Biological Process Design for Wastewater Treatment
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Lecture 23
Sequential Batch Reactor

Welcome, everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, in the last lecture we studied regarding the biological treatment systems which are used in the wastewater treatment. So, one of the first system which was we discussed was activated sludge process, which is actually a aerobic process in which the oxygen or air is used for oxidizing the organic matter present in the wastewater into CO_2 and H_2O.

For doing this we used a activated biomass which was suspended inside the reactor and then the treatment was done in the activated sludge process, the wastewater which is coming from the primary treatment unit is treated in a reactor and then we have a secondary clarifier where the settling is done to remove the biomass and some of the biomass is returned back into the reactor so, as to maintain the concentration of the active biomass at a particular concentration which is called MLVSS and most of the biomass which is actually wasted.

Now, that means, three operations are performed, the aeration was performed the during the aeration itself the treatment was performed, then we have a secondary clarifier where the settling etc., was done and after that there was a return system also. Now, these systems are designed initially when the flow rates of water were less and the space was also more so, activated sludge systems require a lot of space for their treatment.

In between there is another technology which is which is evolved which is called as sequential batch reactor and it is used now, very commonly in many of the industries. The good thing about the sequential batch reactor is that that it requires lesser volume or space as compared to activated sludge system and efficiencies are as good as that.

Now, if you know the batch if anybody is from the chemical engineering background or they have the knowledge of reactor systems, so, we have two types of reactor system basically batch reactor and continuous reactor. Now, continuous reactor may be a completely mixed tank reactor which is called CSTR or it may be plug flow reactor. The plug flow reactor always has better efficiency as compared to CSTR.

Now, the plug flow reactor and batch reactor they have similar efficiencies. Now, if we compare batch reactor with CSTR the batch reactor always gives better efficiency as compared to CSTR if the operations are performed in batch. So, here in the sequential batch reactor, all the operations are performed in a batch mode.

So, that means the efficiencies are higher, Sequencing Batch Reactor does not mean that we have a sequence of batch reactor here, it means that we have a batch reactor where operations are performed in sequence. So, this is called sequential batch reactor.

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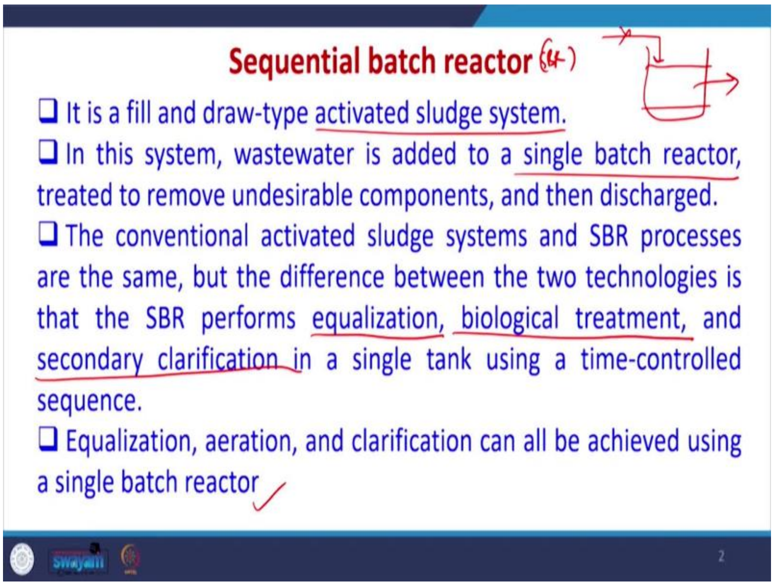

So, essentially SBR, the Sequencing Batch Reactor is a fill and draw type activated sludge system it is similar to activated sludge system, but with some differences. In this system the wastewater is added in a single batch reactor treated to remove the undesirable components and then discharge that means, we have a reactor where all the operations are performed some the wastewater is coming after that the waste, this flow rate is stop then we have some time is given for the treatment of water. After sometime this water is also taken out and again next batch is coming.

So, we have sequence of operations being performed in the same batch. The conventional activated sludge system and SBR processes are the same. But the difference between the two technologies is that the SBR performs equalization, biological treatment and the secondary clarification in the single tank using time controlled sequence.

So, we have sequence of operations, where equalization is being performed, biological treatment is being performed settling is being performed and then the removal of the treated water and sludge is being performed. Equalization, aeration and clarification can all be achieved using a single batch reactor and this reactor is called SBR or sequential batch reactor.

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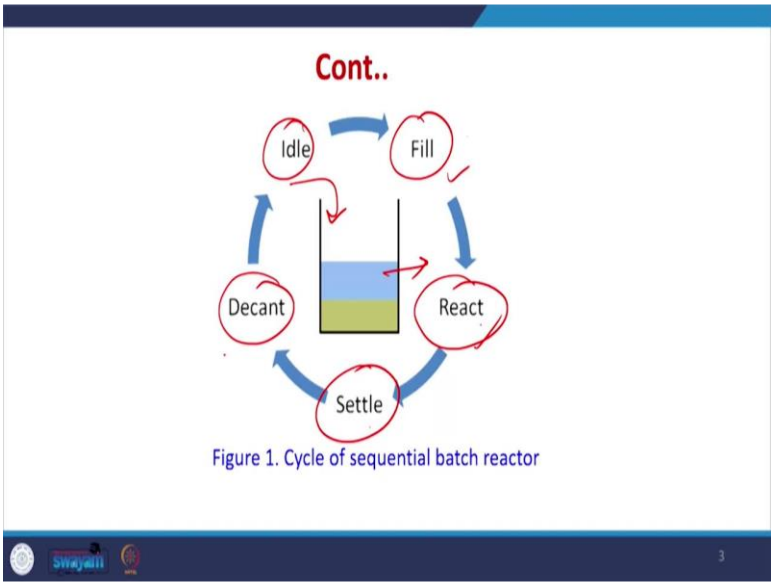

This is the usual cycle of sequential batch reactor. So, first process the water will be filled in after that some time will be given for reaction to happen that means, a treatment will happen during that time once the treatment has been completed and desired efficiency have been achieved, the settling time will be given so, that the sludge and water gets separated then decantation time when the water will be taken out and after that some time is given depending upon the operation.

So, it this idle time may or may not be there depending upon how the what are the different timings of different these phases. So, what is the time for fill what is the time for React what is the time for settling what is the time of decantation then we can have ideal time also this is possible.

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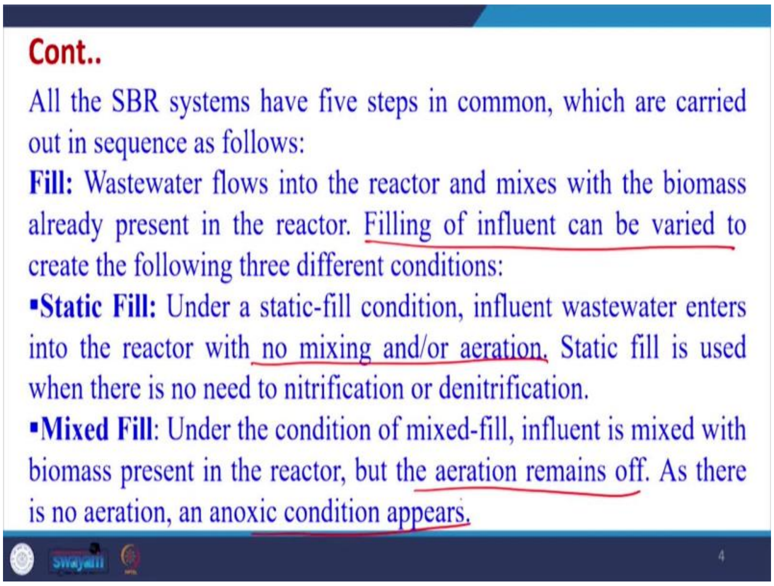

All the SBR systems have five steps in common which are carried out in sequence as follows. So, first is fill phase the wastewater flows into the reactor mixes with the biomass already present in the reactor. So, the biomass activated biomass is already present in the reactor, wastewater flows into the reactor and mixes with the same. Filling of the influent can be varied to create the following three different conditions it is possible to vary this filling condition.

Static fill under static fill condition the effluent wastewater enters into the reactor with no mixing or aeration and static fill is used when there is no need of nitrification denitrification then we can have mix fill under the condition of mixed fill influent is mixed with the biomass present in the reactor but aeration remains off. So, mixing is on but aeration is not on as there is no aeration, the anoxic conditions prevail inside the reactor.

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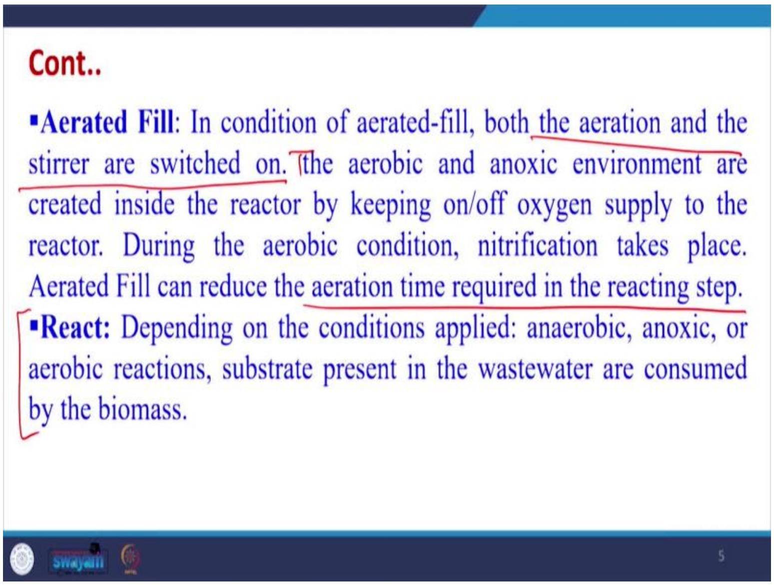

Then we can have aerated fill, in the aerated fill both the aeration and the stirrer are switched on. That means the aerobic and anoxic conditions are created inside the reactor by keeping on and off oxygen supply to the reactor during the aerobic condition nitrification takes place aerated fill can reduce the aeration time required in the reacting steps.

So, if only oxidation is required, aeration can be done in the filling stage also and it will essentially reduce the time which is required for the react phase, then the react phase depending upon the conditions applied, whether it is anaerobic, anoxic, aerobic condition the substrate present in the wastewater are consumed by the biomass active biomass presence inside the reactor.

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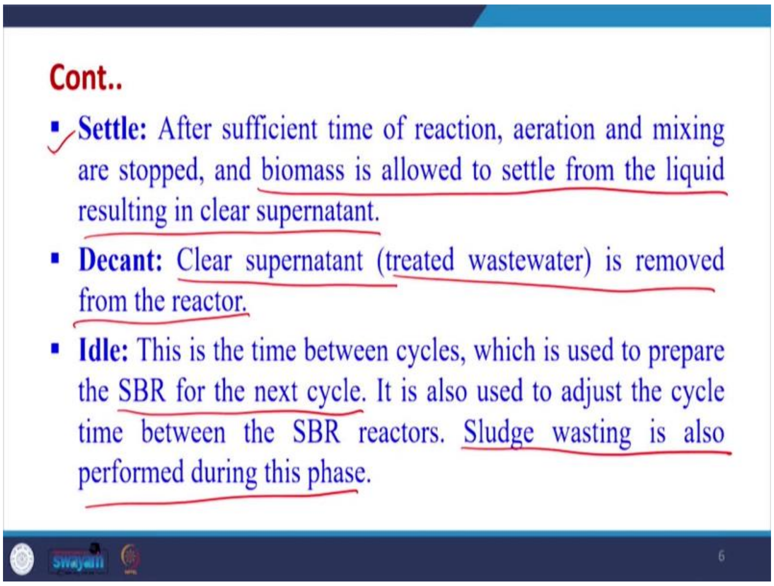

After the react, fill phase and react phase, then we have a settle phase. In the settle phase after sufficient time of reaction, aeration and mixing are stopped. That means, once the sufficient type of reaction has been achieved, aeration and mixing will be stopped the biomass is allowed to settle from the liquid resulting in clear supernatant. So, how much time will be given depends upon the quality of biomass being produced, how much or the settling or the clear difference is required in terms of the supernatant.

So, this this is called settle phase then the clear supernatant which is the treated wastewater is removed from the reactor that it is decanted out then we have idle time this is the time between cycles which is used to prepare the SBR for next cycle. It is also used to adjust the cycle time between SBR reactor also during this time the sludge wasting is also performed during this phase.

So, we can perform the sludge because with every treatment the sludge may increase. So, we may have to remove the sludge after certain cycle this is possible. So, SBR can be used for carbon removal or organic removal it can be used for nitrogen removal nutrient removal also.

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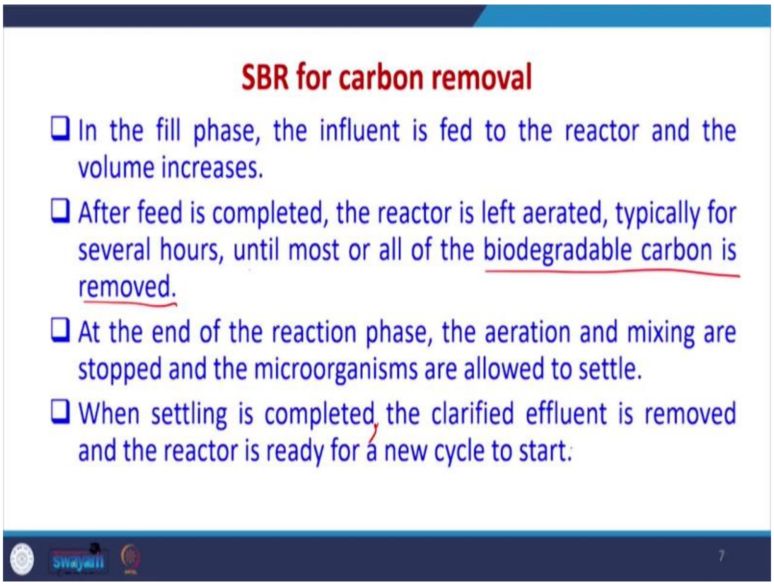

So for SBR when it is used for carbon removal, our organic removal in the fill phase influent is fed to the reactor and the volume increases. So, as the influent is fed into the reactor the volume of liquid inside the reactor increases, after feed is completed the reactor is left aerated, typically for several hours until most of the biodegradable carbon organic portion is removed.

At the end of the reaction phase the aeration and mixing are stop and microorganism are allowed to settle. When settling is completed, the clarified effluent is removed and the reactor is ready for new cycle to stop. So, this is same as usual operation.

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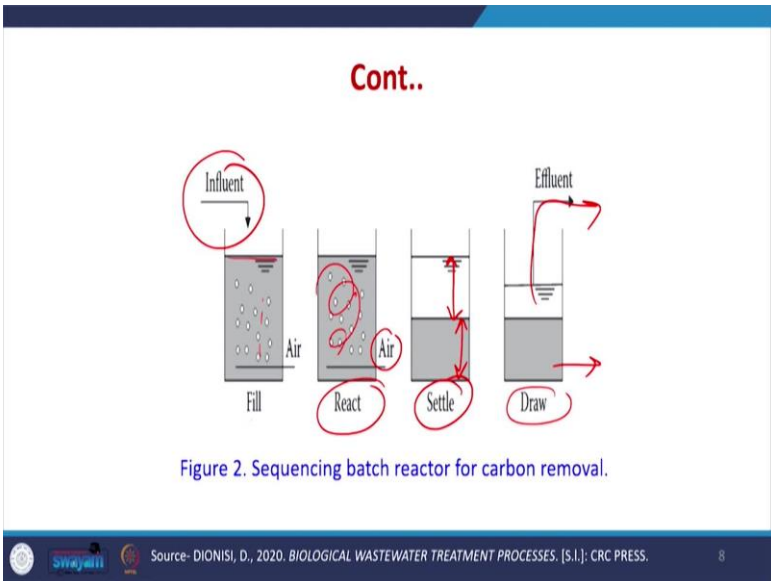

So, we have influent which is coming in the fill phase we have aeration which is on. So, remember all these operations are being performed inside the same batch reactor. So, aeration is on so, this is the reactor will be filled after that we have react with again air is on the reaction will be carried out and the organic content will be converted into CO_2 H_2O after the reaction is complete and we have achieved the desired efficiency settling time some settle phase will be there where some settling time will begin.

We will be having clear supernatant and a section where biomass is concentrated. Now, this effluent from the top is taken off drawn off and again some idle time is given it may be possible that this sludge may be wasted also and again the process repeats itself. So, this is for carbon removal.

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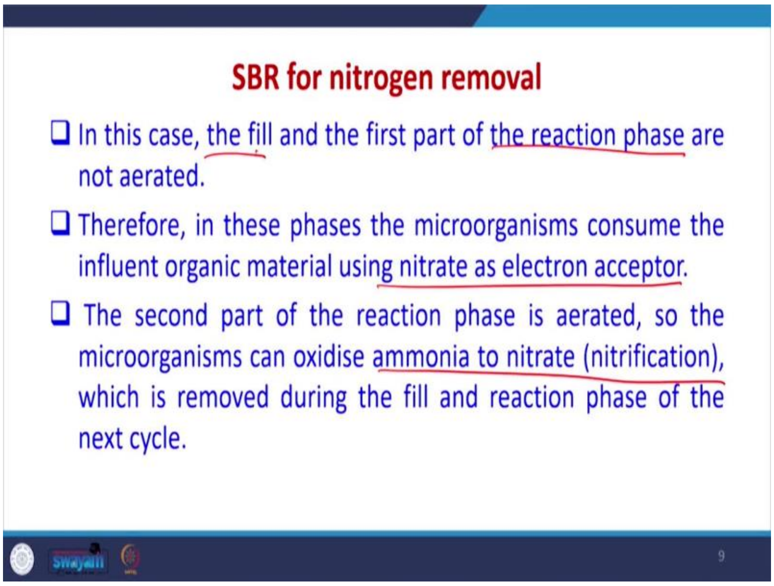

Now, for nitrogen removal in this case the fill and the first part of the reaction phase are not aerated. Remember the fill phase is not aerated and certain fraction of the reaction phase is also not aerated. Therefore, in these phases the microorganism consumes the influent organic material using nitrate as an electron acceptor, the second part of the reaction phase is aerated, so, that the microorganism can oxidize the ammonia which is formed to nitrate which is nitrification which is removed during the fill and the reaction phase of the next cycle. So, in the next cycle it will be removed.

So, you have some modification is done in the nitrogen removal. So, as compared to in the carbon removal, the essential difference is that the aeration is switched off in the fill phase and the certain fraction of the reaction phase. So, this is the difference.

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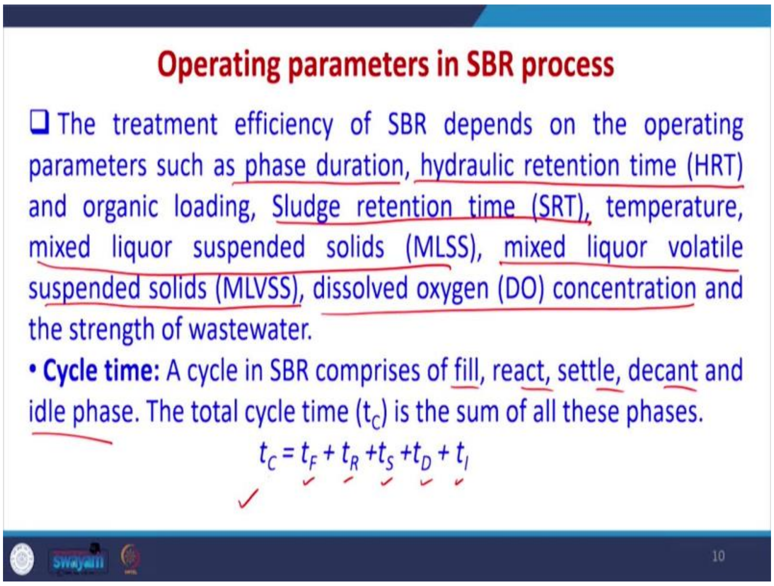

The total cycle time (t_C) is the sum of all these phases:

$$t_C = t_F + t_R + t_S + t_D + t_I$$

Now, operating parameters in the SBR process, the treatment efficiency of the SBR depends upon the operating parameters such as what is the duration of each of the phase fill phase react phase, settle phase draw phase, ideal phase etc. What is the hydraulic retention time during the treatment process? What is the organic loading that we are going to give? The sludge retention time SRT temperature at which the operations will take place the MLSS and the MLVSS inside the reactor that have to be maintained.

For maintaining this the sludge has to be removed after certain times the dissolved oxygen concentration that has to be maintained depending upon whether we are going for organic carbon removal or nitrogen removal etc. this is there. So, these are the important considerations and certainly the strength of wastewater is also important consideration.

Remember for same efficiency desirable, the SBR can handle wastewater which is having higher strength though as compared to activated sludge system. So, SBR can handle much higher strength of wastewater as compared to activated sludge process. Now, there are essential parameters that have to be determined and some of them are like what is the cycle time? The cycle time in SBR process will comprise of all the phases which are fill, react settle, declined and idle phase.

So, total cycle time can be defined like this t_C equal to t_F, t_R, t_S, t_D and t_I. So, all F R S D and I mean for fill, react, settle, decant, and idle phase. So, this is the total cycle time which is given here.

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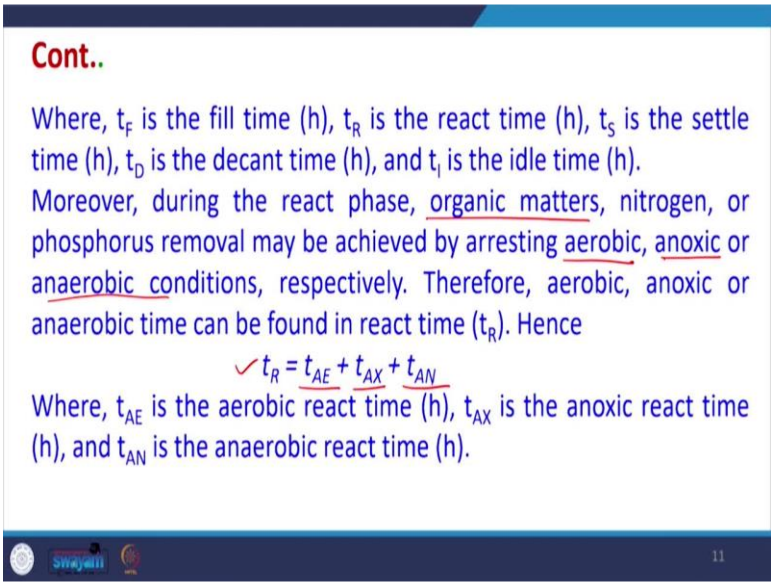

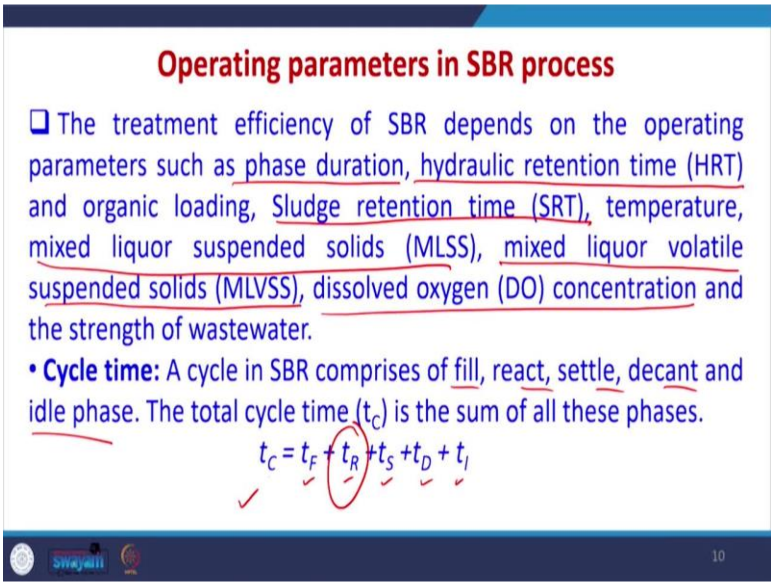

React time (t_R):

$$t_R = t_{AE} + t_{AX} + t_{AN}$$

Where, t_{AE} is the aerobic react time (h), t_{AX} is the anoxic react time (h), and t_{AN} is the anaerobic react time (h).

Now, moreover, during the react phase organic matters nitrogen phosphorus removal may be achieved by arresting aerobic, anoxic and anaerobic conditions respectively. So we can have aerobic conditions for organic matter removal, anoxic or anaerobic conditions for nitrogen or phosphorus removal.

Therefore, these aerobic anoxic, anaerobic time can also be found out in the react phase. So, the react phase itself can be divided into different phases, what is the aerobic phase, anoxic phase anaerobic phase. So, all these can be the react t_R within the cycle may be composed of different phases.

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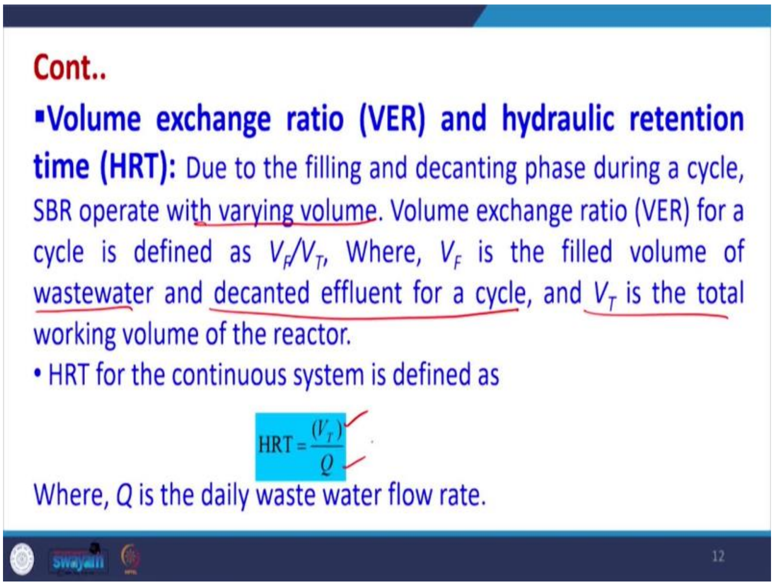

Now, there is another term which is very important for SBR which is called volume exchange ratio and certainly hydraulic retention time due to filling and decanting phase during a cycle SBR operates with varying volume that means, we have the volume which is varying. So, volume exchange ratio for a cycle is defined as V_F by V_T, where V_F is the field volume of the wastewater that means, how much volume of wastewater will be filled and decanted effluent for a cycle and then V_T is the total working volume of the reactor.

So, it is possible that out of the total volume only certain fraction 0.6 0.8 fraction is being used as a volume exchange ratio. Now, HRT for a continuous system is generally defined as volume of the reactor divided by the flow rate.

$$\text{HRT} = \frac{(V_T)}{Q}$$

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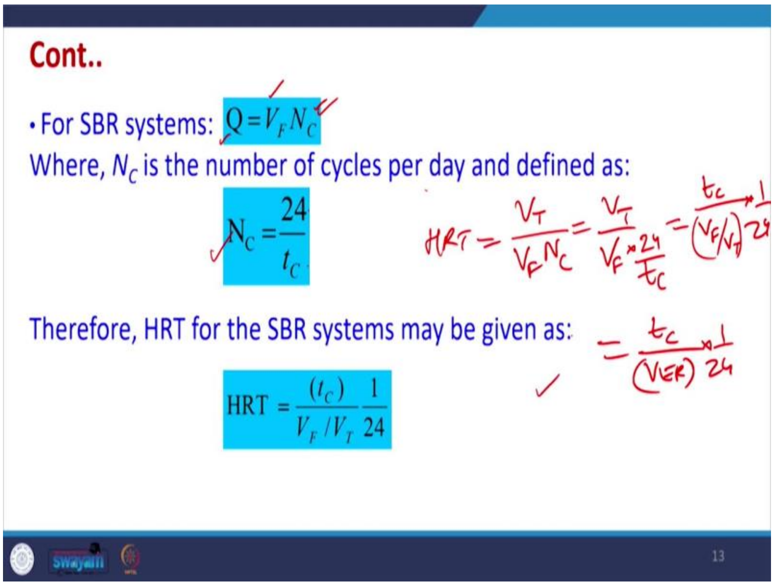

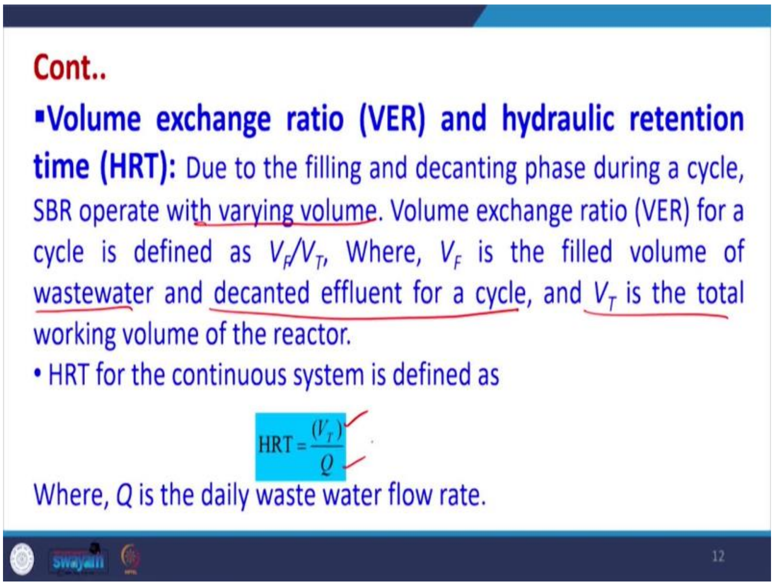

For SBR systems:

$$Q = V_F N_C$$

Therefore, HRT for the SBR systems may be given as:

$$N_C = \frac{24}{t_C}$$

$$\text{HRT} = \frac{(t_C)}{V_F / V_T} \frac{1}{24}$$

Now, for this case, it is different for SBR systems, the Q that total flow rate can be how it can be defined is the volume of the filling volume in each of the cycles. So, if we have number of cycles depending upon number of cycles, so, we can find out there in 24 hours or what is the cycle time. So, where N_C is the number of cycles per day defined as N_C is equal to 24 by t_C okay. So, which is the total cycle time.

So, thus we can replace N_C here and once N_C is replaced here we can find out Q and if Q is found out, we can divide the total volume by Q. So, that means that we have to find out the HRT can be found out using the equation which is given here V_T by Q. So, this is V_T volume of the reactor is known to us, but the flow rate is V_F into N_C and this V_F, V_F is known now this N_C is 24 by t_C.

So, from here we can find out and we can actually manipulate it t_C can go up 1 by 24 can remain here and this is V_F by V_T. So, this is the total volume. So this is actually the volume exchange ratio so HRT and volume exchange ratio R, this is VER into 1 by 24. So, this is the HRT which is used for calculation in the case of SBR system, so this is HRT.

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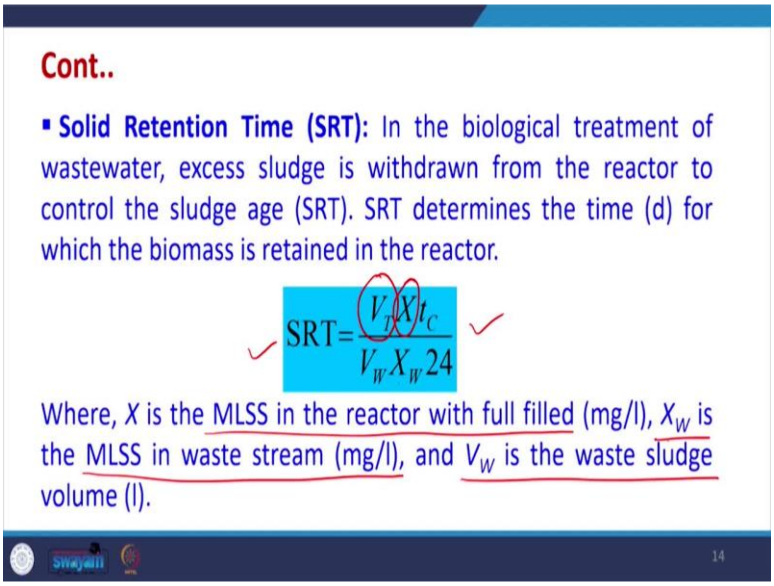

SRT is given by the following expression:

$$\text{SRT} = \frac{V_T X t_C}{V_W X_W 24}$$

Now, then similarly we can define the solid retention time in the biological treatment of wastewater, excess sludge which is withdrawn from the reactor to control the sludge, it is it actually helps in determining the solid retention time SRT determine the time for which the biomass is maintained inside the reactor.

So that means, already we have calculated now, in this case, the SRT for SBR can be defined by this equation, where X is the MLSS inside the reactor with full filled condition. So, when during the reactor phase, what is the MLSSs inside the reactor? Now, Xw is the MLSS in the waste stream. So, that will be wasted, it is possible that the wasting of the sludge is not done in every cycle it may be done in after a certain cycle or it may be done in every cycle also say how much X_W is the in the waste system we are going off and what is the V_W volume of the wasted sludge after certain time.

So taking 24 hour as consideration the SRT will be determined by this. So V_T is the total volume X is the concentration of the MLSS inside the reactor. Then V_W and X_W are the volume and concentration of MLSS in the waste stream.

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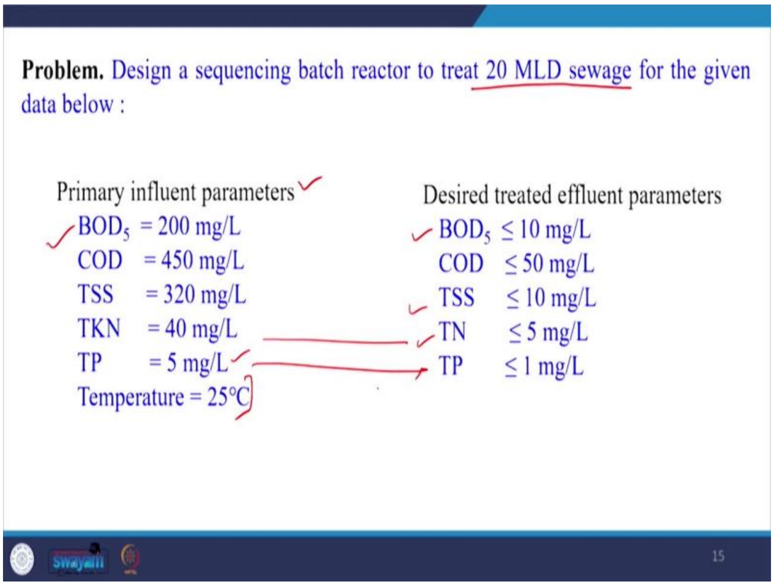

Now we will try to solve one problem to understand the SBR process design a little bit. So, we have to design a sequential batch reactor to treat 20 MLD of sewage wastewater for the given data which is given below. So, the influent parameters the sewage or the wastewater is having BOD_5 of 20 milligram per 200 milligram per liter COD 450 milligram per liter TSS 320, TKN 40 and the total phosphorus is 5 milligram per data temperature is 25.

And the desired condition is that the BOD should be less than 10 COD should be less than 50, the TSS should be less than 10 that total nitrogen should be less than 5 and the total phosphorus should be less than 1 milligram per liter, this is the actual desire mean which is there.

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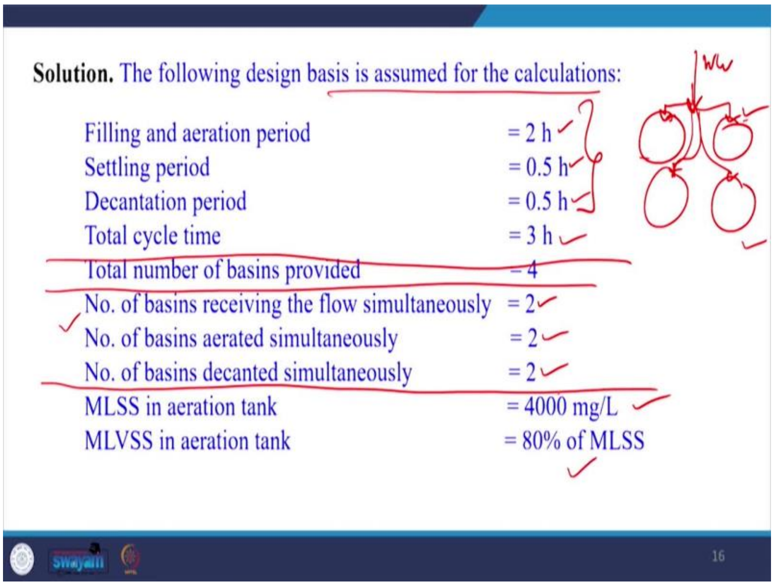

Now for solving this condition, we will use certain assumptions for calculation and these assumptions for design link are given you we are assuming that we are going to have a filling period remember, if under these assumptions, we are not able to meet the criteria we can change these assumptions that means, so, filling an aeration period, we are assuming to be 2 hours after that we are assuming that we are going to give 0.5 hours of settling time and 0.5 hour of decantation.

t at means and there is virtually no idle time. So, if anytime some wasting of sludge has to perform it will be inside this. So the total cycle time is 3 hours. So and we are also assuming that we will be having 4 number of basins, so the number of basin SBR remember the wastewater which is coming is being continuously generated.

So, what is done is that we use a number of SBR. So, when the filling is being done for 1 SBR at least another will be in the React phase, another will be in the decant phase and once the filling has been completed and its react phases where the wastewater goes inside this reactor. That means in the actual way, we have continuous operation which is going on the wastewater is not being blogged only thing is that it is going into different reactors at different times and all the reactors are operating in a batch mode, but or treatment is happening in a continuous mode.

So, we have number of basins, which are receiving the flow simultaneously at two that means this and this both will be receiving the flow and after certain time these will be receiving the flow. Now the number of basins which are aerated, simultaneously at 2 and number of basins which are being decanted simultaneously by 2.

The MLSS we are assuming in the aeration tank to be 4000 milligram per liter. That means an MLVSS will be 80 percent of the fleet is 80 percent so MLVSS will be around 0.8 of this. So, this is there.

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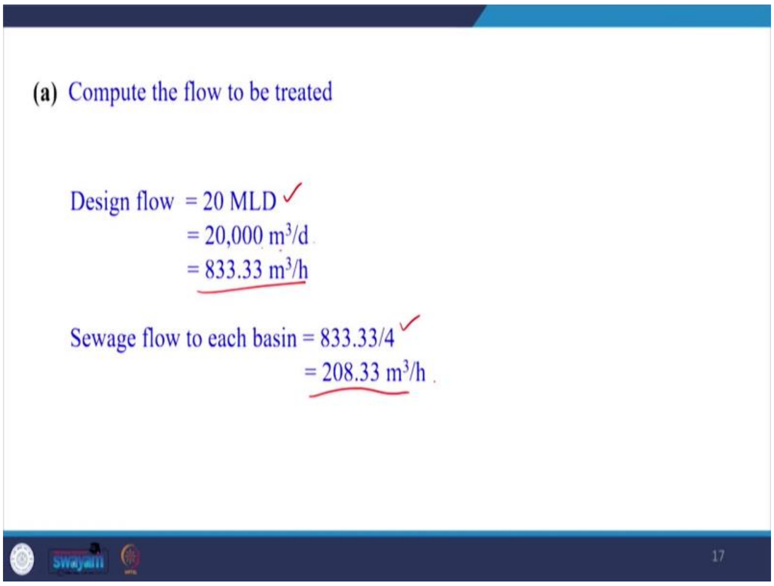

Now compute the flow to be treated. Now, we have 20 MLD of water which is to be treated. So that means 20000 meter cube per day that means which is equal to 833.33 meter cube per hour. Now, since we have 4 basins to see which flow to each basin will be around divided by 4 to 208.33 meter cube per hour we are assuming to be 4. So, this is how the division will take place.

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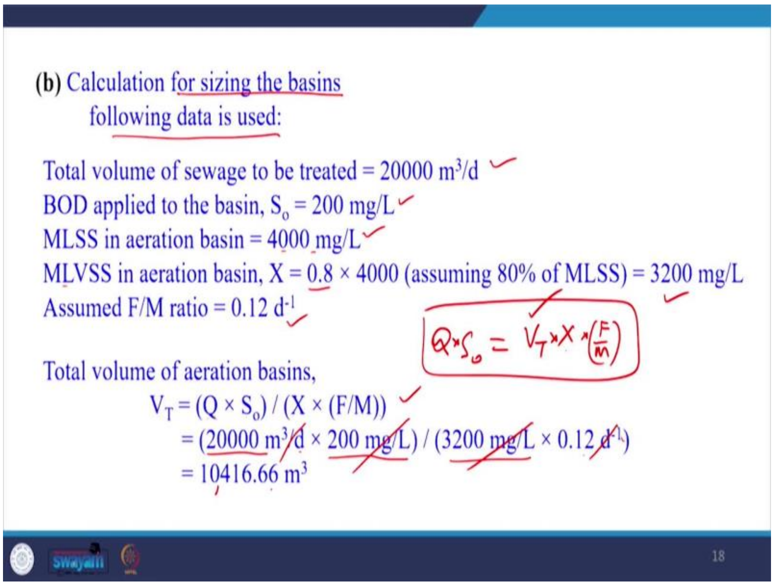

Total volume of aeration basins:

$$Q \times S_0 = V_T \times X \times \frac{F}{M}$$

$V_T = (Q \times S_o) / (X \times (F/M))$

$= (20000\ m^3/d \times 200\ mg/L) / (3200\ mg/L \times 0.12\ d^{-1})$

$= 10416.66\ m^3$

After the calculation of sizing of the basin. So, we have to calculate the size of the basin and the following data is with you, total volume of events to be treated is 20,000 meter cube per day. So this is already there BOD applied to the basin is 200 milligram per liter and MLSS is 4000. So MLVSS is 0.8 of 4000 that means 3200 milligram per liter under this condition, we are assuming that we will try to maintain the food of microorganism ratio of 0.12.

So the total volume will be calculated. What is the inlet? Inlet is Q into S_0. Remember, in the what is the concentration we can put it other way, thus in the influence what is the concentration of BOD which is coming and what is the concentration inside the reactor for that, we know that the what is the volume of the reactor what is the biomass concentration and since biomass concentration is known using the food to microorganism ratio we can calculate convert it into what is the substrate concentration.

So, this actually balance is being used here. So, V_T reactor volume be calculated Q into S_0 divided by X into food to microorganism ratio. So, 20,000 meter cube per day 200 milligram per liter divided by 3200 milligram per liter in to 0.12 per day, so, milligram per liter milligram per liter goes up per day per day goes off, then we have meter cube. So, this meter cube is calculated to be total volume of edited bases that are required is 10,416 meter cube. So, this is the requirement.

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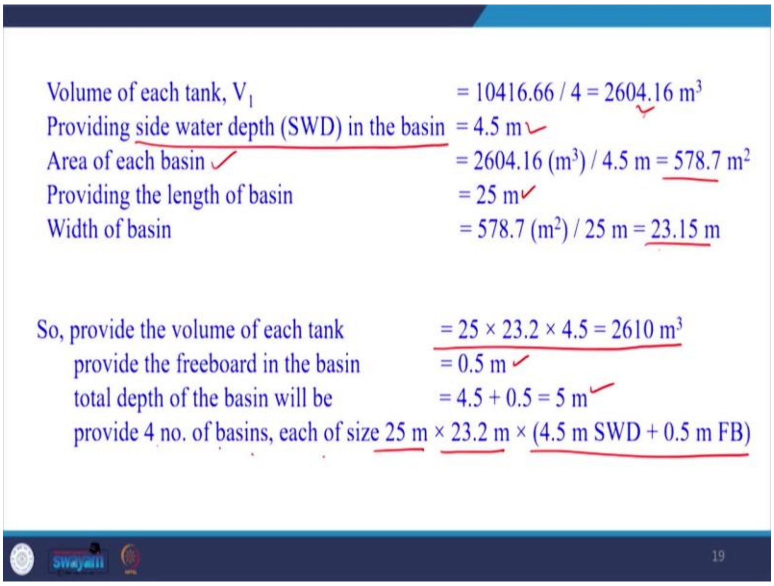

So, volume of each tank will be divided by 4 to 2604 meter cube. Now, if we assumed the side water depth of 4.5 meter, so, that means, the area of each basin should be around 578.7 meters square and if then we assume them to be rectangular basins, then if we assumed the length to be 25 meters that means, the width should be 23.15 meter. So, these are the huge reactors, which dimensions of 23 into 25 into depth of 4.5 meter.

So, this is the volume of each tank which is there now, we have to should give some freeboard region in the basin also, if we knew freeboard is of 0.5, so, that total depth will be 5 meter. So, provide 4 number of basins each of size 25 meter 23.2 meter and 5 meter in total. So, this is the phone number of bases with such huge dimensions are required for treatment of such wastewater.

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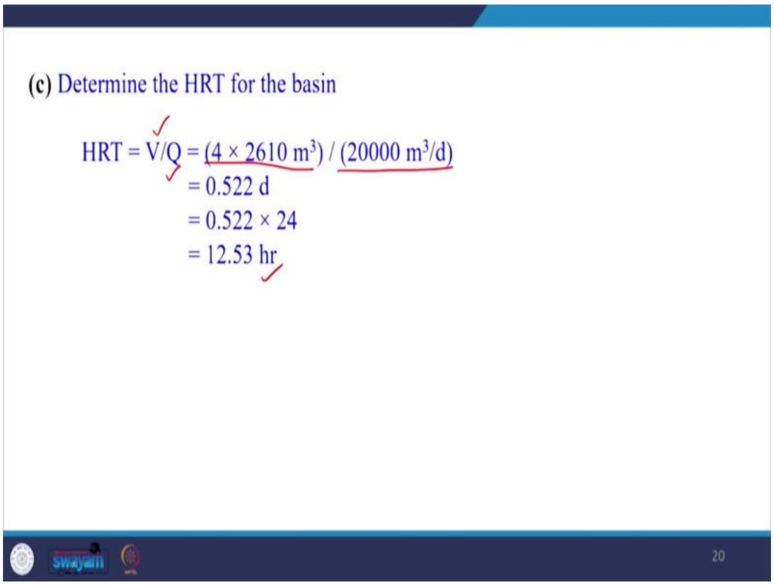
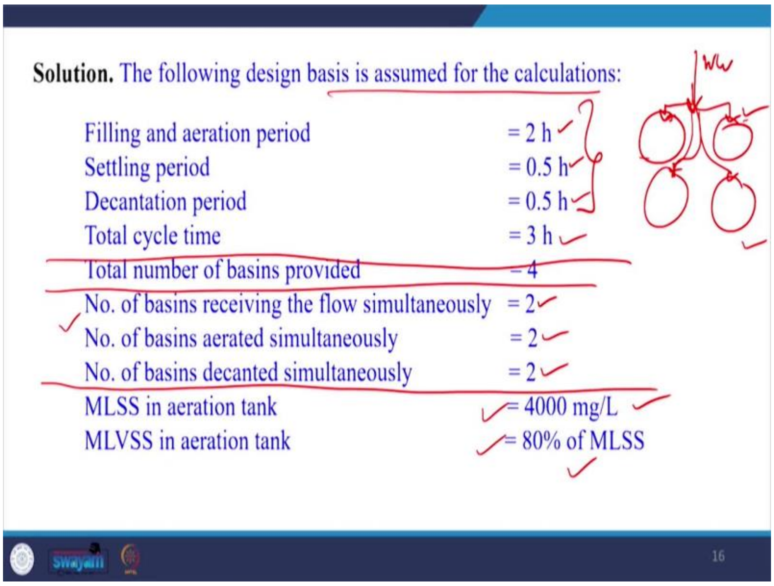


HRT = V/Q = (4 × 2610 m^3) / (20000 m^3/d)

= 0.522 d

= 0.522 × 24

= 12.53 hr



Now, we have to find out the HRT also of the basin. So, what was the volume and what is the total flow rate, so, volume is 4 into 2610 meter cube and this is being divided by 20,000 meter cube per day. So, because this is the total flow rate, so, we have HRT of 12.5 hours which is given.

So, this way we can essentially calculate some amount of calculation based upon the basic thing is that, we have already fixed some of the parameters, it is possible that these parameters may not be good enough. So, we can change back these parameters to optimize the design of the system. So, this is also possible, so we can always perform these calculations to calculate all these things.

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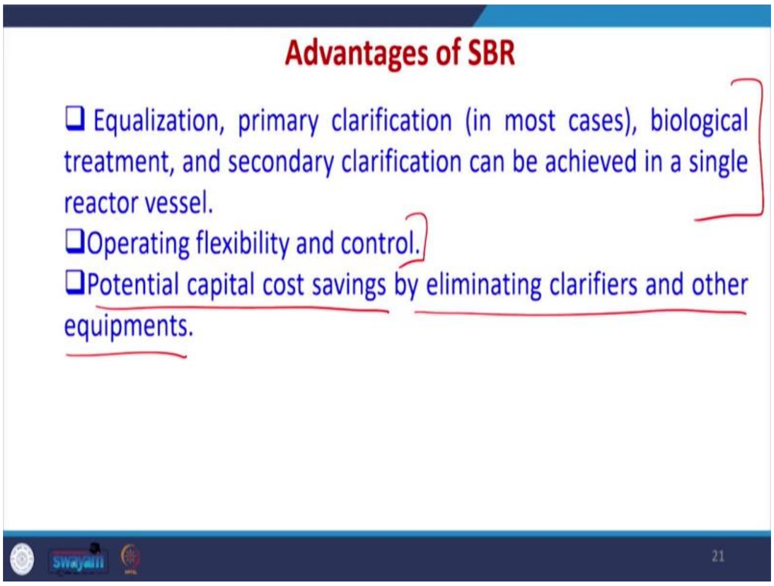

And so, there are certain advantages of SBR that we have done. So, equalization, primary clarification, in most cases, the biological treatment and secondary clarification all can be achieved in a single basin. So, this is one of the major advantage of SBR we have operational flexibility and control because we can always change back the fill time react, time settle time etc.,

Then we can have potential capital cost saving by eliminating the clarifiers and other equipment's. So, these are the advantages of SBR remember SBR also have higher efficiency, because they are being operated in the batch mode. So, this is also there.

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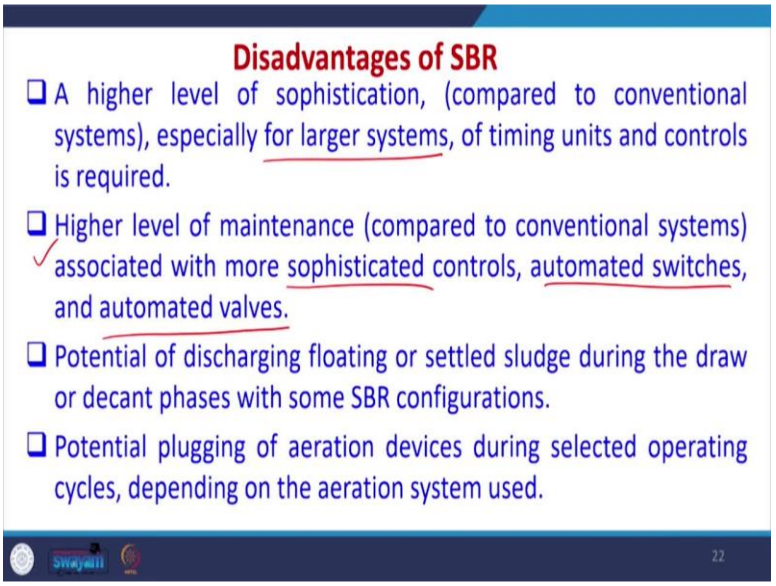

What are the disadvantages of the SBR. So, a high level of sophistication as compared to conventional system conventional activated sludge system is required, especially for larger systems for timing the units and control because we have to always maintain all the units properly all the phases have to be controlled.

So, that means we have a lot of piping and all these systems are required so, that the flow or maintain, pumps are always in operation mode. Pumps are properly timed so, that we have all the phases which are maintained inside the design parameters itself a higher level of maintenance compared to conventional system is required.

And that means we have more sophisticated controls, automated switches and automated valves are required. Potential of discharge floating or settled sludge during the draw or decant phase with some SBR configurations have been reported. There is potential of plugging of aeration devices during selected operating cycles depending upon the result system use. This is all are possible disadvantages.

So, we have to select between advantage and disadvantage for a smaller system certainly SBR is highly beneficial for larger system we have to select properly that whether we have to go for activated sludge system or SBR system.

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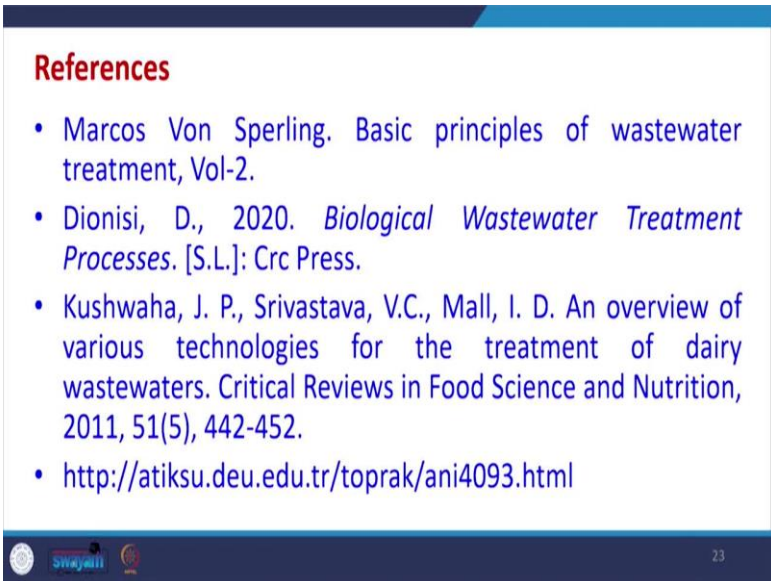

These are the differences which have been used for preparation on these slides. You can always refer to these slides. Thank you very much.