Biological process design for wastewater treatment
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Lecture 25
Rotating Disc Reactor

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, in today's lecture we will continue studying different types of aerobic wastewater treatment systems. So today we will be understanding that rotating disc reactor. Earlier we have studied the activated sludge system then trickling filter, sequential batch reactor. Now, continuing further when we study the rotating disc reactor, which is commonly used in some of the reactor systems for treatment of wastewater via aerobic means.
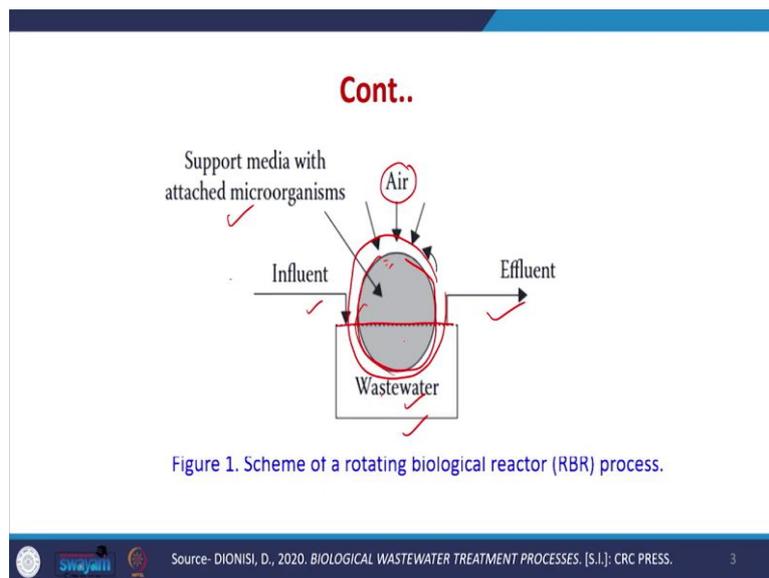
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Now, the rotating biological disc reactor are type of attached-growth system which is similar to like the trickling filter. So, it is very similar to trickling filter, but the system of attached is different as compared to that trickling filter in that trickling filter, the attachment is done on some packing's whereas, here the attachment is done on a rotating disc. So, in RBRs the microorganisms are attached to support materials which are placed inside a cylinder which is partially immersed in the water to be treated.

Now, the cylinder with the microorganisms it keeps on rotating so, that the microorganisms are alternatively exposed to the wastewater and to air from which they obtain the oxygen required for the removal of the substrate. The RBR does our aerobic processes. Now, that

means, we have a system where a cylinder is there on the cylinder on the shaft, a rotating disc is there that rotating disc keeps on revolving.

Now, on the rotating disc we have microorganisms when the rotation of the disc happens the microorganisms are once exposed to wastewater and another time they are exposed to the air from which they take the oxygen and does the treatment takes place. So, we can see this is the design.

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Figure 1. Scheme of a rotating biological reactor (RBR) process.

Source- DIONISI, D., 2020. *BIOLOGICAL WASTEWATER TREATMENT PROCESSES*. [S.l.]: CRC PRESS.

So, we have this figure shows the schematic of the rotating biological reactor. Now, we have this disc you can see here now, on this disc we have microorganisms which are grown now, this this keeps on rotating like this. Now, while rotation the partial disc is immersed inside the wastewater which has to be treated, now, the wastewater comes from this side in the form of influent and after some time it goes from this side as effluent.

Now, when this part is outside the air, then the exposure of the microorganism to the air takes place and thus they grow. Also when the disc goes inside the wastewater treatment happens. So, this is the schematic of the RBR.

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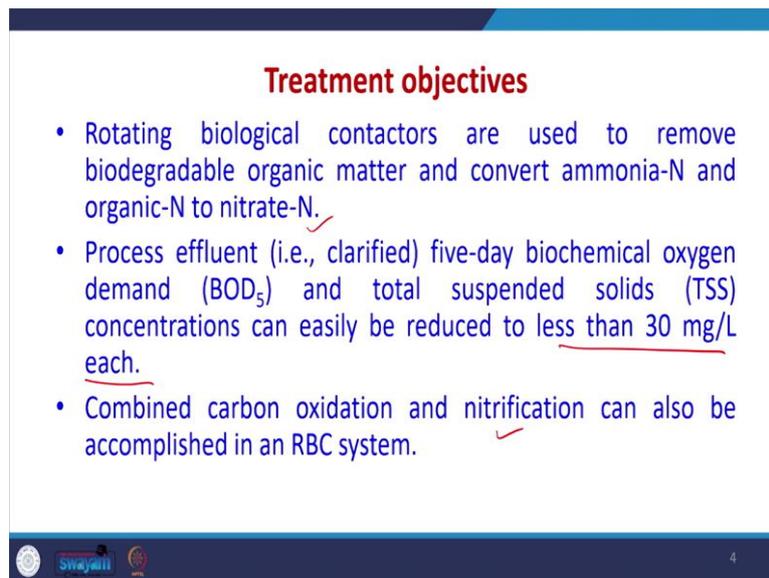
Now, rotating biological contactors have treatment objectives. They are used to remove the bio degradable organic matter and convert ammoniacal nitrogen and organic nitrogen to nitrate nitrogen.

So, there this is one of the major objectives when there are rotating biological contractors are used. The process effluent which is the clarified 5 day BOD and total suspended concentration can easily be reduced to less than 30 milligram per liter each using the RBRs. Now, the combined carbon oxidation in nitrification can also be completed in the RBC system. So generally, in the activities of our system, we can only treat the carbon part but in the RBRs, we can also take care of the nitrate part and we can perform the nitrification as well.

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- Rotating biological contactors can also be used for separate stage nitrification; that is, to nitrify streams containing relatively high concentrations of ammonia-N and low concentrations of organic matter.
- Rotating biological contactors have also been used to accomplish denitrification.

Some other objectives of the RBRs include the RBC or RBRs can be used for separate stage nitrification also that is only to nitrify the streams containing relatively high concentration of ammoniacal nitrogen and low concentration of organic matter.

So if we have any wastewater which contains more amount of ammoniacal nitrogen, something which is coming from a fertiliser industry or other places, then we can have specifically use the rotating biological contractors for treatment of such wastewater. Now, the rotating biological contractors can also be used to accomplish denitrification also, it is possible to perform that denitrification using the rotating biological contactors.

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**Typical characteristics of rotating disc reactors**

- High volumetric reaction rates because of the high biomass concentration.
- Typical dimensions of the discs used for RBRs are 3.5 m in diameter and 8 m in length.
- Suited for relatively low flow rates of the wastewater to be treated.

The typical characteristics of the rotating disc reactors include high volumetric reaction rates because of the high biomass concentration. So, since the biomass is more concentrated on the rotating disc, so, we can have more throughput and high volumetric reaction rates can be obtained typical dimension of the disc used for RBRs are like 3.5 meter in diameter, so, you can think of an 8 meter in length.

So, we can have various discs rotated on the same RBC reactors. So, this is possible and these are suited for low flow rates of the wastewater to be treated. So, depending upon the quantity of the water, we can design the RBRs in different manners and then we can use them for treatment of wastewater.

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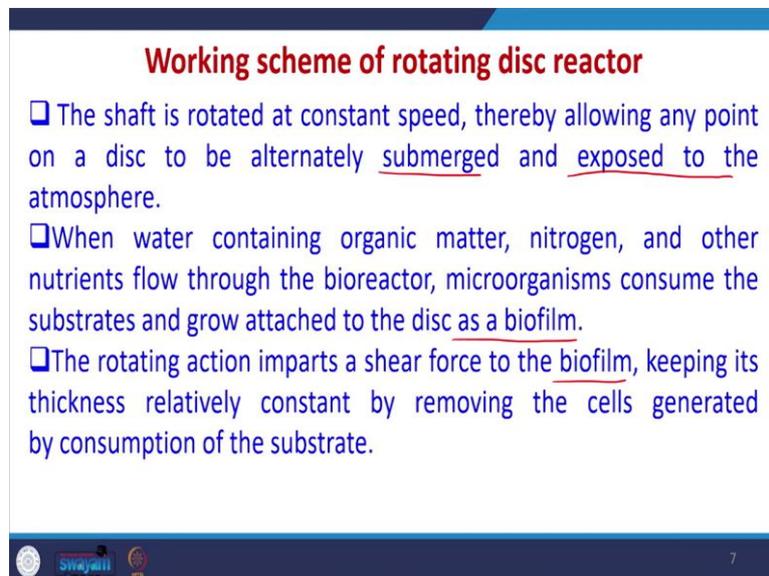

Now, working scheme for rotating disc reactors is that shaft is rotated at a constant speed thereby allowing any point on a disc to be alternatively submerged and then alternatively exposed to the atmosphere. So, it will be rotating at a constant speed first it will be exposed to the wastewater and then it will be exposed to the atmosphere also, when water containing organic matter nitrogen or other nutrients flow through the bio reactors, the microorganisms consume the substrate and grow attached to the disc as a biofilm.

So, they grow as a biofilm on the disc that rotating action imparts a shear force also to the biofilm because it is continuously rotating. So, keeping its thickness relatively constant by removing the cells generated by consumption of the substrate. So, there is always a shear force when the disc is coming back when the section of the disc which is exposed to the atmosphere it is coming back to the wastewater then a shear force is exerted and because of

the which the extra biofilm which has been generated that gets peeled off. So, that means the thickness of the biofilm also remains constant when we are rotating the disc.

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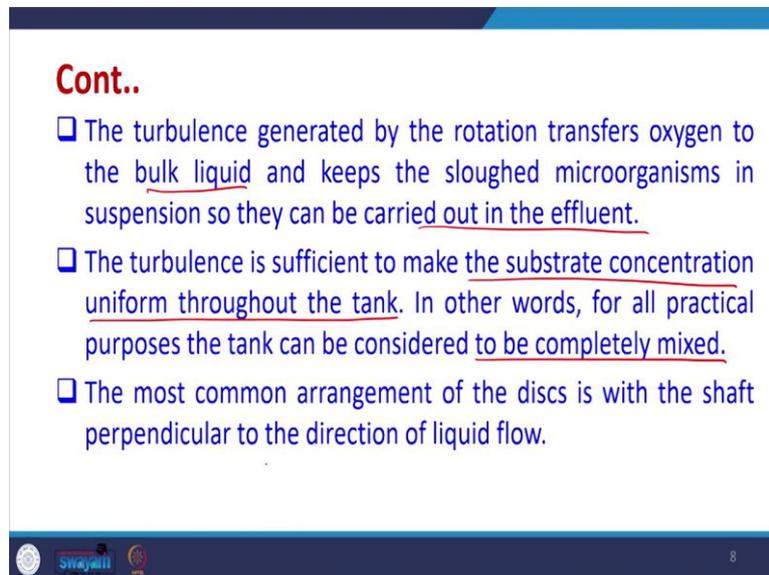
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❑ The turbulence generated by the rotation transfers oxygen to the bulk liquid and keeps the sloughed microorganisms in suspension so they can be carried out in the effluent.

❑ The turbulence is sufficient to make the substrate concentration uniform throughout the tank. In other words, for all practical purposes the tank can be considered to be completely mixed.

❑ The most common arrangement of the discs is with the shaft perpendicular to the direction of liquid flow.

That turbulence generated by the rotation transfers oxygen to the bulk liquid and gives us sloughed microorganisms in the suspension so they can be carried out in the effluent. So, this is the removed microorganism layer remains suspended in the effluent and it is carried out as effluent and further on it can be separated out that turbulence is sufficient to make the substrate concentration uniform throughout the tank.

So, we have to see that the enough turbulence is there, so, that we can have constant concentration of substrate inside the RBR reactors. In other words, for all practical purposes that tank to be considered is completely mixed. So, this is a completely mix reactor we can always follow this assumption, the most common arrangement of the disc is with the shaft perpendicular to the direction of the liquid flow, this is how earlier in the figure also we have seen.

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Figure 2. Schematic diagram of a single disc in an RDR system.
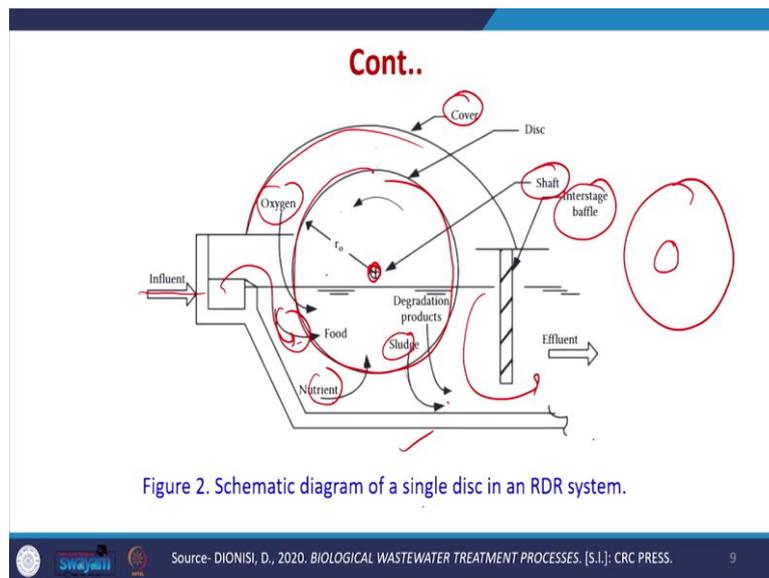
So, we can see here the influent is coming, the water will go like this, this is the disc now, this disc is perpendicular to the flow direction of the influent and there can be 10 to 15 or more than that the continuous parallel disc also. So, there will be a large number of disc which will be parallel to each other and mounted on the same shaft which is here. So, and then this all that disc system is covered by this layer.

So, we have a cover on the top also after treatment, the water will come like this, the nutrients, food they will be taken by the microorganisms which are grown on this disc oxygen will be taken when this case is exposed to the atmosphere. Now, oxygen is taken from your food and nutrients are taken from the wastewater and we have degradation products and sludge. Sludge means the period of the microorganism layer. This will go into the effluent and this inter-stage backfill will transfer this to the effluent.

We can have a secondary stage RBC also if required and we can have a second stage RBC here also if we depending upon the whether we want to design such a system or not, so, it is possible to have second stage or third stage RDR systems or RBR systems in series. So, we have parallel disc and whole system can be replicated in series also. So, this is the schematic diagram of a single disc, but we can have multiple disc systems also.

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So, the design criteria for the rotating biological disc reactors is number of modules maybe four to five depending upon the requirement, the diameter of flat disc may be varied from 2 to 6 meter, the thickness of flat disc is around up to 10 millimeter, the thickness of plastic disc if they are used is 1 to 2 meter.

The disc spacing which is there between different parallel disc it may be 20 to 40 millimeter, the speed of rotating shaft is 1 to 2 rpm, so, it is not very quick it is slow like 1 to 2 rotations per minute and the peripheral velocity of the disc that means is this is a disc. So, what is the velocity here, so, it will be 10 to 25 meter per minute. So, this is the speed.

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Now, generally 40 percent of the disc area is submerged inside the reactor, inside the wastewater and 60 percent is exposed to the atmosphere. The thickness of biofilm is 2 to 4 meter and the length of the shaft may be up to 8 meter. The hydraulic retention time that means the how much time the water remains inside the disc may vary from 0.5 to 4 hours depending upon the characteristic of the water and how much treatment we require.

The organic loading rate maybe 3 to 20 gram BOD_5 per meter square of the disc area, the hydraulic loading in terms of volume maybe the 0.02 to 0.16 meter cube per meter square per day and the sludge production rate may be 0.5 to 0.8 kg per kg BOD_5 removed. So, based upon these considerations, we can design the system. So, let us try to solve the problem.

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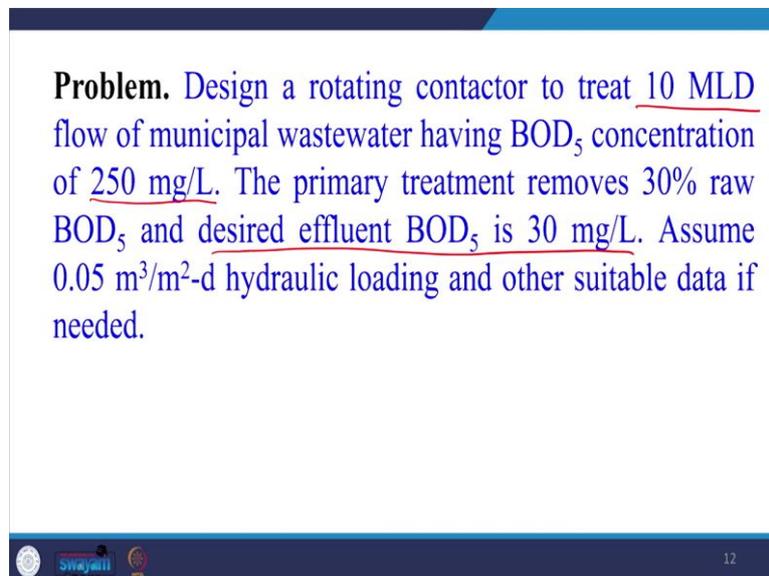
Problem. Design a rotating contactor to treat 10 MLD flow of municipal wastewater having BOD_5 concentration of 250 mg/L. The primary treatment removes 30% raw BOD_5 and desired effluent BOD_5 is 30 mg/L. Assume 0.05 m^3/m^2-d hydraulic loading and other suitable data if needed.

In this question it is given that we have to design a rotating contractor to treat 10 MLD of municipal wastewater having BOD_5 concentration up to 50 milligram per liter. So, we have 10 MLD of municipal wastewater which is getting generated and it is having 250 milligram per liter of BOD_5, the primary treatment, it is found that 30 percent of the BOD_5 is removed rest we have to remove in the this rotating biological disc contactor. Now, the desired effluent quality is 30 milligram per liter.

So, that means, we have to reduce the BOD_5 up to 30 milligram per liter. Now, we have to make certain assumptions that what are the conditions that will be taken. So, we are assuming to have an hydraulic loading of 0.05 meter cube per meter square per day and other suitable data can also be acquired if needed. So, how to go ahead let us go further. So, the disc area which is required can be calculated like this.

The number of discs per module is determined by using the equation:

$L = xn + y (n+1)$

So, we know the wastewater flow rate is it has been given 10 MLD so that means, 10,000 meter cube per day is the flow rate. Now, if it divided by the hydraulic loading, which is assumed to be 0.05 meter cube per meter square per day, so, we can get tentatively the area which is required on the disc.

So, we have 2 lakh meters square is the area which is required. Now, assuming that the standard module is 7.6 meter in length and with disc of 5 millimeter thickness and with 30 millimeter spacing between each disc now, we are going to design so, and also we are going

to take 3.7 meter disc is used for the treatment. So, now, we have to find out the number of disc which is required per module for treatment.

So, we can calculate this very easily the length of the shaft is 7600 millimeter, now, the thickness of the disc is 5 millimeter. So, that means, the number of discs the total length, this is the shaft now, this is the total shaft which is given as that it is given that it is 7600 millimeter. Now, on this we can have different disc. Now, each disc have certain thickness among themselves, if we assume n number of disc, which is the number of disc per module, then for each thickness, we first take care of the thickness of the disc these discs themselves.

So, this is why, x into n gives the thickness of the total thickness, which has been taken care of by the number of disc. Now, if y is the clear displacing distance between the disc which is this is the y distance. Now, the number of such partitions are if you can see the number of disc plus 1, so, that is why this is there, and we multiply by y. So, we get the total length. So, when we add this x into n plus y into n plus 1 we get the length. Now, we have already assumed any of the parameters here.

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Solution. Disc surface area, A_s = wastewater flow / hydraulic loading rate

$$= 10000 \ (m^3/d) \ / \ 0.05 \ (m^3/m^2\text{-}d)$$

$$= 200000 \ m^2$$

Assuming that a standard module of 7.6 m in length with discs of 5 mm thickness with 30 mm c/c spacing and 3.7 m in diameter is used for the treatment, the number of discs per module is determined by using the equation,

$$L = xn + y \ (n+1)$$

where, L = length of shaft = 7600 mm

x = thickness of discs = 5 mm

n = the number of discs per module

y = clear spacing distance between discs, mm

Thus, $7600 = 5n + (30\text{-}5) \ (n+1)$

n = 252.5 ≈ 253 discs

Surface area of each disc = 2 × $(\pi/4 \times (3.7)^2)$ = 21.5 m^2

Therefore, the total surface area of 253 discs = 253 × 21.5 = 5439.5 ≈ 5440 m^2

Theoretically, the number of modules required,

N_m = total area required / area of disc of one module

= 200000 / 5440 = 36.76 ≈ 37

The number of standard modules required,

N_s = total area required / specific area of discs by one module

= 200000 (m^2) /10000 (m^2) = 20

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So, now, we can find out the number of discs that we can calculate so, 7600 into 5 into n because n we do not know number of disc. So, and then 30 minus 5 which is 30 minus 5 because we have already y is the clear spacing distance between the disc and n plus 1 is the spacing so, n plus 130 minus 5 because 5 has been taken care of. So, this is n comes out to be 253 disc, now, surface area of each disc can be calculated we have remember, for each disc, we have disc surface and this surface also.

So, we have two surfaces that is why multiplication has been done with two. So, 2 into pi by 4 and 3.7 is the diameter of the disc that we have taken. So, this is 3.7 square. So, we have for each disc, the number surface area is 21.5 meters square. And now, if you multiply the disc into this surface area, so we have 5400 meters square. That means, for each module we will be having only this much amount of surface area.

Now, the number of modules which are actually required can be calculated by dividing the total area required with the area of the disc of one module. So, what we do is that, we divide these 2 lakh divided by 5440. So, we get the answer as 36.76 which is equivalent to 37 modules. So, that means, we will be requiring 37 modules for treatment of such system.

The number of standard module specific suppose we have some standard modules which are available and a specific surface area of each module, many times you will be given the in place of 5440 some standard module is available, which is having an area of 10000. So, we can take this module and if we divide we get 20. So, here we understood how we can perform to calculate the number of disc which may be required and the number of modules which may be required for treatment of any waste water. So, this is there.
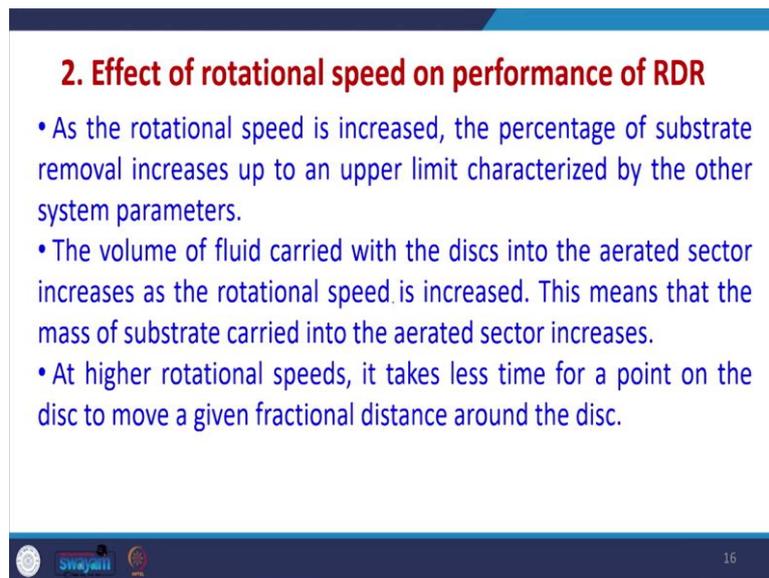
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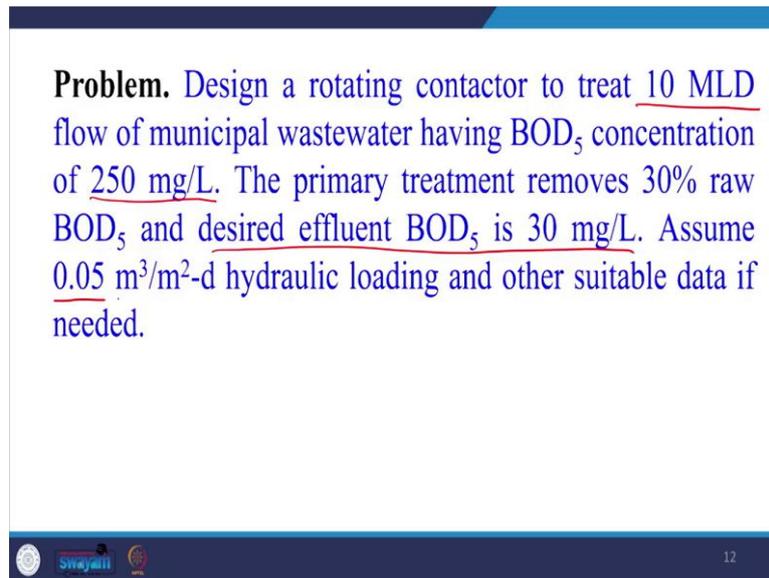
Problem. Design a rotating contactor to treat 10 MLD flow of municipal wastewater having BOD_5 concentration of 250 mg/L. The primary treatment removes 30% raw BOD_5 and desired effluent BOD_5 is 30 mg/L. Assume 0.05 m^3/m^2-d hydraulic loading and other suitable data if needed.

Now, in this case, the inherent thing is that the most important parameter that we have assumed is this. Now, it is possible that this hydraulic loading may have to be changed depending upon the data which is available and how much treatment happens. So, it is possible that if the treatment desired quantity is not achieved, then we may have to increase or decrease the hydraulic loading.

So, if we are able to get the treatment efficiency will continue this further. However, if we are not getting we may have to reduce this hydraulic loading, so, that the treatment efficiency may be achieved. So, we have to look for the data of such wastewater at what hydraulic loading they have been able to treat the wastewater so that the desired objectives with respect to standards requests are achieved.

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Now, the performance of the rotating disc reactor systems depends upon number of parameters. So, the most important parameter is the entering rate and the performance of the RDR. Increasing the flow rate entering the RDR results in an increase in the effluent substrate concentration and a decrease in the percentage of the substrate removal. So, that means, if we go on increasing the flow rate influent rate, certainly the efficiency will be decreased.

So, we have to optimise the flow rate, increasing the flow rate into the system while maintaining a constant influent substrate concentration results in higher mass application rates of the substrate and which may not be good. So, to obtain a steady state which requires high reaction rate at higher flow rate, the substrate flux into the biofilm must also increase. So, it may cause problem also it may happen it may not happen.

So, as second is the effect of rotational speed and the performance of RDR as the rotational speed is increased the percentage of the substrate of removal increases up to an upper limit characterized by the other system parameter. So, rotating speed also has an effect. The volume of fluid carried with the disc into the aerated sector increases as the rotation speed is increased. This means that the mass of substrate carried into the aerated sector increases at higher rotational speed, it takes less time for a point on the disc to move a given fraction distance around the disc and which may have some effect on the performance of RDR.

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As the rotational speed increases, the amount of substrate entering the aerated sector increases, but the time required for a point on the disc to move through the aerated sector decreases these act together to allow substrate to move further around the disc. So, this happens when the rotational speed is about 3.75 or 4 rpm the substrate concentration reaches 0 at very end up the aerated sector so that typical rotation speeds are 1 to 2 rpm for the RBCs.

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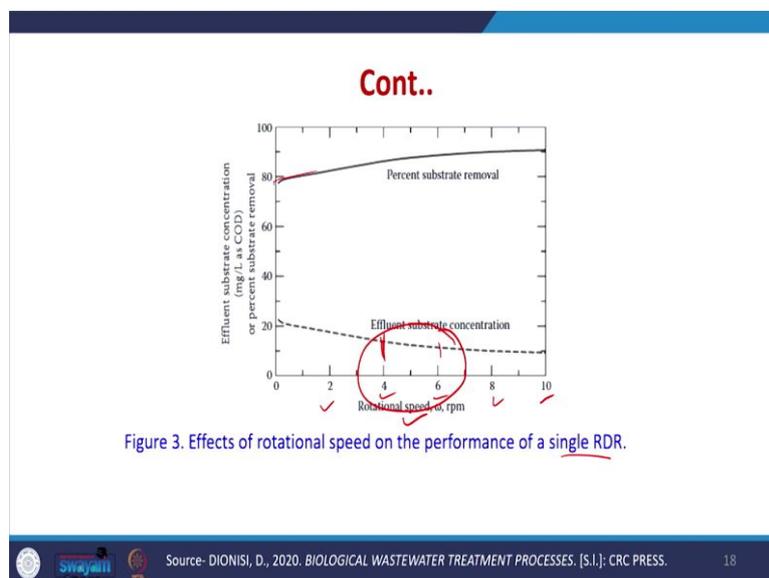
We can see here the effects of rotational speed and the performance of single RDR. So, we have rotational speed 2, 4, 6, 8, 10 rpm, and that the percentage surface removal is we can see it is increasing and effluent substrate concentration is decreasing. So, at 6 at these places, that difference is not much. So, we can optimise at any condition we can perform such studies on

newly acquired RDRs for the treatment of wastewater and once we have the performance data we can set the required rotational speed.

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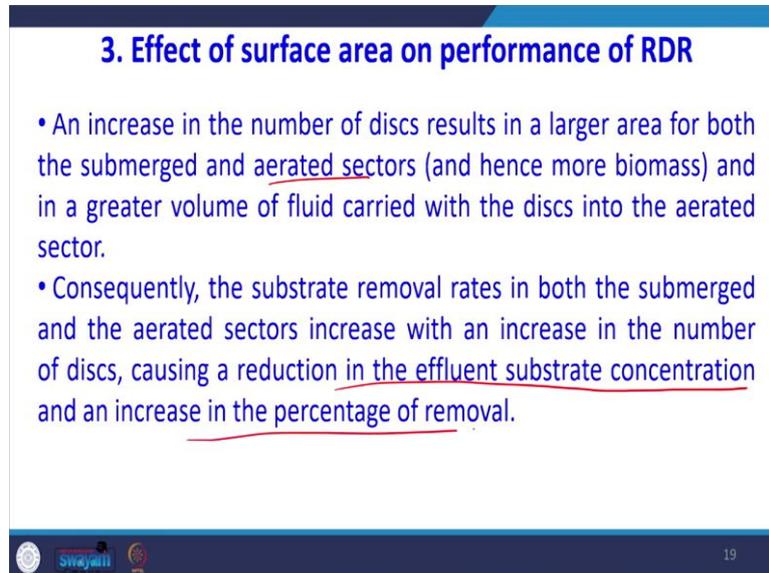
Now, the effect of surface area on the performance of RDR. An increase in the number of disc results in a large area for both the submerged and aerated sectors. Hence, more biomass can be grown and a greater volume of fleet can be carried with the disc into the aerated sector. Consequently, the substrate removal rates in both the submerged and aerated sectors also increases with an increase in number of disc, causing a reduction in the effluent substrate concentration and an increase in the percentage of the removal. So, this is directly correlated, higher the surface area better is the performance of RDR.

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An increase in the fractional submergence increases the total submerge area which allows more microorganisms to grow on a disc at a fixed size, it causes substrate removal rate in the submerged sector to increase although it also decreases the substrate flow through the aerated sector the net effect on increase in the substrate removal because the submerged sector provides the majority of the total substrate removal. But we have to optimise that how much of the submergence have to be taken. So, generally 40 percent of the submergence is optimum because the microorganisms must also be exposed to oxygen for their growth.

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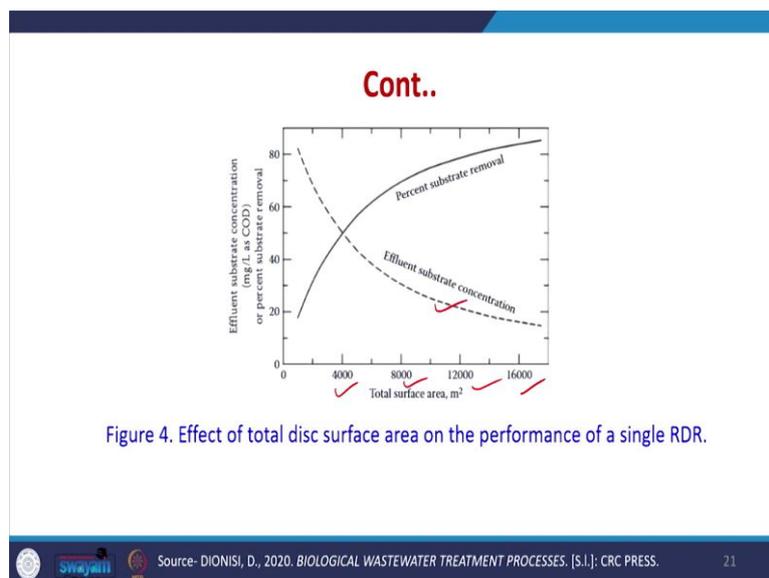
This is how you can see as the surface area is increasing percentage surface removal is increasing and the substrate concentration is decreasing.
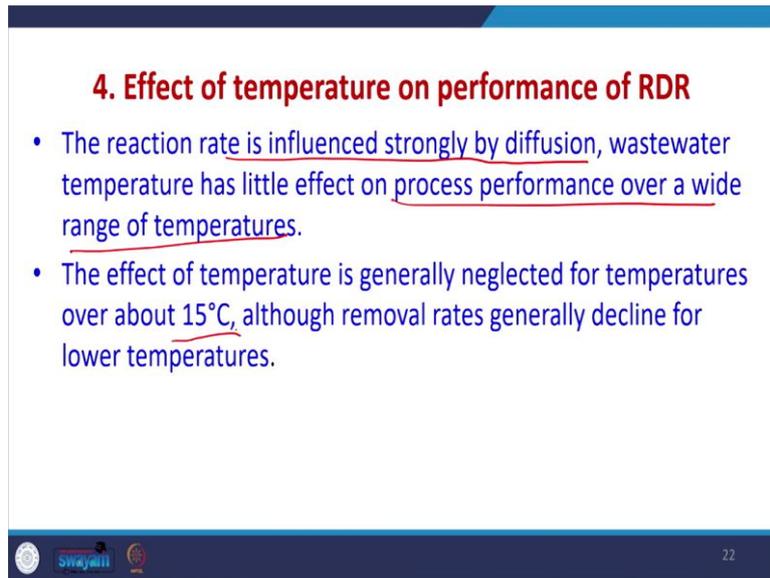
So, effect of temperature. As for other types of systems, wastewater biological treatment system that temperature also affects the performance of RDR the reaction rate is influenced strongly by diffuser. So wastewater temperature has little effect on process performance over a wide range of temperatures. The effect of temperature is generally neglected for temperatures over and above 15 degrees centigrade if but if the temperature is less than 15 degrees centigrade, certainly it will decrease the performance of RDRs. Then the wastewater characteristics also have lots of effect on the performance of RDRs.
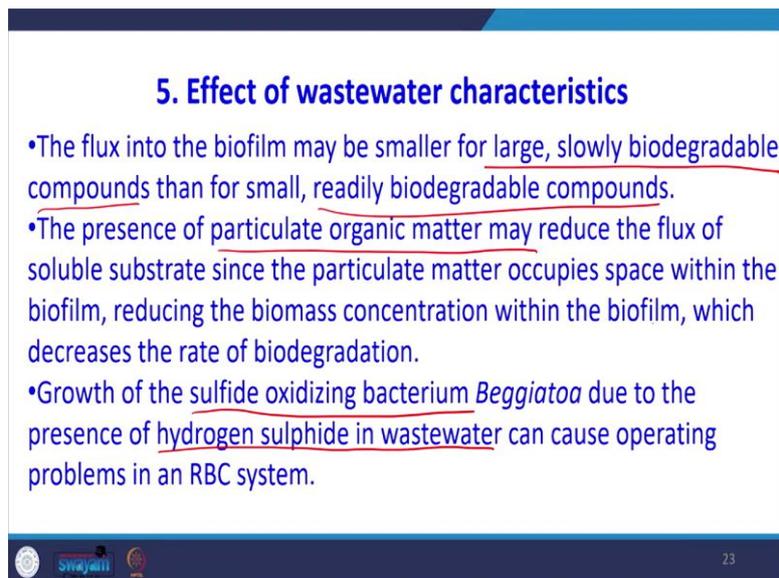
The flux into the biofilm may be smaller, for large and slow biodegradable compounds than for small readily biodegradable compounds. So, it is for large slowly biodegradable

compounds, the flux into the biofilm may be smaller. So, if the wastewater contains large compounds which are slowly biodegradable, it may be difficult to take because the flux into the biofilm may be smaller.

The presence of particulates organic matter also reduces the flux of soluble substrate since the particle matter occupies a space within the biofilm and reducing the biomass concentration within the biofilm, which decreases the rate of biodegradation. So, wastewater which contains particulate matter under those conditions that efficiency of RDRs will go down.

Similarly, if wastewater contains slowly biodegradable compounds, which are larger in size, again the performance will go down growth of sulfide oxidizing bacterium due to the presence of hydrogen sulphide in wastewater can cause operating problems in RDC or RBC system so this is there.

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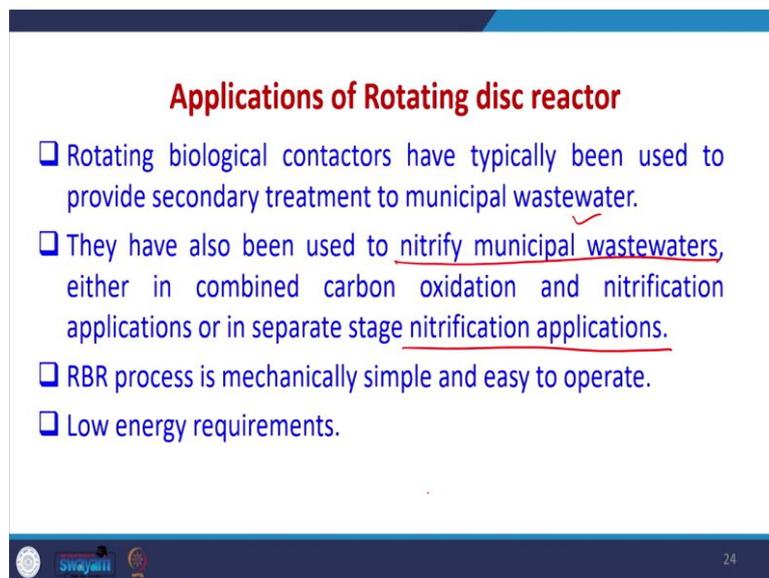
Now, applications of the rotating biological disc reactors, so, rotating biological contactors or rotating biological disc reactors have typically been used to provide secondary treatment to municipal wastewater. So, we can use them for secondary treatment, they have also been used to nitrify municipal wastewater is either in combined carbon oxidation and nitrification application are a separate stage in nitrification applications only RBR process is mechanically simple and easy to operate and its energy consumptions are also low.

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Drawbacks of RDR include the performance is highly susceptible to wastewater characteristics, that depending upon the wastewater characteristics, we may have to change the parameters and depending upon that, the performance may vary. So, the performance is susceptible to wastewater characteristic, then we have limited process flexibility, because we have a standard modules the process we cannot modify that much.

So, we have only limited process flexibility and also a scale up is not very high because we can use only a series or parallel RDR systems to treat such waste water. So, it may depend upon the wastewater characteristics more and what is the flow rate.

So, we have the scalar can be only in the form of series either in different modules of RDR in parallel or in series and we require adequate pretreatment before using RDR so, that all the

particulate matter suspended materials etc., can be removed maximum and only organic loading happens on the RDR otherwise the performance of RDR will go down.

So, this is with respect to RDR. We have used these references will continue further studying the different wastewater treatment systems. Till now we have studied the aerobic systems. Now we will study the anaerobic wastewater treatment system in the later lectures. Thank you very much.