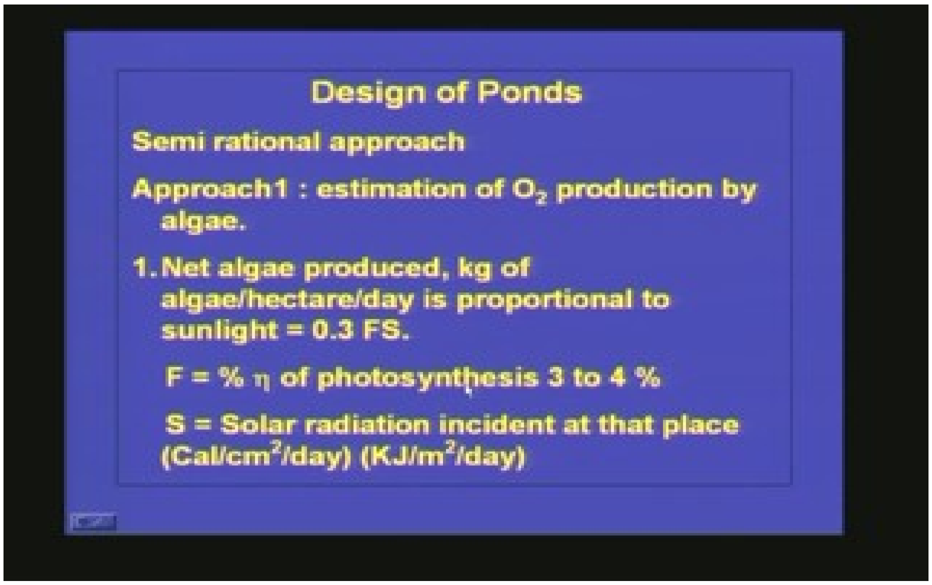
Now we will see if you want to design a pond based upon this (noise 28:29) or semi rational approach because we know that we cannot go for the CSTR approach and design a pond because most of the time the tanks will not be completely mixing.

Therefore, in most of the design cases for ponds and lagoons people use semi rational approach or empirical formula so this is one approach which is most commonly used for the design of ponds. So here what we are doing is we are finding out the oxygen produced by the algae and we know what is the oxygen requirement by the biomass so we can find out what is the area requirement. We will see this design approach in detail.

The first step is we have to find out what is the net algae produced. That means kilogram of algae per hectare per day is the net algae produced. We are exposing this unit algae per hectare per day so it is proportional to the sunlight available because if sunlight is there then photosynthesis will be more efficient and as a result more and more algae cells will be produced that is why this formula is being used.

The net algae produced is equal to 0.3 into F into S where F is the percentage efficiency of photosynthesis. Usually we take 3 to 4% because if that much of sunlight is available so 3 to 4 percentage is the efficiency of photosynthesis and S is the solar radiation incident at that place and the unit can be either called per centimeter square per day or kilojoules per meter square per day. So if you can put that one here you will be getting what is the net algae produced in kilogram algae per hectare per day.

(Refer Slide Time: 30:06)

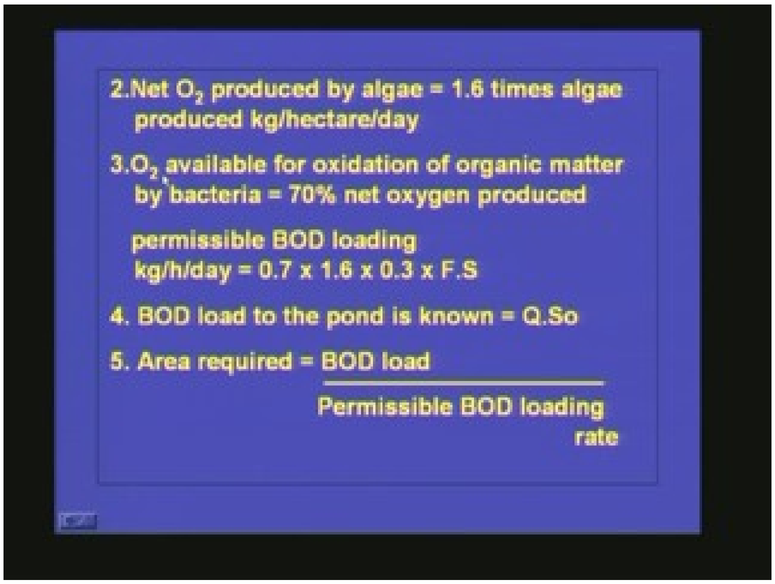


Now what we have to do is we have to find out algae produced. Now we want to find out what is the oxygen produced by this amount of algae because we know what is the total quantity of algae produced using the formula then we can find out what is the net oxygen produced by the algae and by experiments it has shown that the algae produced one point six times the algae mass. So, if you know the total algae produced the total oxygen produced is 1.6 times the algae available. That means 1.6 times algae produced in kilogram per hectare per day.

Now we will see what is the oxygen available for oxidation of the organic matter by the bacteria. Whatever the total amount of oxygen produced will not be available for the microorganisms for those oxidations so we are assuming whatever the oxygen production by the algae only 70% of the oxygen is available for the microorganisms. From this information we can find out what is the permissible BOD loading. The permissible BOD loading is nothing but the oxygen available in the system. So we have seen what is the total algae produced and if you know the total oxygen produced by the algae that is nothing but 1.6 times the mass of the algae per hectare per day.

We have also seen that whatever the oxygen produced by the algae 100% is not available for the microorganisms for the organic matter conversion so we are taking a factor of 0.7 because. We are assuming that whatever the oxygen available only 70% is available for the microorganisms. If this information is available we can find out what is the permissible organic loading rate.

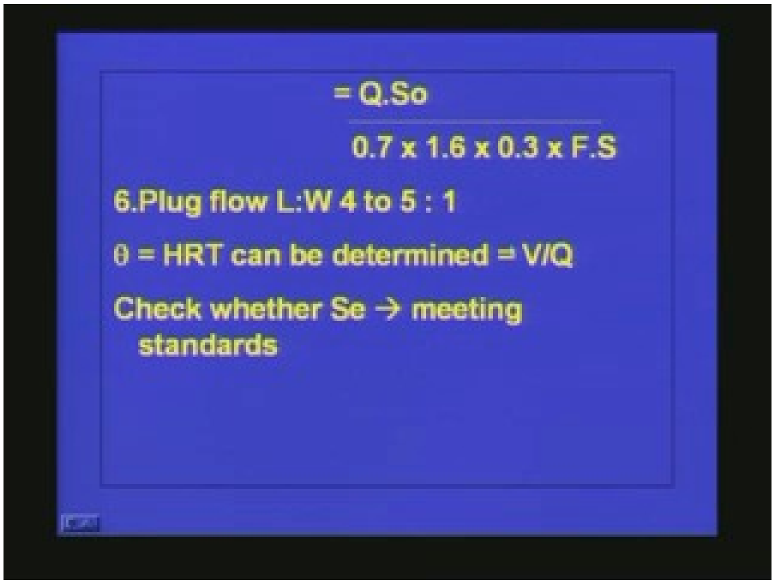
(Refer Slide Time: 31:00)



The permissible organic load is nothing but the total oxygen available so this is what I have given here. This is nothing but 0.7 that is coming from this factor into 1.6 into 0.3 into F into S. So this much is the BOD loading permissible so BOD load to the pond is also known because we know the amount of water we have to treat. This is the flow rate and this is the initial BOD so you know what is the load coming to the pond, it is nothing but Q into S0 and you know the permissible loading rate. Hence, we can find out what is the area required that is nothing but BOD load divided by permissible BOD loading rate that means Q into S0 divided by 0.7 into 1.6 into 0.3 into F into S.

We are assuming that the pond is having a flow regime of plug flow so if it is a plug flow reactor then we can provide l is to length is to width ratio of 4 to 5: 1 so we know the ratio then we can find out what is the length and what is the width we can provide and we know the theta which is equal to HRT which can be determined by V by Q that is HRT.

(Refer Slide Time: 33:27)



Therefore once the volume is known and Q is known we will know the HRT and we can check whether your design is correct by using other procedures.

I will explain once again. First we have to find out this design is based upon empirical results or many researches have been conducted in the field on pond system and based upon the results obtained from them from that results this design approach is developed. So first one what we are doing is find the algal production.

Algae production will depend upon the solar incidence. So we can find out the algal production per hectare per day using the formula point three into F into S, F is the efficiency of photosynthesis and usually it varies from 3 to 4%. Once the algae is produced then our interest is how much is the oxygen supplied by this algae that also we know that a factor 1.6 can be used for the calculation of oxygen produced by the algae because this 1.6 also is got from the experimental results so we know what is the oxygen produced by the algae.

Now we will see how much oxygen is available for the microorganisms for the oxidation of the organic matter. So we are assuming that out of the total oxygen requirement only 70% is available for the microorganisms so we know what is the oxygen available. This oxygen available is nothing but the permissible organic loading because if that much of organic matter comes to the system this much oxygen is available. So it can be converted into carbon dioxide and water and you will be getting 100%.

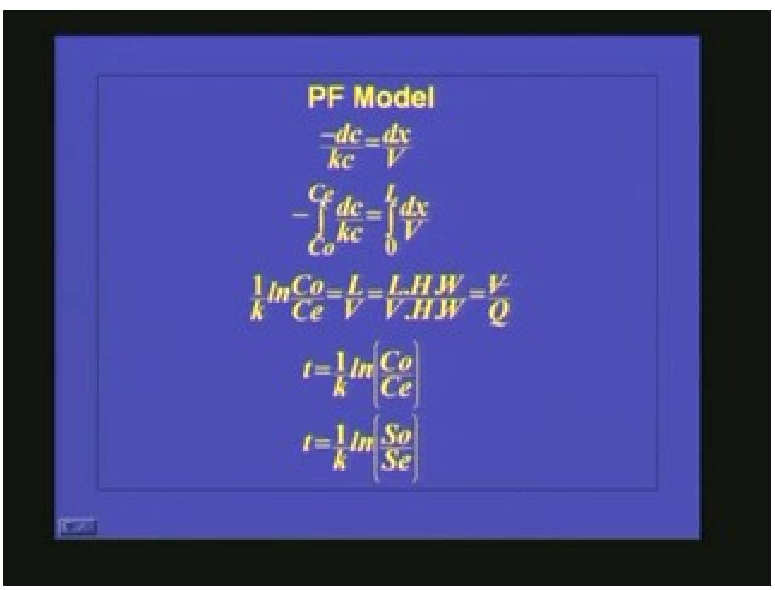
With this data we can get the permissible organic loading and you know the total load that is going to come to your system because we know what is the quantity of wastewater we have to treat and what is the BOD or organic content of the wastewater from that one we can find out the total loading to the system and as we know the permissible loading so we can find out what is the area required.

Once the area required is calculated then we are assuming that it is a plug flow regime so we can find out the length and width we have to provide because we are assuming a ratio 4 to 5:1 the length is to width ratio so we have fixed up the area and you also know what is the depth you have to provide. If it is an anaerobic pond it is 1m and if it is a facultative pond we can go up to 2.5 m. So we can provide the depth according to the requirements. Once the depth length and width is known we know the volume of the tank and you know the flow rate so you can find out what is the HRT of the system.

Now we will see how we can find out the efficiency of the system or whether the design is correct. We can go for some other approach and check whether the HRT we have provided in the system is sufficient to treat the waste.

What is the organic matter left over after a particular time? This l is equal to l0 into e raised to minus kt or from this equation we can write like this; I0 by l is equal to 10 raised to kt. Here I0 is nothing but the ultimate BOD and l is the BOD remaining in the system so that is equal to 10 raised to kt or we can write like this I0 divided by I0 minus yt which is equal to y t is the BOD exerted so I0 minus yt that means whatever is totally presented and whatever is removed that is nothing but whatever is left over so I0 by I0 minus y t is equal to 10 raised to kt. Thus, if you take the logarithm of both sides we will be getting log I0 by l is equal to kt or t is equal to 1 by k into log S0 by Se, S0 is the initial BOD and Se is the effluent BOD the desired BOD. So from this one we are getting a time. This is nothing but the hydraulic retention time we need to supply to get this efficiency so you check whether this t is less than the earlier t, this t is more than the hydraulic retention time we have provided in the tank. Further if the design is not proper then you have to give more hydraulic retention time so this is the check for the semi empirical approach.

(Refer Slide Time: 38:45)



Now we can come to the same conclusion using the plug flow model theoretically. We know that in plug flow this is the concentration variation with respect to the position in the plug flow reactor so dc by kc is equal to dx by V and if you integrate C0 over Ce and throughout the length we will be getting dc by kc limit C0 to Ce is equal to dx by V limit 0 to l. Or we can write like this; 1 by k into ln C0 by Ce is equal to l by V so here V is nothing but the velocity of flow and dx is the length of the instantaneous or the length of the incremental distance so we can write like this; 1 by k into ln C0 by Ce is nothing but l by V so if you multiply it with the cross sectional area l by V into h into w is equal to l into depth into width is equal to volume and here velocity into cross sectional area is giving you the flow rate. So V by Q we are getting it here so this is nothing but the hydraulic retention time for hydraulic retention time t is nothing but 1 by k into ln C0 by Ce or S0 by Se. So this derivation part we have seen earlier, what is the change in concentration with respect to time in a completely mixed batch reactor, it is equivalent to the change in the concentration with respect to space in the plug flow reactor. That is why we are getting this one and you know the concentration is changing from C0 to Ce and length is varying from 0 to l. This derivation we have seen earlier.

So if you go by this plug flow approach also you will be getting the same hydraulic retention time. So we can use this hydraulic retention time as a check for the semi rational approach which we use for the design of oxidation pond or a facultative pond. So it is always advisable to go for a series of pond instead of a single pond. the reason is, if you go for a single pond we know that we will not be able to maintain the plug flow regime throughout the pond system so mixing will be taking place in the system so the concentration whatever we are putting such as C0 is initially given to the system and the concentration will be changing to Ce within a short period of time in the same time.

Therefore, the concentration gradient is the driving force for the biodegradation because we know that in first order reaction the dc by dt the rate of change of pollutant concentration is equal to k into c. So, if c is nothing but C0 by Ce so if c is high the rate of change of concentration will be higher. So if we go for a single pond this c value will be less. But if you go for a series of ponds first it is changing from C0 to C1 then from c1 to c2 c2 to c3 and so on so in different stages it will be getting converted to Ce so definitely the efficiency will be much more if you go for a series of ponds instead of a single pond.

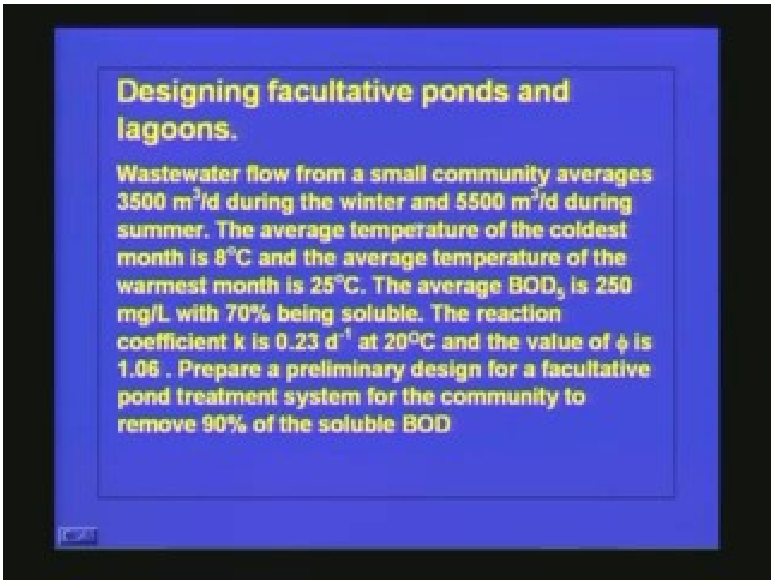
It is also shown that if you go for a series of ponds then all the pond volumes are the same then you will be getting maximum efficiency. How can we derive that one? It is very simple because we have seen that the formula S0 by Se is nothing but 1 by 1 plus k theta raised to n if you have n ponds so we will take only two ponds so the efficiency Se by S0 will be equal to 1 by 1 plus k theta 1 into 1 by 1 plus k theta 2.

Theta 1 and theta 2 are the hydraulic retention of two independent ponds and if you want to get maximum efficiency that means your Se value should be minimum. If you want to get Se by S0 a small value definitely your denominator in this side should be less. So if the denominator is nothing but 1 plus k theta 1 into 1 plus k theta 2 so if you want to make that one less. If you want to make the total value small the denominator should be more that means 1 plus k theta 1 into 1 plus k theta 2 should be maximum.

Or if you want to make the make it maximum at what is the maximum condition we differentiate it with respect to theta and equate it to 0 then we can find out the value of theta and from that value we can find out the condition required for getting maximum efficiency and equate to 0. You can see that when theta 1 is equal to theta 2 you will be getting maximum efficiency so this one is true for n series of ponds also.
So you can try the derivation by yourself.
I have already explained how to do it. You have to make the denominator maximum to get maximum removal efficiency or a minimum value for Se by s0. So how can we make the denominator maximum? You differentiate it and equate to 0 and find out how the theta 1 and theta 2 are coming.

Hence, for n series of ponds if you provide the same hydraulic retention time in each and every tank then you will be getting maximum efficiency. It is always advisable to go for a series of ponds instead of having a single pond to get maximum efficiency.

(Refer Slide Time: 44:40)

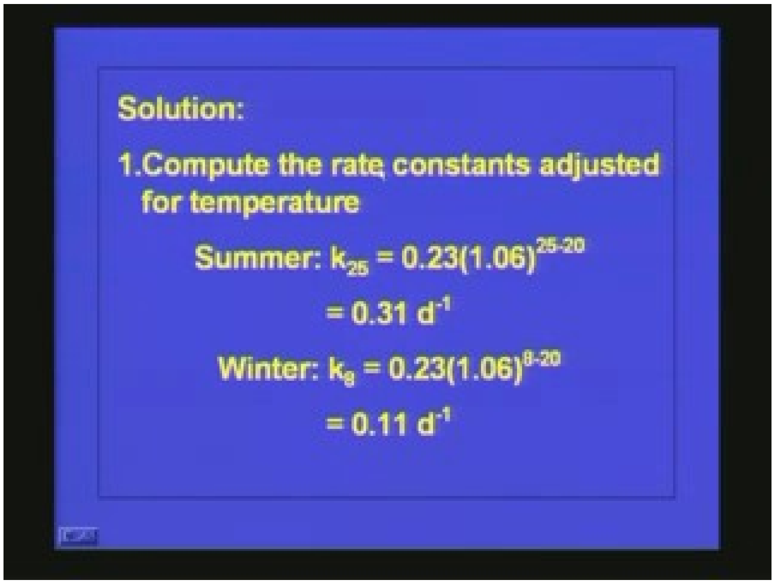


We will see the designing of facultative ponds and lagoons. Solve one problem then it will be clear. This is the problem; Wastewater flow from a small community averages 3500 meter cube per day during the winter and 5500 meter cube per day during summer. The average temperature of the coldest month is 8 degree centigrade and the average temperature of the warmest month is 25 degree centigrade. The average BOD5 is 250 mg per liter with 70% being soluble. The reaction coefficient k is 0.23 per day at 20 degree centigrade and the value of phi is 1.06. Prepare a preliminary design for a facultative pond treatment system for the community to remove 90% of the soluble BOD.

Therefore, we have the flow rate in summer and winter and we know the extreme temperature available. We know what is the incoming BOD value and what is the soluble part of that one and we also know the bio kinetic constant at 20 degree centigrade and the required efficiency is also given. So, based upon this one we have to design the pond system. We will discuss it in detail.

The first step is to compute the rate constants which are adjusted for temperature because we have the rate constant for 20 degree centigrade. But we know that in summer the temperature will go up to 25 degree centigrade and in winter it comes down up to 8 degree centigrade so we have to apply the corrections to the rate constants which is the first step.

(Refer Slide Time: 46:00)

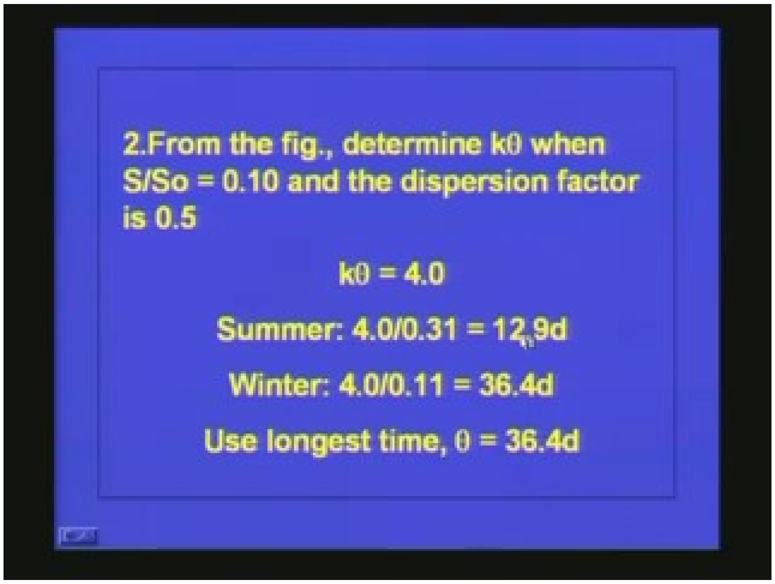


We will see how to find out the temperature corrector rate constant so k_{25} is equal to 0.23 into so this is the phi value which is already given so phi rise to t minus 20 so t is 25 degree and phi is 1.06 so you will be getting the k value or k_{25} was 0.31 per day and for winter we have to put the t as 8 degree centigrade. So you will be getting k_8 or the rate constant at winter for a temperature of 8 degree centigrade as 0.11 per day so here we can see that as the temperature increases the rate constant also increases from 0.23 to 0.31 and in winter when the temperature has come down it has reduced drastically from 0.23 to 0.1 so definitely the reaction rate will be affecting the performance of the system, this is an important step.

We have seen a family of curves in the earlier lecture. So using that figure we have to find out what is the k theta value for an efficiency of 90%. So if you want to achieve an efficiency of 90% the left over S value will be 10% so S by S0 will be 0.1and we assume that dispersion factor is 0.5. That means point system is in between a plug flow and a CSTR regime so that is why we are taking dispersion factor as 0.5. So, for the dispersion factor 0.5 and S by S0 value of 0.1 we can find out what is the k theta value from this family of curves as per our earlier discussion.

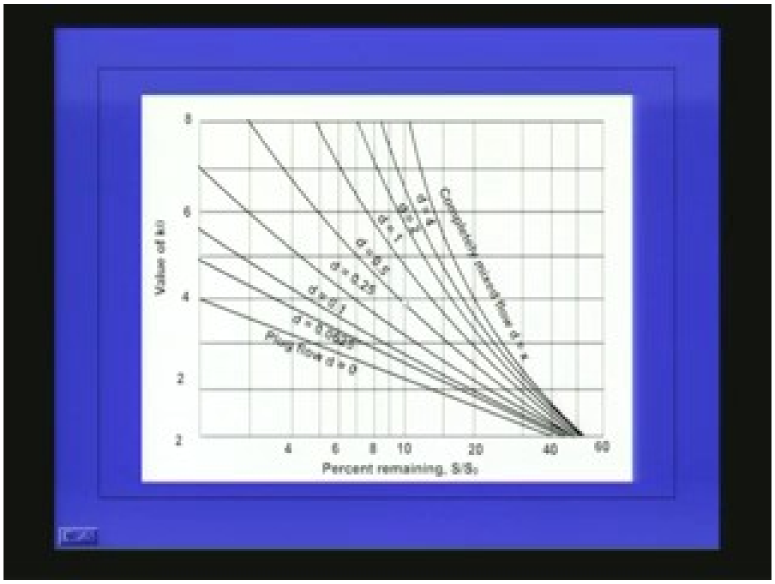
Here the remaining 10% and the family we have to see is d is equal to 0.5 so you will be getting k theta value as 4 from this figure so this is the k theta value, that is what we have substituted here k theta is coming as 4 so you know what is the k value and you know the k theta value so we can find out theta. Theta is nothing but hydraulic retention time. So during summer the hydraulic retention time required is 4 divided by 0.31 which is equal to 12.9 days.

(Refer Slide Time: 47:25)



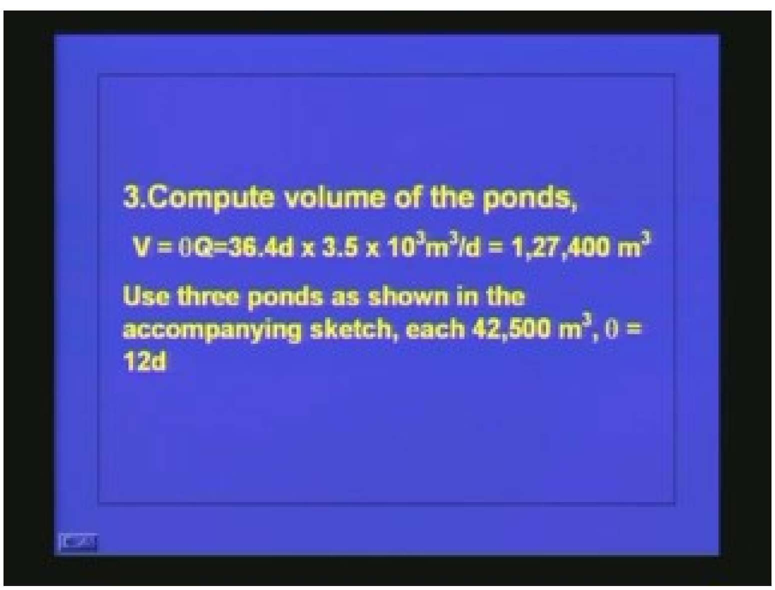
In winter the requirement is 4 by 0.1 because the rate constant is considerably low in winter time so we will be getting a hydraulic retention time of 36.4 day. But whenever we design a system we have to design for the adverse condition so here we have to provide the maximum value of the hydraulic retention time so the hydraulic retention time for the present system should be 36.4 days.

(Refer Slide Time: 48:00)



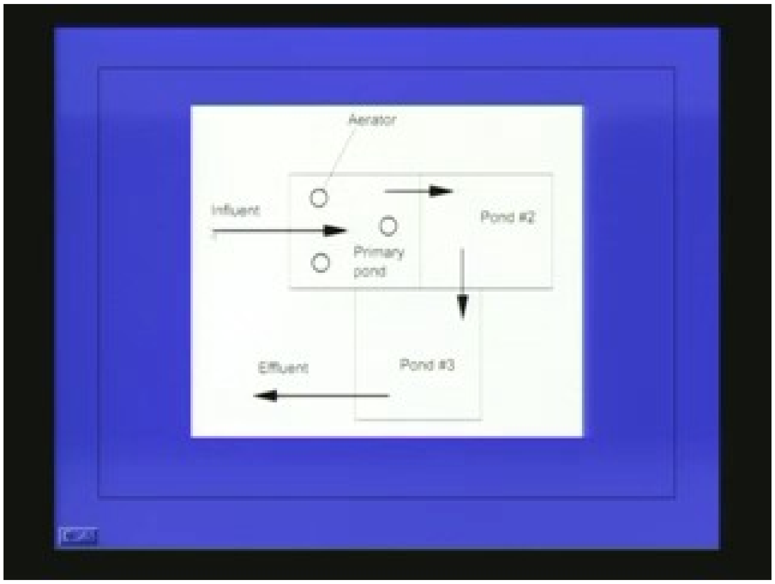
Now what we have to do is, we know the hydraulic retention time, we have to find out the volume of the ponds. So how can we find out the volume of the ponds? It is nothing but hydraulic retention time into the flow rate that means this is the flow rate coming in and we have to keep the wastewater for such a long time so we will be able to get the volume. We know the hydraulic retention time and this is the flow rate during winter. We know that the extreme condition occurs in winter so we have to consider that flow rate. So the volume is coming as 127400 meter cube so we can use a series of ponds. This we have seen earlier.

(Refer Slide Time: 49:30)



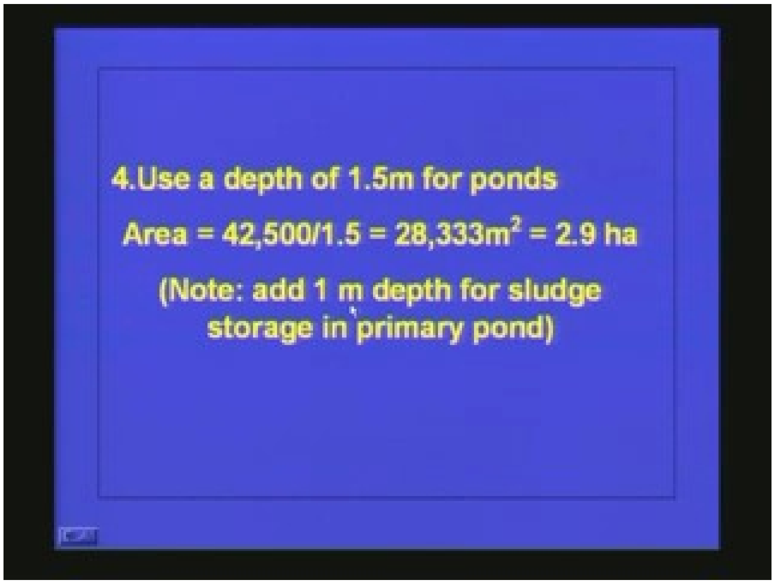
If you go for a series of ponds the efficiency will be higher compared to a single pond because it will be approaching the plug flow regime. So, since we are providing three ponds the detention time of each pond will be around 12 days because three ponds are there and each will be having a volume of 42500. We are getting this value by dividing this 127400 by 3 so the pond system will be like this.

(Refer Slide Time: 50:18)



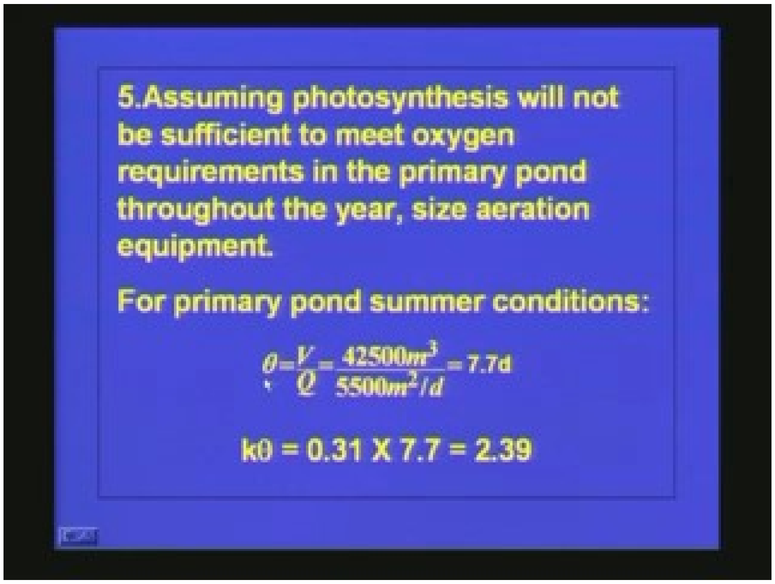
This is the first pond the influent is coming like this and from this one the influent is going to the second pond and from here it is coming to the third pond finally we will be getting the treated effluent. And in case of the first pond what is happening is the organic loading will be very very high so we can even provide artificial aeration by providing mechanical aerators. Now we have to find out what is the area requirement so provide a depth of 1.5 m for the ponds so we can find out the area because we know the volume of pond and we know what is the depth so we will be able to find out the area. Area is nothing but volume divided by depth so it is coming as 28333 meter squared or it is 2.9 hectares.

(Refer Slide Time: 51:30)



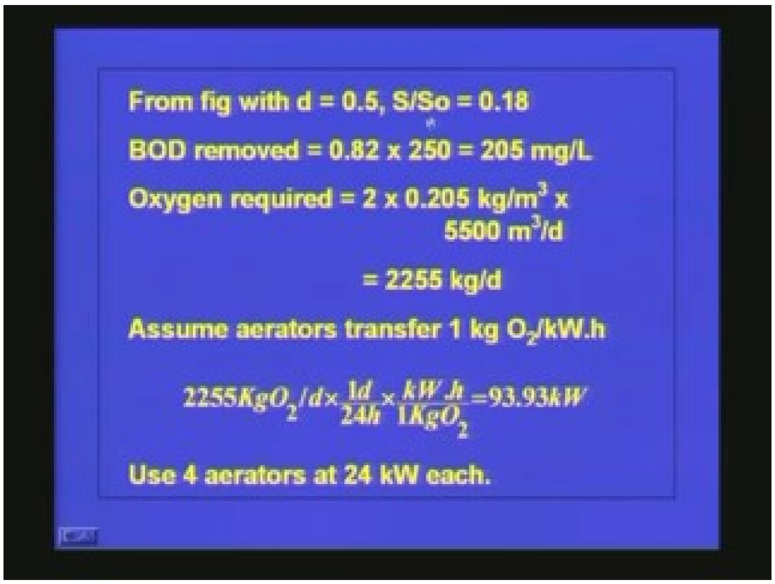
Even though we are providing 1.5 m as the depth we have to give additional 1 m depth because the wastewater whatever is coming to the pond will be having lot of suspended solids so it will be getting accumulated in the system so you should provide in a storage place. That is why apart from the working depth we have to provide 1 m additional depth for the storage of the sludge.

(Refer Slide Time: 52:10)



Now we are assuming that the photosynthesis will not be sufficient to meet oxygen requirements in the primary pond throughout the year so we have to provide some aeration equipment so what we have to do is we have to see what is the detention time available during the summer. We have seen that during the summer the flow rate is very very high so we can find out what is the theta value during the summer. We also know the volume, volume is the fixed quantity but the only thing varying is the flow rate. So during summer time the flow rate is up to 5500 meter square per day so we can see what is the detention time available during summer so it is coming as 4500 divided by 5500 which is equal to 7.7 days. Though we are providing 12 days in summer the effective detention time is only 7.7 days and the k theta value corresponding to this theta value is 2.39.

(Refer Slide Time: 53:00)

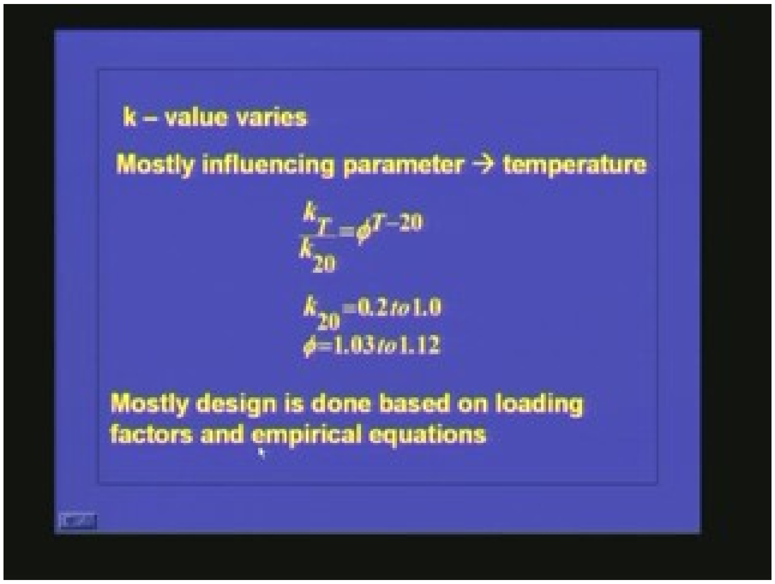


Now we know the k value, we know the theta value so we can find out k theta value. Once you know the theta value and the dispersion coefficient we can refer by to the same figure and get the S by S0 value. That means this will be the efficiency at the time and this value we got from the family of curves is coming as 0.18 which means we are able to achieve only eighty two percentage of removal during summer time.

So BOD removed is equal to 0.82 into 250 so 250 mg per liter is the total BOD coming to the system so BOD removal is equal to 205 mg per liter so the oxygen requirement is 2 into 0.205 kilogram per meter cube into 5500. So we are assuming that per 1 kg of BOD we need 2 kg of oxygen so we can find out the total oxygen requirement which is coming as 2255 kilograms per day and we are assuming that the aerator oxygen transfer rate is only 1 kg of oxygen per kilowatt hour. So if this is the case then we can find out what is the total kilowatt hour requirement.

Hence, we know what is the total oxygen required and we know what is the oxygen transfer per kilowatt hour so we will be able to find out what is the total kilowatt hour so 2 to 5 kilogram oxygen per day into one day by 24 hours because we want in terms of kilowatt hour so it is coming as 93.93 kilowatts so we can advise aerators at 24 kilowatt each. Therefore, if you want to provide aerators we have to provide four aerators of 24 kilowatt capacity in the primary and if the oxygen requirement is not sufficient we can provide oxygen externally. Now we have discussed how to design the aerators.

(Refer Slide Time: 55:15)



Whenever we talk about the pond system the k value varies it is not a constant and it is temperature dependent value so mostly design is based on the loading factors and empirical equation and most of the time this pond systems are advisable in the places where the temperature is reasonably high if you go for low temperature region what will happen is during winter season ice formation will be taking place in the top of the pond so virtually no treatment will be taking place in the pond so we have to provide a huge volume to contain all the wastewater whatever is coming during the winter time and the treatment will be taking place only in summer time. These ponds are better for the region where the temperature will not fall too long.

We have also discussed about the polishing ponds. How can we design a polishing pond? The same principle we can use and most of the time we go for the CSTR approach. So in each system Se by S0 is equal to 1 by 1 plus k theta so depending upon that one what is the number of microorganisms you require. Finally once the treatment is done based upon that one we can find out the number of ponds you have to give and the hydraulic retention time you have to provide. So based upon that one, we can design the system.

Whenever we go for these polishing ponds it is always advisable to go for a series of ponds having the same volume throughout. We have also discussed that if we give series of ponds the efficiency will be maximum if we provide the same hydraulic retention time or same volume in all the ponds.

One more thing that is very very important is, when we design a series of ponds that too facultative ponds it is always advisable to design in such away that the first pond will not become anaerobic at any condition. If you want to maintain that condition by experiment it is shown that the Se maximum whatever is coming out from the first facultative pond should be more than 50 or 60 mg per liter. If you put that condition for the domestic wastewater your first pond will never become anaerobic so that you will be getting a better efficiency at the end.

Now we will see what are the things we have discussed today. We have seen what is the pond and what is the difference between the pond and lagoon and what are the different types of ponds available and when we are using each variety. We have seen that if you want to go for a polishing pond most of the time we go for aerobic ponds because all throughout the dissolved oxygen is available and for municipal wastewater treatment most of the time we go for facultative pond. And if you have high organic concentration waste or high organic content waste it is always advisable to go for anaerobic ponds because the oxygen requirement will be so high. We will not be able to provide sufficient oxygen.

We also discussed what are the design criteria used for the design of facultative pond. It is basically based on empirical approach and in the empirical approach we have seen what is the algae production and what is the oxygen supplying by the algae and what is the efficiency of the system. Hence, based upon that one we will be able to find out the area required.

We have also seen that it is always better to go for a series of ponds instead of single pond and pond system will be effective only in regions where the temperature relatively is higher. If the temperature is lower ice formation will be taking place in the top of the pond and it will be affecting or obstructing the sunlight that passes through the system. So naturally there will not be any photosynthesis and ultimately there will not be any treatment.