Basic Environmental Engineering and Pollution Abatement
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Lecture 33
Advanced secondary processes 1

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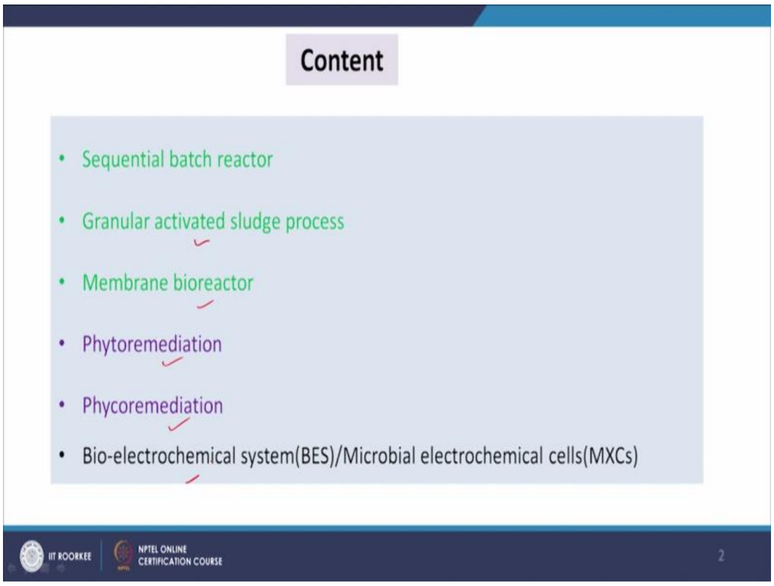

Hello everyone. Now we will discuss on the topic, advanced secondary processes part 1. And in this class we will discuss on sequential batch reactor, granular activated sludge process, membrane bioreactor and in this topic we will also discuss phytoremediation, phycoremediation and Bio electrochemical systems and microbial electrochemical cells. So, in the previous class, we have discussed about the equipment used in the secondary processes, and we have seen that activated sludge process is an important route or method which is used for secondary treatment for wastewater.

So, we have made enough discussion on the conventional activated sludge process. And we have seen that the main disadvantage of activated sludge process is that it requires larger floor area and it includes number of separate units like say aeration, then clarification then decanter.

So, number of units are needed to complete this process. So, people try to develop advance process as the modification of this activated sludge process or the advanced activated sludge process we can say so, that is sequential based reactor and granular activated sludge process and membrane bioreactor is another type of improvement in secondary treatment and phytoremediation is also a new concept.

Although this is a very old process, but in engineered way, these are being implemented in recent years, the living plants are used for the remediation of pollution and phycoremediation in this area, we will see that algae and micro algae are used for the treatment of wastewater and bio electrochemical systems and microbial electrochemical cells, these are recently new advancements, which are being investigated widely for the production of electricity and hydrogen along with the treatment of wastewater.

So, we will discuss all this topic in this module and this class will be focusing on sequential waste reactor, granular activated sludge process and membrane bioreactor. So, as we have just mentioned, that activated sludge process has some difficulty because of its large floor area requirement. So, that can be reduced by using a new concept that is sequential batch reactor, so unlike activity sludge process, one unit will be used in this process, but at with time the activities in the reactor will change.

So, if we see the activity sludge process, the water gets entry into the aeration tank, then aeration takes place, then reaction takes place microbes degrade the organic compounds and then it is settled in the secondary clarifier and then decanter is used to separate the sludge from the treated water. But these different activities can be taking place in the same reactor in a batch mode. So, that is called sequential batch reactor different steps takes place in a sequential order. So, that is why it is a sequential batch reactor.

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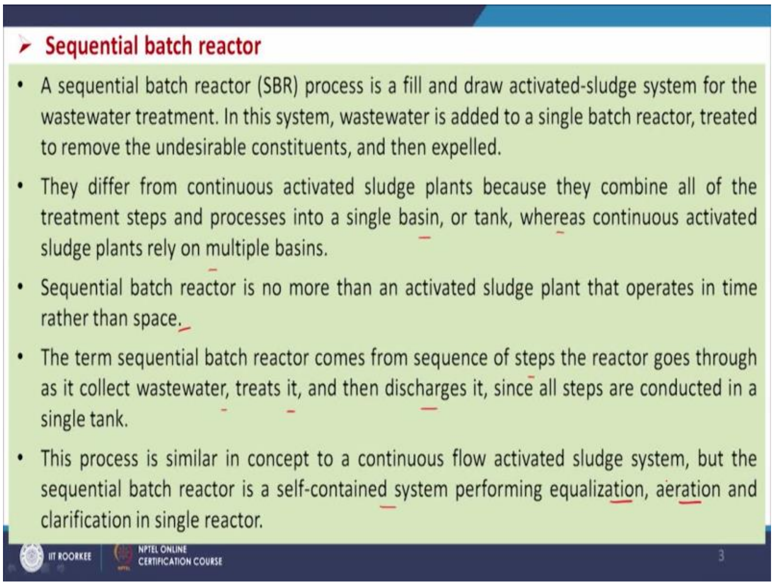

And you see a sequential batch reactor process is a fill and draw activated sludge system for the wastewater treatment. In this system, wastewater is added to a single batch reactor treated to remove the undesirable constituents and then expelled. They differ from the continuous activated sludge plants because they combine all of the treatment steps and processes into single basin or tank whereas continuous activated sludge plants rely on multiple basins. And sequential batch reactor is no more than an activity sludge plant that operates in time rather than space. The term sequential batch reactor comes from sequence of steps, the reactor goes through as it collects wastewater treats it and then discharge it. Since all steps are conducted in a single tank. This process is similar in concept to continuous flow activities slugde system, but the sequential batch reactor is a self-contained system performing equalization, aeration and clarification in a single reactor. So, these has been written more systematically.

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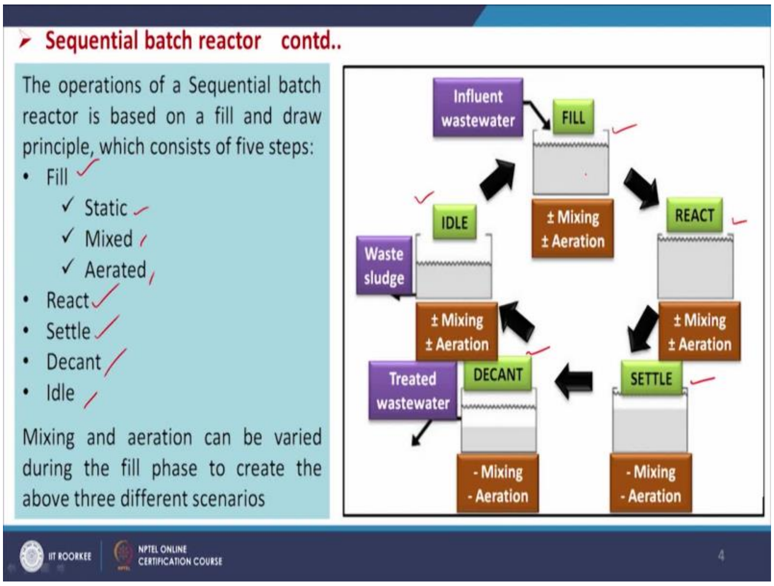

Now, what are the sequences and what are the steps for sequential batch reactor, this slide gives us that idea. So, that is influent is coming into the reactor that is filled stage and then reaction will take place that is react stage and then settling of sludge and then decanting of it and then the reactor will vacant so, again it will be filled, but some idle time is needed. So, that is the complete cycle of the operation of the sequential batch reactor and we see the steps to the field react settle decant and idle. And these fill step can be of different type like say static, mixed and aerated.

Static means the wastewater will enter into the reactor, but there will be no agitation neither there will be any agitation nor oxygen will be supplied. So, that will be not full of oxygen and in the mix page we will be applying some mixing devices or arrangnment but no aeration will be made. So, that will be your an oxygen and under aerated condition. So, air will be provided air bubbles will be provided and then it will be aerobic conditioned. So, we can create different atmosphere in the reactor in terms of the availability of oxygen then the reaction will take place thereafter then settled and decant then again ideal.

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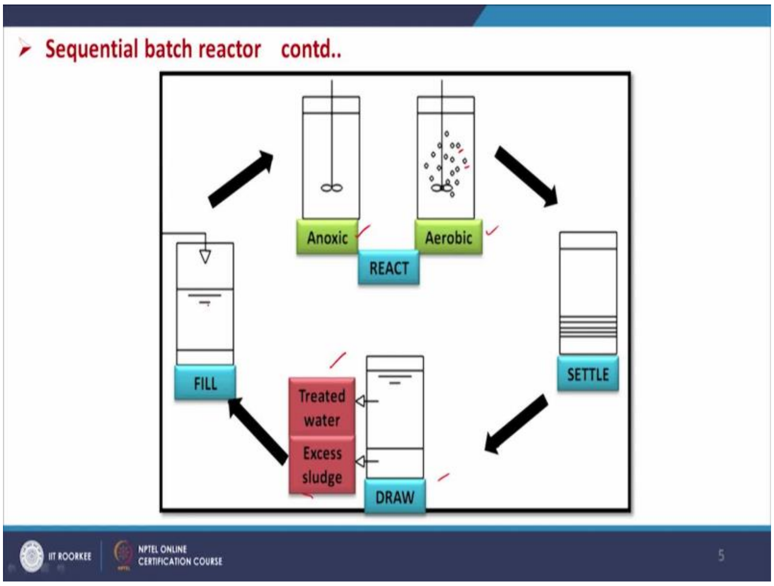

So, this is depending upon the mode of filling the reactor may be in anoxic or in aerobic condition. Aerobic conditions means free oxygen is available, anoxic condition means free oxygen is not available, but bound oxygen may be available like say in terms of nitrate nitrite etc. So, that can be available and that oxygen can be used by microorganism.

So, that is anoxic conditions and aerobic condition basically an anaerobic condition it also will be available in the reactor that in case no oxygen will be available neither in freeform nor in bound form. So, these are the different situations we can get. And other things are there and in the draw stage we can get treated water and excess sludge we can get and again we can feel it here. So, that way the sequential batch reactor works.

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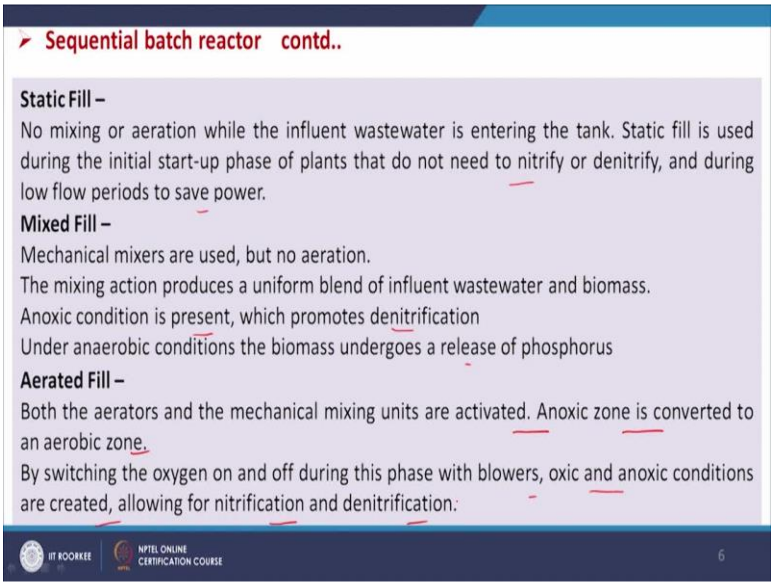

And static fill as you have mentioned that no mixing or aeration while the influent wastewater is entering the tank static field is used during the initial startup phase of plants that do not need to nitrify or denitrify and during low flow periods to save power. So, that is the main objective to fill in a static condition at the initial stage.

Then mixed fill that mechanical mixers are used but no aeration, the mixing action produces uniform blend of influent wastewater and biomass. Anoxic condition is present which promotes denitrification. So, if oxygen is not present in free form, but it is in present in bound form as a nitrate and nitrite then that oxygen can be taken up by the microorganisms and nitrite or nitrate will be converted to nitrogen and that is called denitrification process. And under anaerobic conditions, the biomass undergoes the release of phosphorus. So, this is a uniqueness of this condition.

And aerated fill both aerators and the mechanical mixing units are activated. Anoxic zone is converted to aerobic zone by switching the oxygen on enough during this page with blowers oxic and anoxic conditions are created allowing for nitrification and denitrification. So when we are providing oxygen, then we will be getting nitrification we are not providing oxygen, we will be getting denitrification.

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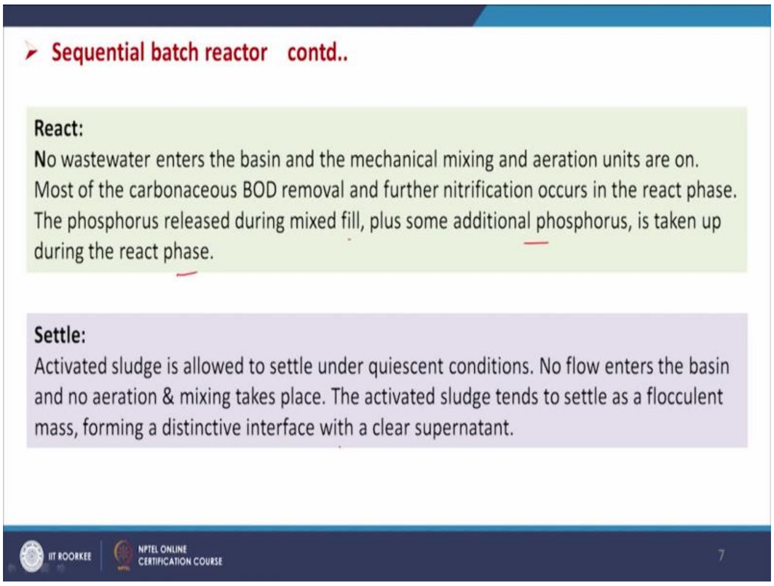

So, under the React phase no wastewater enters the basin and the mechanical mixing and aeration units are on. Most of the carbonaceous BOD removal and further nitrification occurs in the React phase. The phosphorus released during mixed fill plus some additional phosphorus is taken up during the React phase. So, in anoxic condition, Phosphorus is released and then that is used in this case for the growth of the microorganisms. And under settle phase activated sludge is allowed to settle under quiescent conditions no flow enters the basin and no aeration and mixing takes place. The activities sludge tends to settle as a flocculent mass forming a distinctive interface with a clear supernatant.

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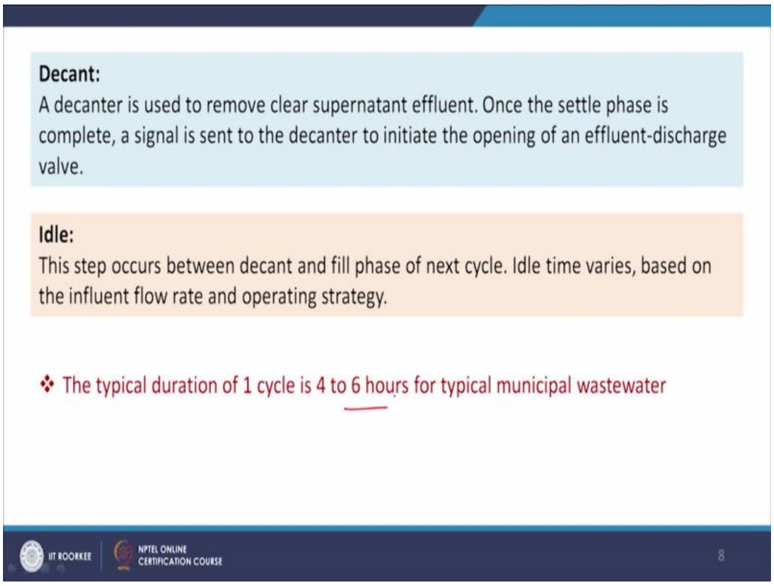

So, and then decanting will be taking place a decanter is used to remove clear supernatant different once the settle phase is complete, a signal is sent to the decanter to initiate the opening of an effluent discharge valve. Then this idle step this step occurs between decant and fill phase of next cycle. Idle time varies based on the influent flow rate and operating strategy and if we see the whole cycle, then typical duration of 1 cycle is 4 to 6 hours for typical municipal wastewater.

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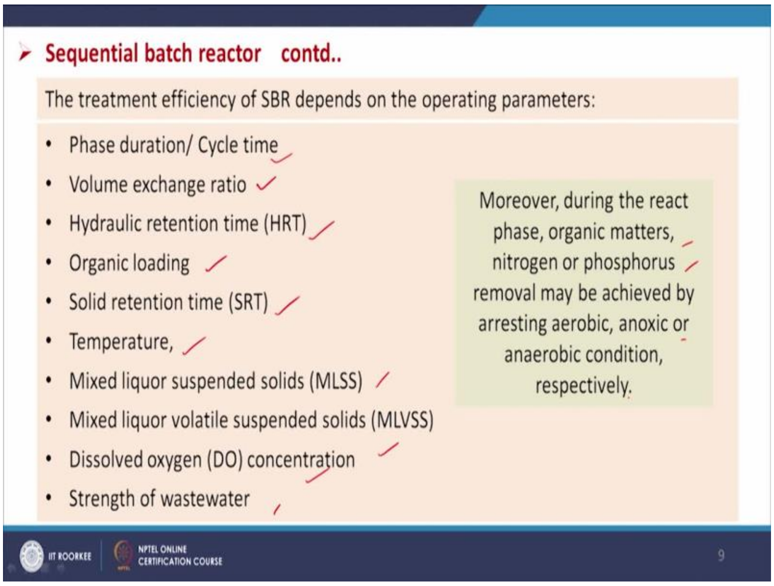

And we will see that the treatment efficiency of this sequential batch reactor SBR depends on operating parameters like say phase duration or at least the cycle time and volume exchange ratio and then hydraulic retention time organic loading and then solid retention time temperature mixed liquor suspended solids, mix liquor volatile suspended solids, dissolved oxygen and strength of wastewater. And moreover, during the react phase organic matters Nitrogen and Phosphorus Removal may be achieved by arresting aerobic, anoxic or anaerobic condition respectively.

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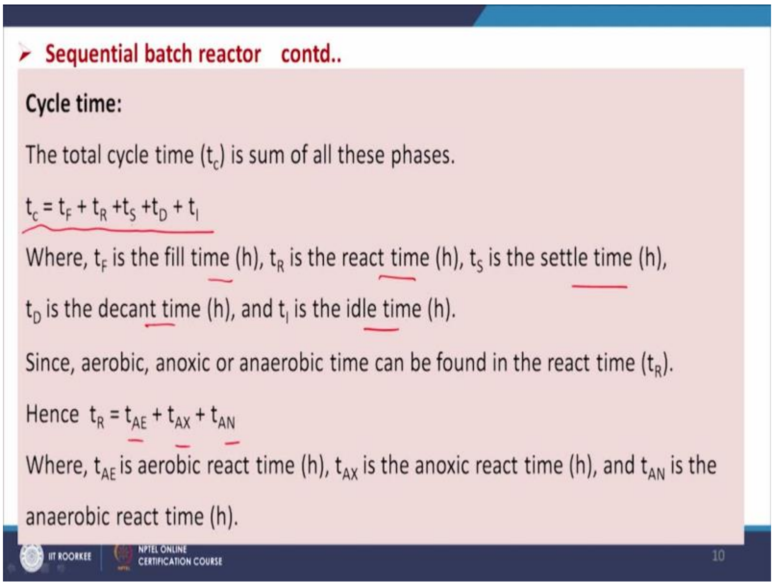

So, then how will you calculate the cycle time? So, the total cycle time will be t_C

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

Where t_F is the field time, t_R is the React time, t_S is the settle time, t_D is the decant time, and t_I is the idle time. So, total time is your t_C and this the react phase are you talking about that may be aerobic anoxic and anaerobic so that way also we can calculate t_R

$tR = t_{AE} + t_{AX} + t_{AN}$.

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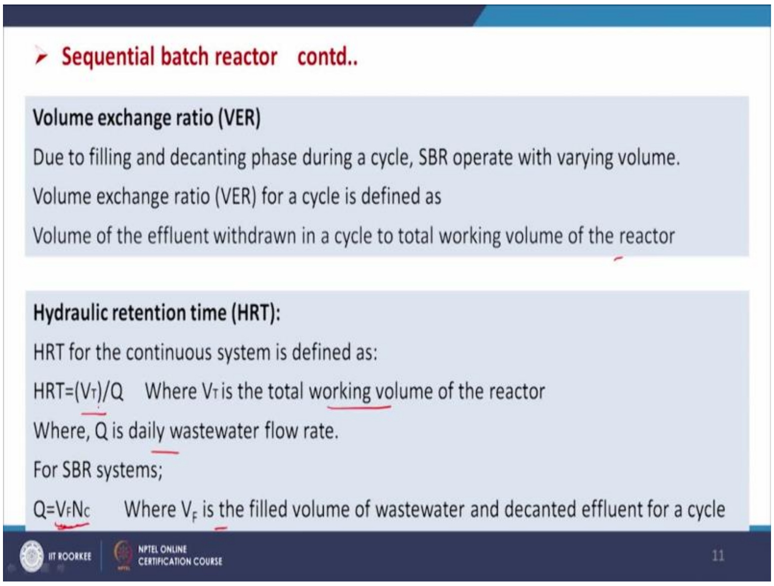

Now we will see what is the volume exchange ratio? So volume exchange ratio basically the ratio of the effluent going out from the reactor per cycle divided by the total volume of the reactor. So, due to filling and decanting phase during a cycle SBR operate with varying Volume. And Volume exchange ratio for a cycle is defined as the volume of the effluent withdrawn in a cycle to total working volume of the reactor.

Then hydraulic retention time and another parameter. So, that can be defined as

$HRT = V_T/Q$

where V_T is the total working volume of the reactor and Q is the daily wastewater flow rate. But for SBR

$Q = V_F*N_C$,

Where N_C is the number of cycles in a day and V_F is the field volume per cycle. So, if there are number of cycles, we will do multiply that number with the V_F so that will be the total flow per day.

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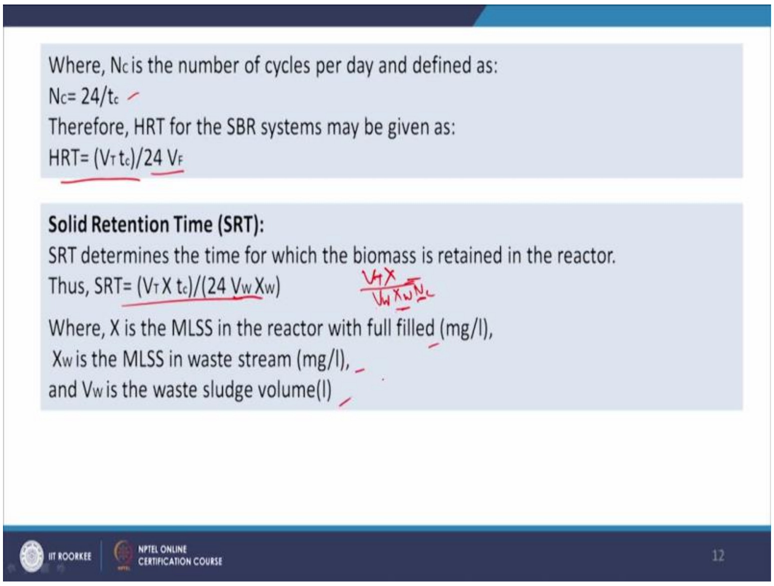

And where N_C is the number of cycles per day and defined as

$N_C = 24/t_C$

HRT for SBR system may be given as

$HRT = (V_T *T_C)/24*V_F$

Then solid retention time. So, solid retention time this can be defined as the solid mass present in the reactor and solid mass going out per day.

$SRT = (V_T*X)/(V_wX_wN_C)$

Where N_C is the number of cycles in a day. So, V_W is the total volume, X_w that is the microbial mass in the waste stream. So, this will be the stream now, if we replace this N_C value as 24/Tc.

$SRT = (V_T\ X\ t_C)/(24\ V_w\ X_w)$

Where X is the MLSS in the reactor with fulfilled and Xw is the MLSS in the waste stream and V_w is the waste sludge volume.

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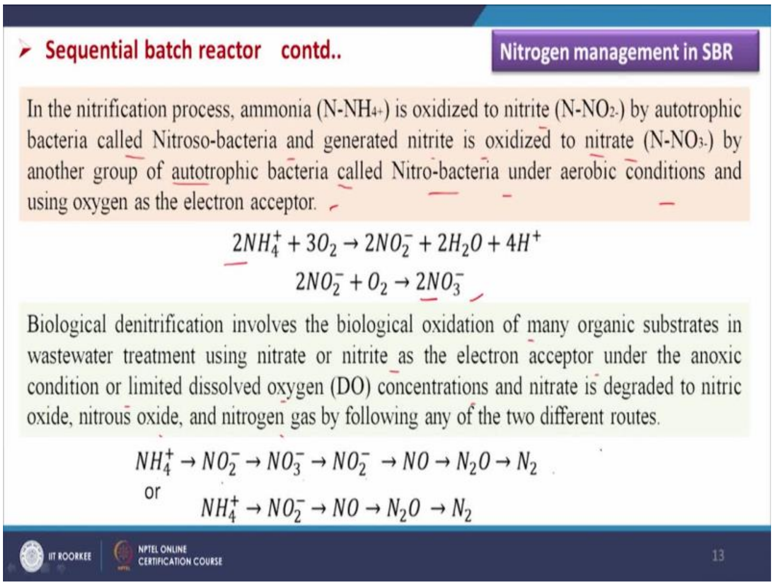

Now, how the nitrogen is managed in SBR, so we have seen that there may be an anoxic and and anaerobic conditions. During aerobic condition the nitrification takes place and in anoxic conditions denitrification takes place. So what is the nitrification that means ammonia is converted to nitrite and nitrate. So, in the nitrification process, ammonia is oxidized to nitrite by autotrophic bacteria called a nitroso-bacteria and generated nitrite is oxidized to nitrate by another group of autotrophic bacteria called nitro bacteria under aerobic conditions and using oxygen as the electron acceptor and these are the reactions.

And biological denitrification involves the biological oxidation of many organic substrates in wastewater treatment using nitrate or nitrite as the electron acceptor under the anoxic condition or limited dissolved oxygen concentrations and nitrate is degraded to nitric oxide, nitrous oxide and nitrogen gas by following any of the 2 different routes it may be ammonia to NO_2 to NO_3 or NO_2 again NO, N_2O and N_2 are NH_4 + 2 NO_2 to NO, N_2O and N_2 like this. So, that way that different sequence is followed.

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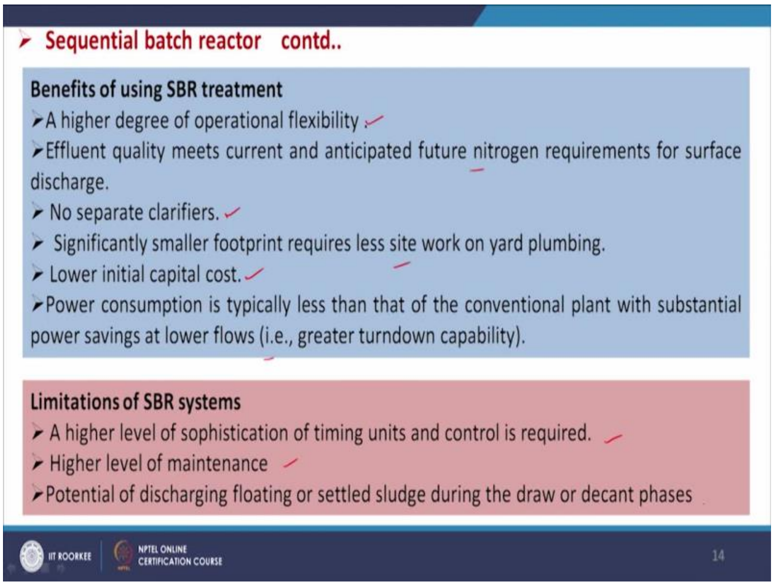

And in this SBR have some advantages or benefits like say a higher degree of potential flexibility, effluent quality meets current and anticipated future nitrogen requirements for surface discharge, no separate clarifiers, significantly smaller footprint requires less side work on eared plumbing, and lower initial capital cost, power consumption is typically less than that of the conventional plant with substantial, power saving at lower flows. And it has some limitation as well, like a higher level of sophistication of timing units and control is required. And then higher level of maintenance is required, potential of discharging floating or settle sludge during the draw or decant phases.

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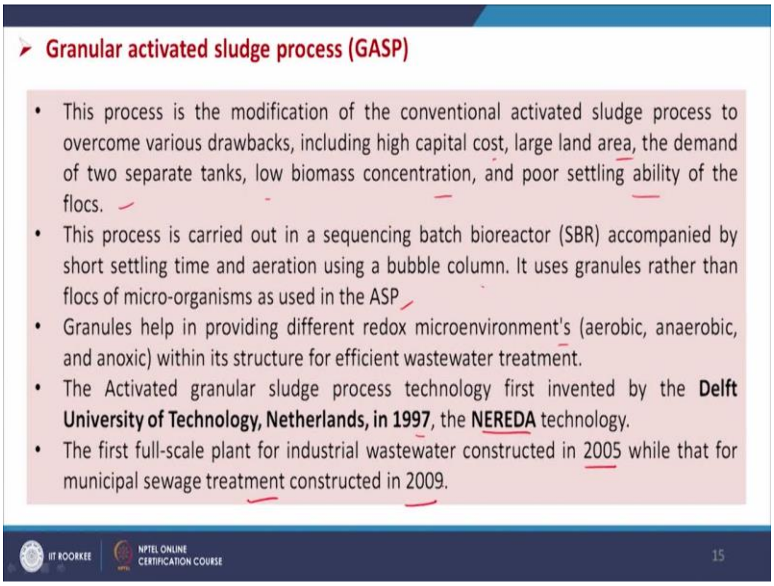

Now, we will discuss about another advanced method or another advancement on the activated sludge process that is granular activated sludge process. So, in our conventional activated sludge process, the microbes are used in a bulk phase, but here the microbes will be converted into granules and due to that, the granules in the microbes will be more effective and the sludge will be very easily settled. So, this will be the advantage of granular activated sludge process.

So you see this process is the modification of the conventional activated sludge process to overcome various drawbacks including high capital cost, large land area, the demand of two separate tanks, low biomass concentration and poor settling ability of the flocs Basically, this GASP or granular activated sludge process is the improved versions of the sequential batch reactor when the granulated biomass will be used. And this process is carried out in a sequential batch reactor accompanied by short settling time and aeration using bubble column. It uses granules rather than flocks of microorganisms as used in the activated sludge process. And granules helping providing different redox environments aerobic, anaerobic and anoxic, within its structure for efficient wastewater treatment.

The activated Granular Sludge process technology first invented by the Delft University of Technology Netherlands in 1997 and the NEREDA Technology is famous and developed by this university, the first full scale plant for industrial wastewater constructed in 2005, while that for municipal sewage treatment plant constructed in 2009.

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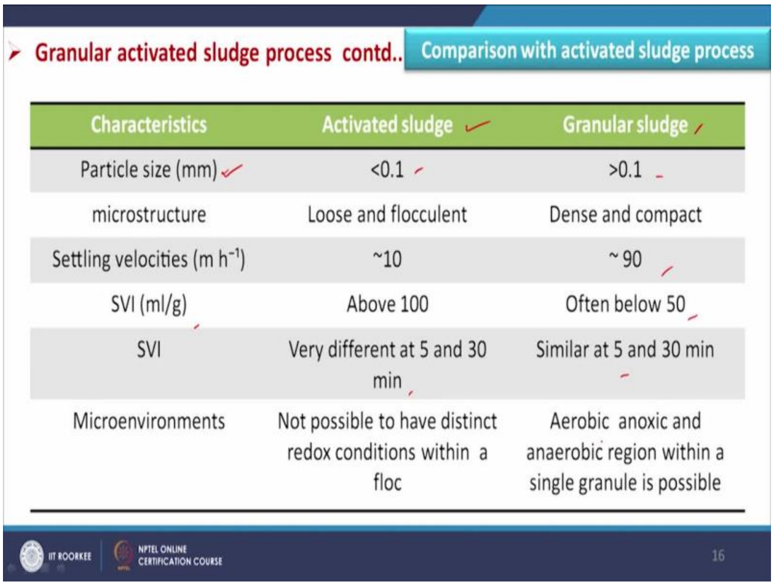

Characteristics	Activated sludge	Granular sludge
Particle size (mm)	<0.1	>0.1
microstructure	Loose and flocculent	Dense and compact
Settling velocities (m h^{-1})	~10	~ 90
SVI (ml/g)	Above 100	Often below 50
SVI	Very different at 5 and 30 min	Similar at 5 and 30 min
Microenvironments	Not possible to have distinct redox conditions within a floc	Aerobic anoxic and anaerobic region within a single granule is possible

And here we will see some comparison of activated sludge and Granular Sludge processes in terms of particle size used and particle size of the granules, basically, the microbial flocks, so, here in activity sludge less than 0.1 mm, but in case of Granular Sludge, it is greater than 0.1 mm, microstructure, dense and compact in case of Granular Sludge then activated sludge and then settling velocities much more in granular activated sludge and sludge volume index is also very less with respect to activated sludge process that means, it will be very easily settleable then activated sludge process. SVI to measure the SVI normally 30 minutes settling is required, but here are only 5 minutes is sufficient and microenvironments inactivated sludge it is not possible but in Granular Sludge it is possible at oxic, anoxic and anaerobic conditions are available in the granules.

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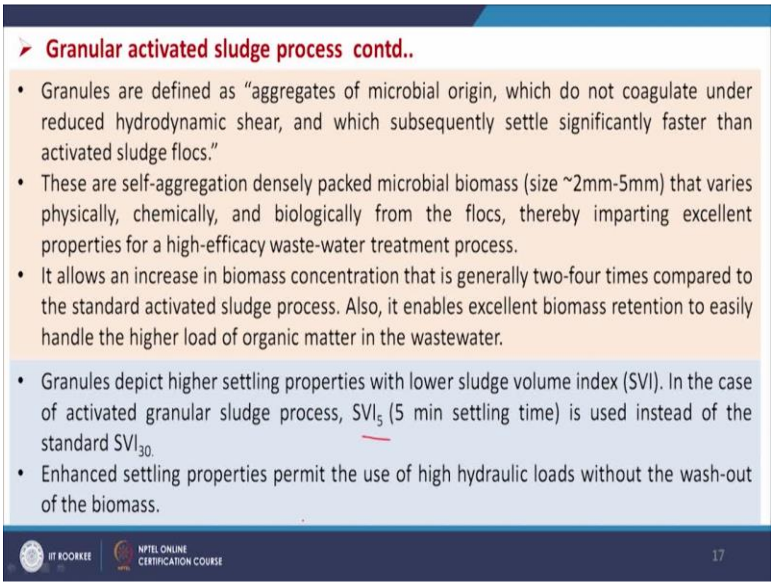

And these granules are defined as the aggregates of microbial origin which do not coagulate under reduced hydrodynamic shear and which subsequently settled significantly faster than activated sludge blocks. These are self-aggregation densely packed microbial biomass size 2 to 5 mm that varies physically chemically and biologically. From the flocks thereby imparting excellent properties of the high efficiency wastewater treatment that means in the granules, different types of microbes will be available and will be effective in different zones like anoxic and aerobic and anaerobic zones.

It allows an increase in biomass concentration that is generally 2 - 4 times compared to the standard activated sludge process. Also, it enables excellent biomass retention to easily handle the higher load of organic matter in the wastewater. Granules depict higher settling properties with lower sludge volume index in the case of activated granules sludge process

SVI5, that 5 minutes settling time is used instead of the standard SVI 30. And enhanced settling properties permit the use of high hydraulic loads without the wash-out of the biomass.

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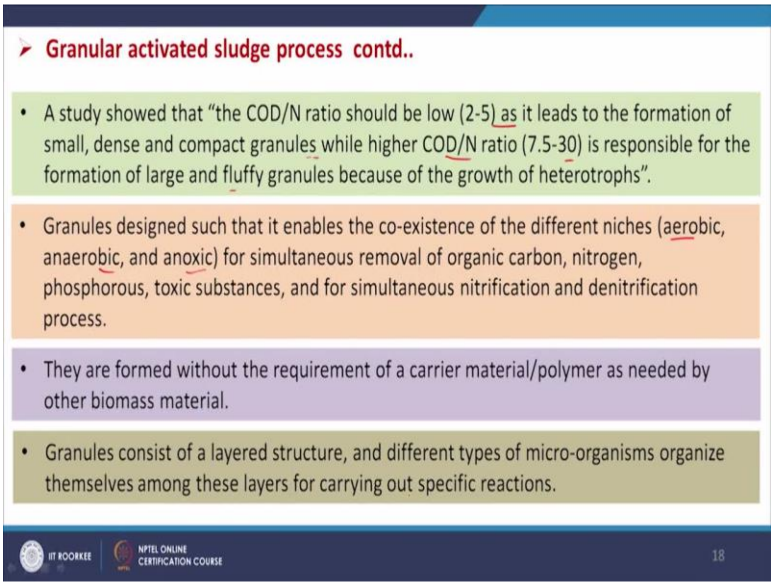

And a study showed that the COD/N ratio should be low that is 2 to 5 as it leads to the formation of small dense and compact granules, while higher COD/N ratio, there is 7.5 to 30 is responsible for the permission of large and fluffy granules, because of the growth of the heterotrophs. So high COD/N ratio is not desirable for this technology. Granules designed such that it enables the coexistence of the different niches that is aerobic, anaerobic anoxic for simultaneous removal of organic carbon, nitrogen phosphorus, toxic substances and for simultaneous nitrification and denitrification processes.

They are formed without the requirement of a carrier material or polymer as needed for other biomass materials like say in trickling filter or any other Super rate trickling filters we have discussed that some solid material is used for the immobilization of the biomass, but in this case, biomass and sludge themselves produce these granules, no external material is needed. And granules consist of layered structure and different types of microorganisms organize themselves among these layers for carrying out specific reactions.

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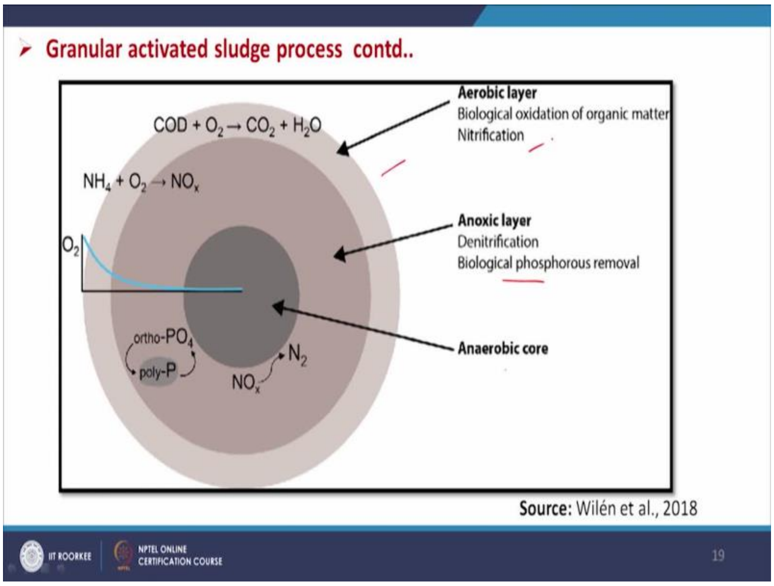

So, this is the granule say this is outer layer that is aerobic layer, the inner layer, anoxic layer and then innermost layer, anaerobic code. So different types of reactions will be taking place. So this anaerobic, this anoxic zone is responsible for the Denitrification and Biological Phosphorus Removal and this zone is for nitrifications and biological oxidation.

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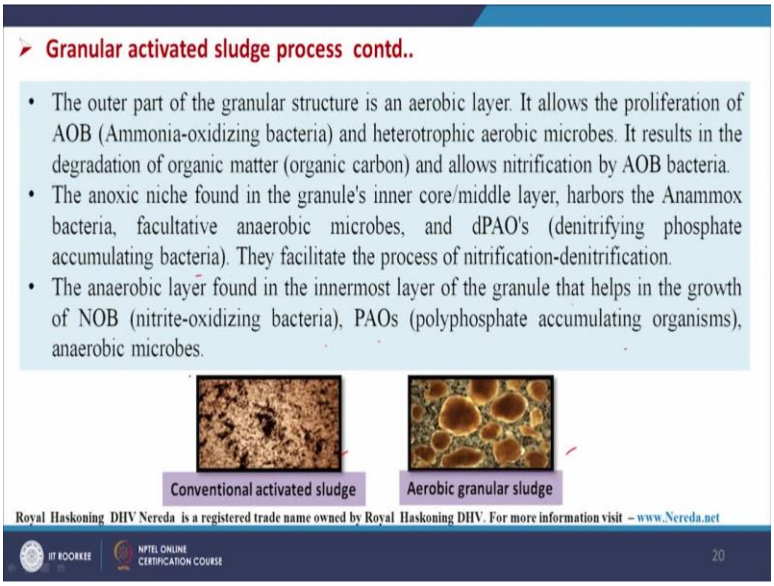

Now, we see this slide shows the photographs of conventional sludge and aerobic granulated sludge or Granular Sludge, so see the outer part of the granular structure is an aerobic layer, it allows the proliferation of the AOB that is ammonia oxidizing bacteria and heterotrophic aerobic microbes, it results in the degradation of organic matter and allows nitrification by AOB bacteria. The anoxic niche found in the granules inner core or middle layer that harbors the Anammox bacteria, that is facultative anaerobic microbes and dPAO's that is denitrifying phosphate accumulating bacteria. So they facilitate the process of nitrification denitrification and the anaerobic layer formed in the innermost layer of the granule that helps in the growth of NOB that is nitrite oxidizing bacteria, PAOs polyphosphate accumulating organisms and anaerobic microbes. So, these are the different zone different types of microorganisms are available and different types of activities are going on.

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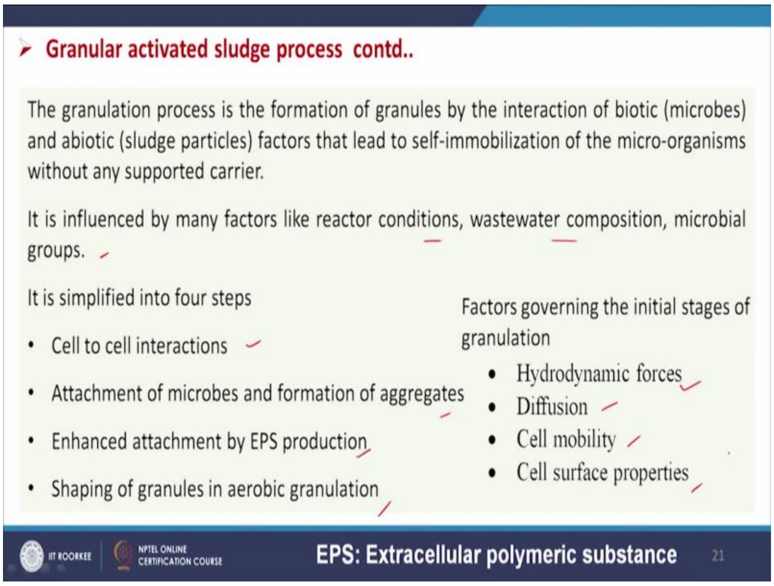

The granular process is the formation of granules by the interactions of the biotic these are the biotic and abiotic factors that lead to self-immobilization of the microorganisms without any supported carrier. And it is influenced by many factors like reaction conditions, that is wastewater composition, microbial groups, and it can be simplified into 4 steps that is cell to cell interactions. So first the cell interacts. Then attachment of the microbes and formation of aggregates second step enhanced attachment by EPS, EPS is extracellular polymeric substance and shaping of granules in aerobic granulation and different factors which influence the initial stage of granulation like hydrodynamic forces diffusion, cell mobility cell surface properties.

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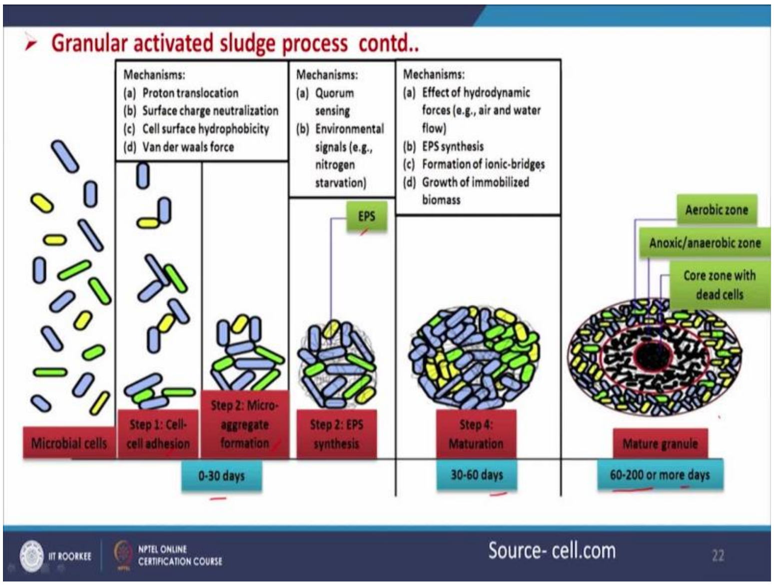

Now these figures show just different steps for the permission of granular activated sludge, let us say this is our microbial cells in the bulk phase, so within 0 to 30 days, the cells will be interact with each other and there will be some cell cell additions and then micro aggregation will be there. So, this is a first step where this is mechanisms is proton translocation, surface charge neutralization cell surface hydrophobicity and Vander Waals forces. So, after 30 to 60 days, we will see here they are some EPS is formed. So, EPS that is your extracellular polymeric substances.

So, these producers and make more maturation, the granules is maturated upto 30 to 60 days and then if we allow more time say 60 to 200 days or more days, so, then we can get a matured granules which have 3 layers on a aerobic zone, anoxic zone and core zone with the dead cells that is your anaerobic zones. So these are the different mechanisms for the effect of hydrodynamic force ARN water forms for this maturation and EPA synthesis permission of ionic bridges, growth of immobilized biomass etc.

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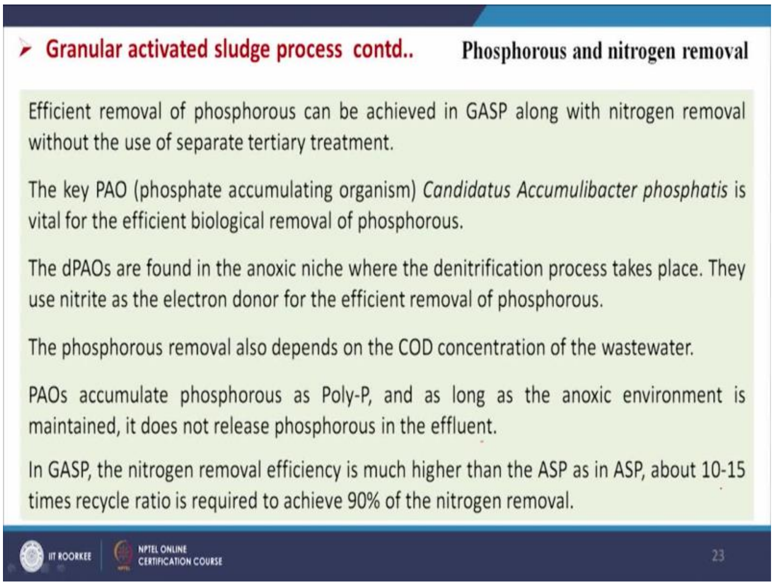

And phosphorus and nitrogen removal in this case. So, efficient removal of phosphorus can be achieved in GASP along with nitrogen removal without the use of separate tertiary treatment. So, that is the beauty of this process. And the key PAO that is phosphate accumulating organisms like Candidatus Accumulibacter phosphatis is vital for the efficient biological removal of phosphorus. And dPAO's denitrification phosphate accumulating organisms are found in the anoxic niche, where the denitrification process takes place they use nitrite as the electron donor for the efficient removal of phosphorus. And the Phosphorus Removal also depends on the COD concentration of the wastewater and PAOs accumulate phosphorus as polyphosphate and as long as the anoxic environment is maintained, it does not release phosphorus in the environment, that is accumulation of phosphorus takes place. Only in oxygenic phage that is in aerobic phage this oxygen will be this phosphorus will be released.

In GASP the nitrogen removal efficiency is much higher than the activated sludge process as in ASP about 10 to 15 times recycled issue is required to achieve 90 % of the nitrogen removal.

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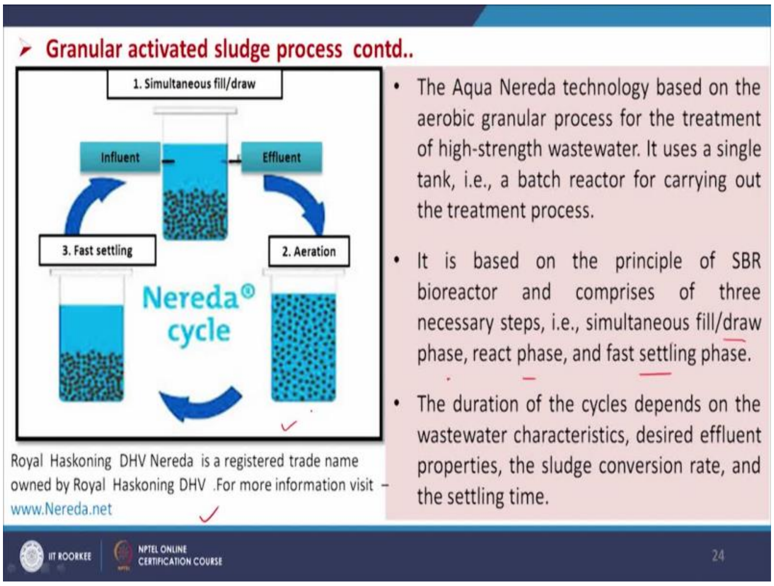

And this is your Nereda technology. So, the Aqua Nereda technology based on the Aerobic Granular process for the treatment of high strenght wastewater. It uses single tank batch reactor for carrying out the treatment process. It is based on the principle of SBR bioreactor and comprises of 3 necessary step that is simultaneous fill draw phase, react phase and fast settling phase. And the duration of the cycles depends on the wastewater characteristics, desired different properties, the sludge conversion rate and the settling time. So, these are the different steps already we have discussed this is a photographs taken from the source and this this indicates the Nereda technology and this figure shows the Nereda cycle.

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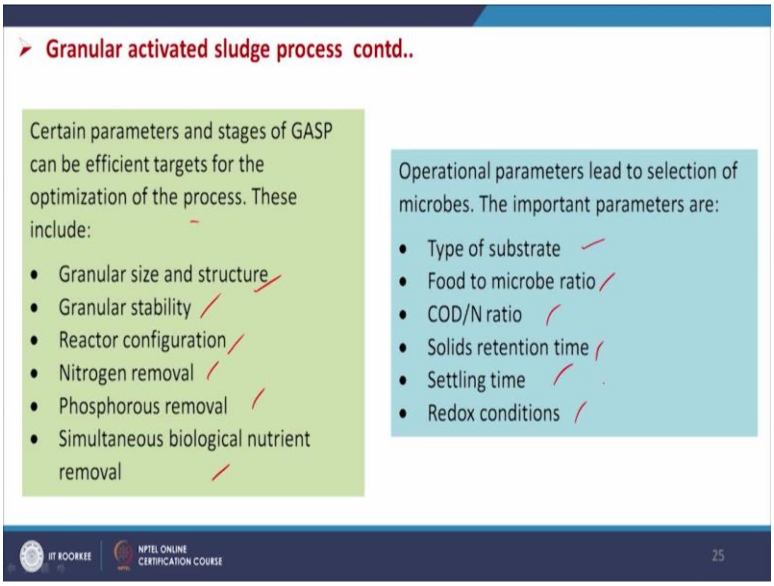

Now we will see that there are certain parameters and stages of GASP and that can efficient targets of the optimization of the process, and these include granular size and structure, granular stability, reactor configuration, nitrogen removal, phosphorus removal, simultaneous biological nutrient removal. And operational parameters lead to selection of microbes, the important parameters are type of substrate, food-to-microbe ratio, COD/nitrogen ratio, solids retention time settling time, redox conditions, so, these operational parameters lead to the selection of microbes.

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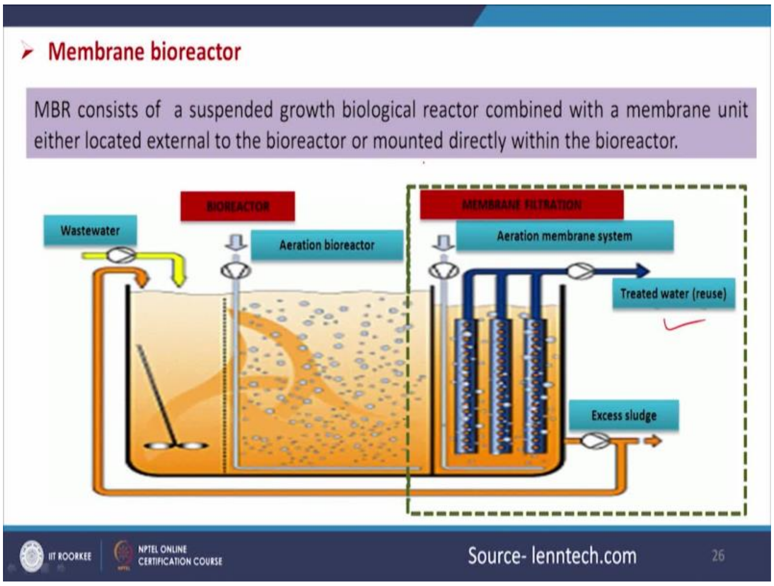

Now, we will discuss on membrane bioreactor. So, this is another type of develop systems for secondary treatment, you see here microbes are used and at the same reactor, at the end of this reactor, we are having another membrane also. So, biological degradation will take place and here it will be filtered and we will be getting the treated water. So, this is the membrane bioreactor, it consists of suspended growth biological reactor combined with a membrane unit, either located external to the bioreactor or mounted directly within the bioreactor. So up to this in this class, thank you very much for your patience.