Biological Process Design for Wastewater Treatment
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Lecture 22
Activated Sludge Process

Welcome, everyone to this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, we started studying the treatment of wastewater using various methods in last few lectures. And in the last few lectures we studied regarding the flocculation, aeration, then sedimentation, now, we are going to start the actual treatment process which happens in most of the treatment units which are installed in industry or in their municipal corporation or common effluent treatment plant and that process is called activated sludge process.

So, this process is always used after the primary treatment where usually the physicochemical treatment is done and after the primary treatment, we try to remove the organic content mostly in the secondary treatment. So, the activated sludge process is the most common process which is used for removal of most of the organics present in the wastewater after removal of the suspended solid and dissolved solids some of those in the primary treatment. So, activated sludge systems are used in most commonly in the treatment unit wastewater treatment unit as well as the water treatment unit.

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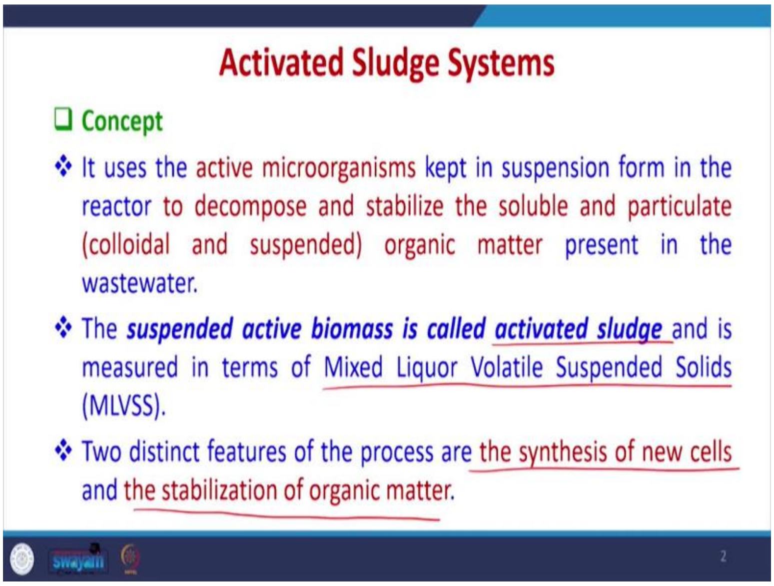

The activated sludge system uses the active microorganisms which are kept in the suspension form in the reactor to decompose and destabilize the soluble and particulate organic matter present in the wastewater. So, that means we have some active microorganisms which are suspended inside the reactor. So, this is one of the basis of the system. The suspended active biomass is called activated sludge and is measured in terms of mixed liquor volatile suspended solids. So, MLVSS we can always measure the amount of suspended active biomass in any activated sludge reactor using the MLVSS.

So, we have already studied regarding this that two distinct features of the process in the activated sludge system are that, during the treatment, we have certainly the stabilization of the organic matter that means we removed the organic matter converted into CO_2 and H_2O and also there is synthesis of new cells also during the treatment process. So, this is the usually the aeration basins.

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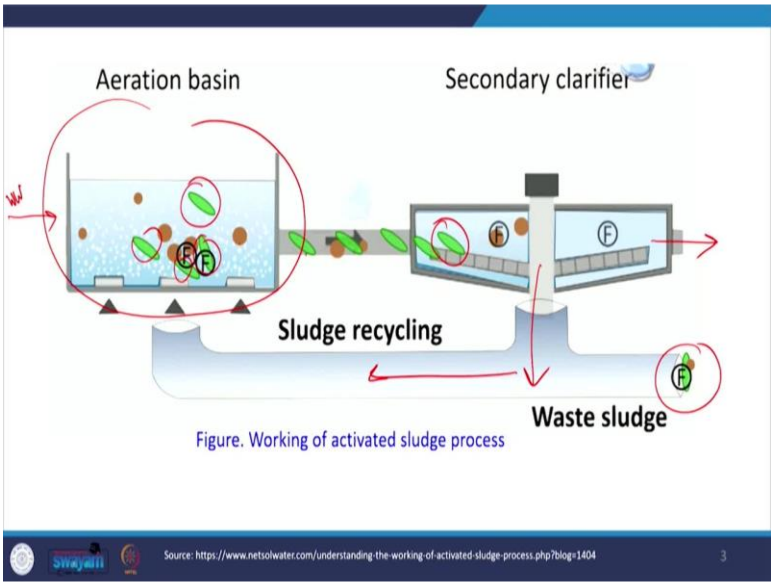

So, we have some wastewater which will be coming from primary treatment. So, it will be going to this aeration basin, which is actually containing the biomass also. So, all these biomass is present and then these biomass, they oxidize all the organic butter present in the water, after that, because it is aerated, it may be aerated, it may be highly mixed. So, the biomass along with the remaining organic matter go into the secondary clarifier where via the gravitational settling, we removed the sludge as well as the biomass.

So, they will go here and the treated water will go out now out of this sludge, which contains the biomass as well as the organic matter remaining if it is there. So, most of them will be oxidized, but still some amount of organic matter may be present or the waste this microorganism may be there. So, this sludge is some of the sludge is recycled back so as to maintain the required amount of MLVSS inside the reactor, and most of the sludge is wasted and further taken for sludge treatment that we will be studying later on. So, this is the working of activated sludge process.

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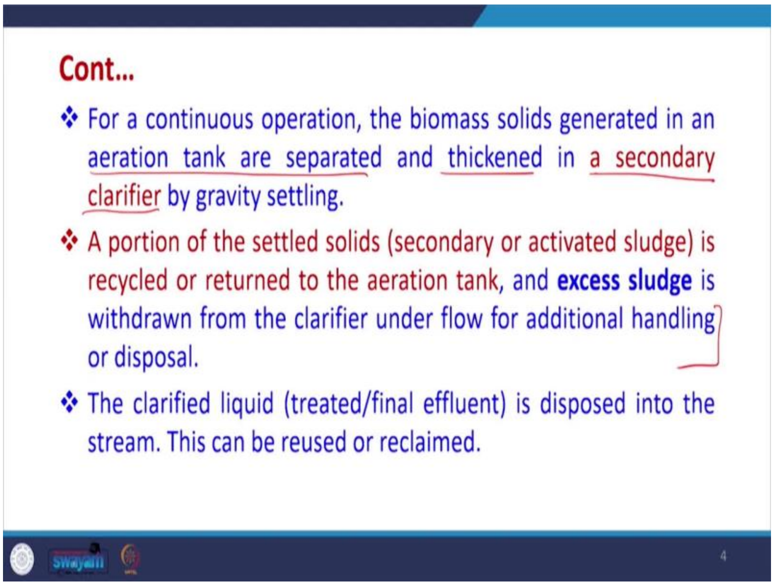
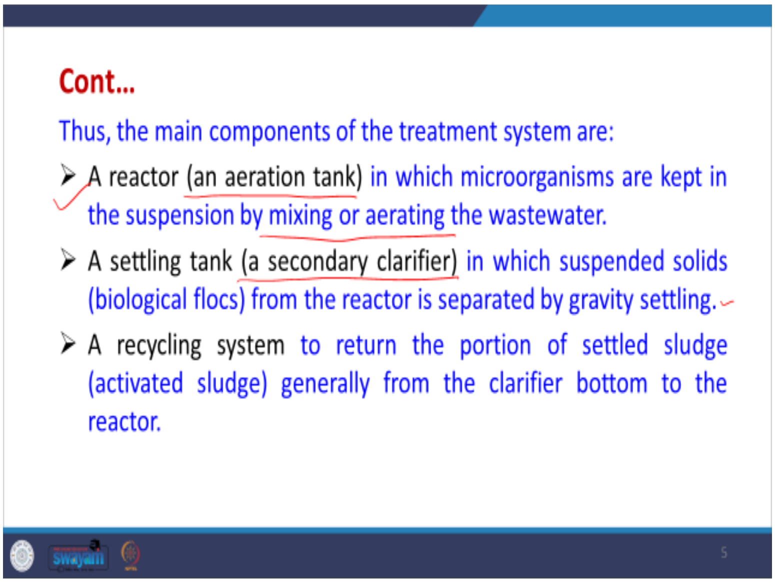


Now, for a continuous operation, the biomass solids generated in the aeration tanks are separated and thickened in this secondary clarifier that we have seen by gravity settling. A portion of the settled solids which is called as secondary or activated sludge is recycled and returned to the aeration tank and the excess sludge is withdrawn from the clarifier under flow for additional handling our disposal later on. So this will be studied in detail later on.

The clarified liquid which is that treated or the final effluent is further disposed of into the stream or maybe further be taken for further treatment depending upon the requirement and the tick when that has happened. So, this is possible. So, this is how activated sludge process works.



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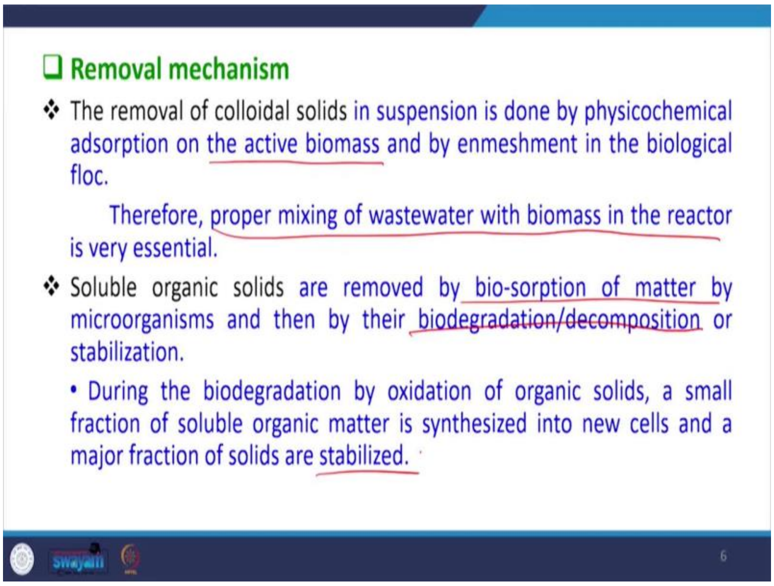

The main component of the treatment systems does a reactor which is actually aeration tank in which the microorganisms are kept in the suspension by mixing or aerating the wastewater. So, we may have some mixing process or aeration process going on inside the wastewater. A settling tank which is a secondary clarifier in which suspended solids which are biological flocs from the reactor separated by a gravitational settling.

Then a recycling system to return the portion of central sludge which is the activated from the clarifier bottom to the reactor. So, as to maintain the required amount of activated sludge inside the reactor itself. These are the three major components of activated sludge process. Now, the removal mechanism how the organic matter gets removed inside activated sludge process, the removal of colloidal solids in solids in the suspension is done via physicochemical adsorption on the active biomass and by enmeshment in the biological flocs.

So, first phenomena is the adsorption of physicochemical adsorption of the colloidal solids may occur on the active biomass. So, this is possible therefore, proper mixing of wastewater with biomass inside the reactor is very essential. So, this is this has to be lived into.

Second thing is that the soluble organic solids are removed via bio absorption of the matter by microorganisms and then their bio degradation or decomposition or a stabilization. So, first the bio absorption will occur and second biodegradation will occur. During the bio degradation by oxidation of the organic solids, a small fraction of the soluble organic matter is synthesized into new cells, because the biomass used is organic matter as nutrient for their growth. So, thus new cells are formed and major fraction of the solid are is stabilized. So, these are the two basic methods which occur.

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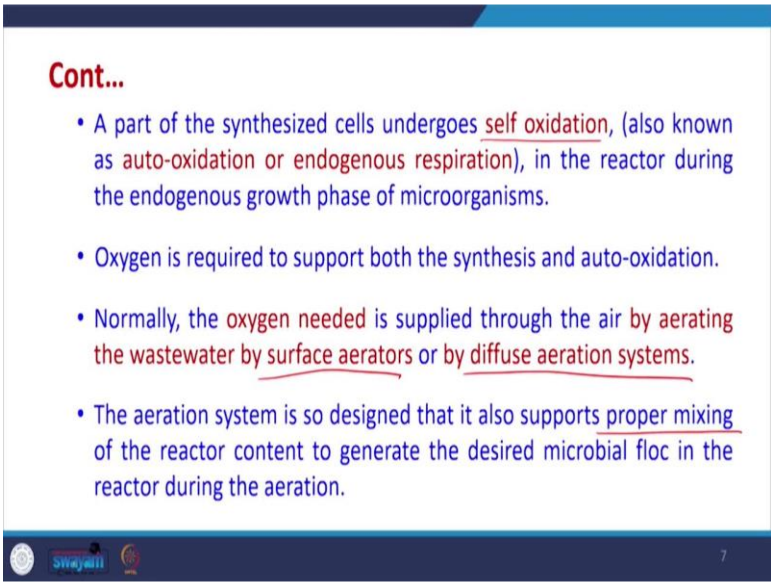

Then a part of the synthesize cells undergo self-oxidation also, this is also possible also known as auto oxidation or endogenous respiration inside the reactor during the endogenous growth phase of the microorganism. Oxygen is required to support both the synthesis as well as auto oxidation or oxidation process normally, the oxygen which is required is supplied through air by aerating the wastewater by surface aerators.

So, we have to supply the oxygen and that may be done via air supply and that air may be supplied via surface aerators or diffused aeration systems. So, both any of them may be installed depending upon the requirement, the aeration system is so designed such that it also supports proper mixing.

So, aeration during the release of the air the turbulent mixing happens inside the reactor so, that the mixing is also proper and so, that we can generate the desired amount of microbial floc inside the reactor during the aeration process. So, aeration along with proper mixing are the two essential requirements inside the reactor part this is there.

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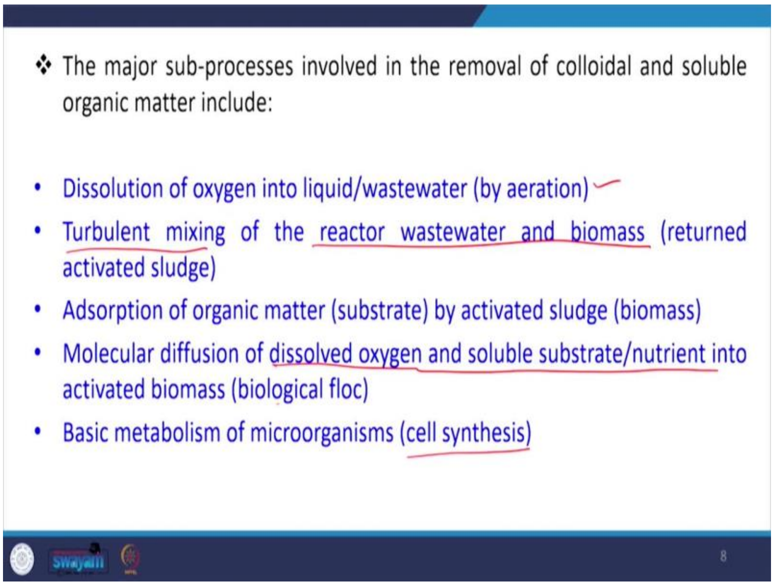

The major sub processes which are involved in the removal of colloidal and soluble organic matter include. The dissolution of oxygen into liquid or wastewater by aeration, then the turbulent mixing of the reactor wastewater and biomass which is returned back so, the recycled biomass has to be mixed together with the reactor wastewater. So, that is why turbulent mixing is required.

Then adsorption of organic matter which is a substrate which is coming from the primary treated wastewater by activated sludge then molecular diffusion of dissolved oxygen and soluble substrate nutrients into active biomass further basic metabolism of microorganism some like cell synthesis, so, all these sub processes occur inside the activated reactor itself.

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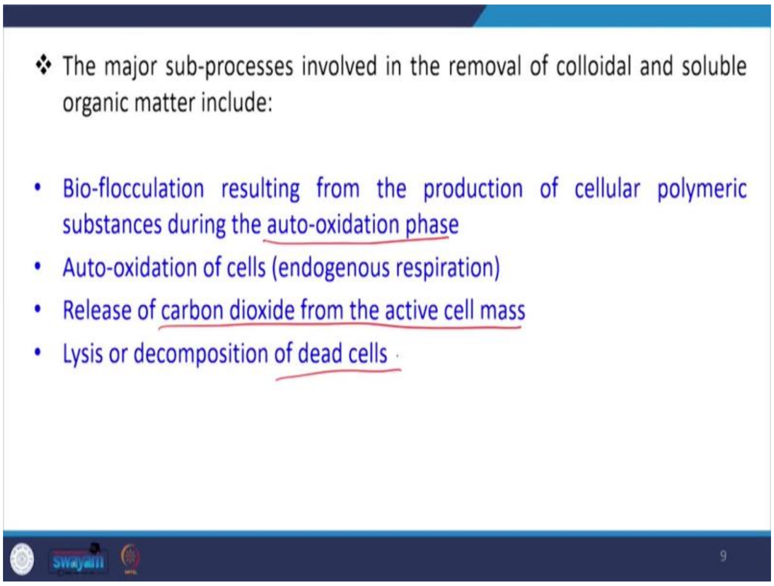

Along with that bio flocculation resulting from the production of cellular polymeric substances during the auto oxidation phase. This also happens also auto oxidation of cells that is the endogenous respiration is another sub process, release of carbon dioxide from the active cell mass. So, this carbon dioxide will get released and further go into the atmosphere.

Lysis or decomposition of dead cells So, all these sub processes are also involved inside the activated sludge reactor. Now, there are different configuration and modifications possible in the activated sludge systems.

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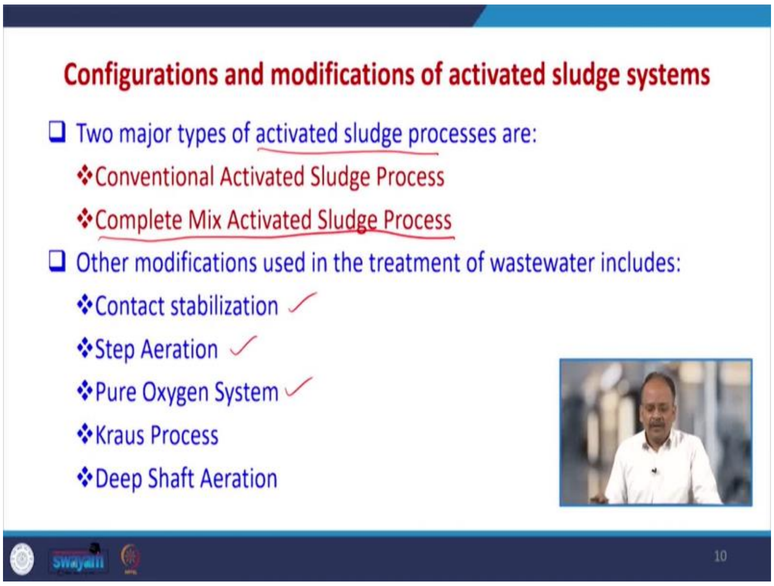

So, the two major types of activities slug processes which are used are conventional activated sludge process, then there is another which is called as complete mixed activated sludge process. So, we will be studying a little bit of that, then other modifications which are used in the treatment of wastewater include like contact stabilization, step aeration, then pure oxygen system in place of air we supply, pure oxygen system, then Kraus process, deep shaft aeration etc., are the some of the modifications which are there. So, we will not concentrate on it, we will concentrate on the basic process only.

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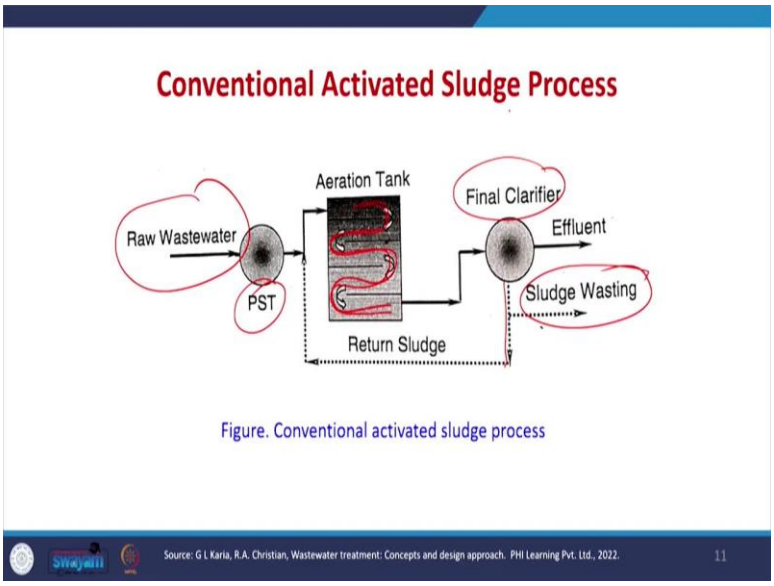

So, the conventional activated sludge process is like that. So, we have raw wastewater, which is coming up the after the primary settling tank and it is going into the aeration tank. So, here the wastewater is going like this. And then in the final clarifier, our secondary clarifier the sludge is being taken off at the bottom of the clarifier and some amount of sludge is being returned back and majority of the sludge is being wasted.

So, this is the conventional activated sludge process where inside the aeration tank, the water is moving like this, then there is another type of system where this tank is completely mixed. But first this conventional activated sludge process.

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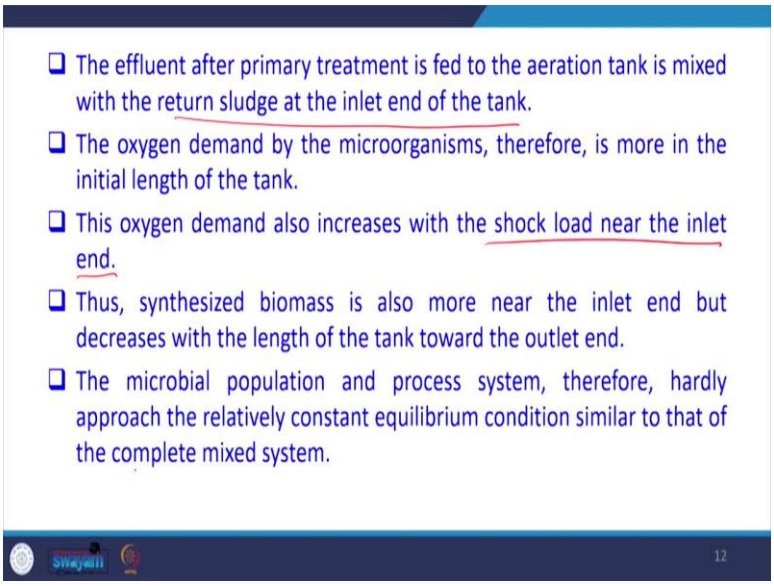

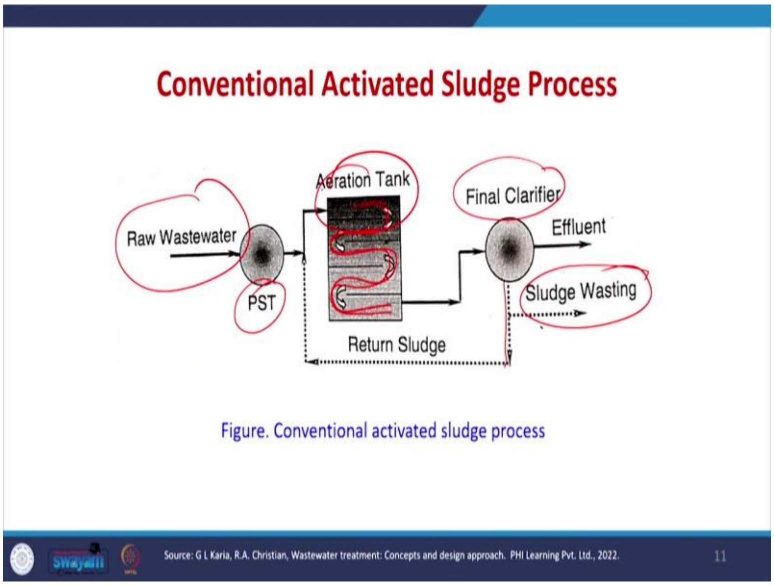

The effluent after primary treatment is fed to the aeration tank and is mixed with the returns sludge at the inlet end of the tank. So, we have the mixing which occurs in this portion. Now, the oxygen demand by microorganism therefore, is more in the initial length of the tank. So, in the initial cells or initial length, the oxygen demand will be more this oxygen demand also increases the shock load near the inlet end.

Thus the synthesized biomass is also more near the inlet end, but decreases with the length of the tank towards the outlet. So, we have biomass is also less the concentration of the remaining organic matter is also less at the end of the reactor. The microbial population and process system therefore, hardly approach the relatively constant equilibrium conditions similar to that in the complete mixed tank. So, this is the traditional or conventional activated sludge process.

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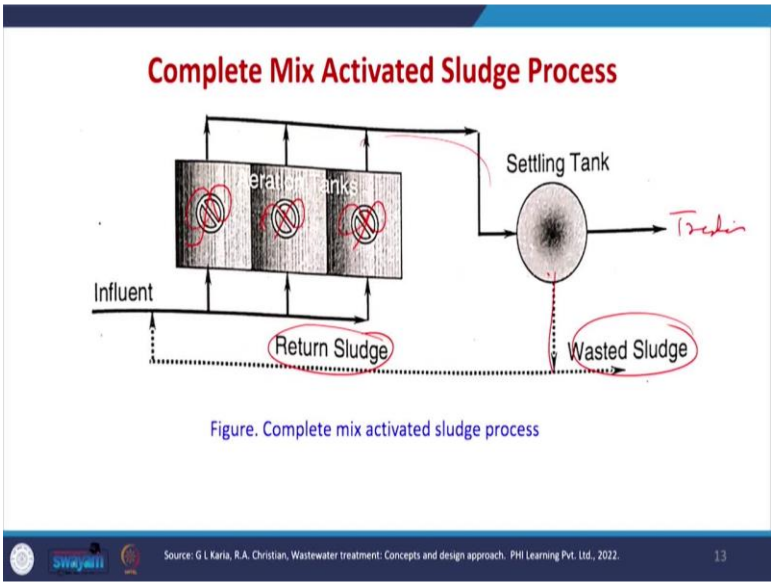

Now, in that completely mixed sludge system, which we have influent which is mixed with the return sludge and these are going into the reactor which are completely mixed. So, each of the reactor there is continuous mixing and from this it is going into this settling tank where the sludge is taken off most of the sludge is wasted and some of them is recycled and we get that treated effluent here.

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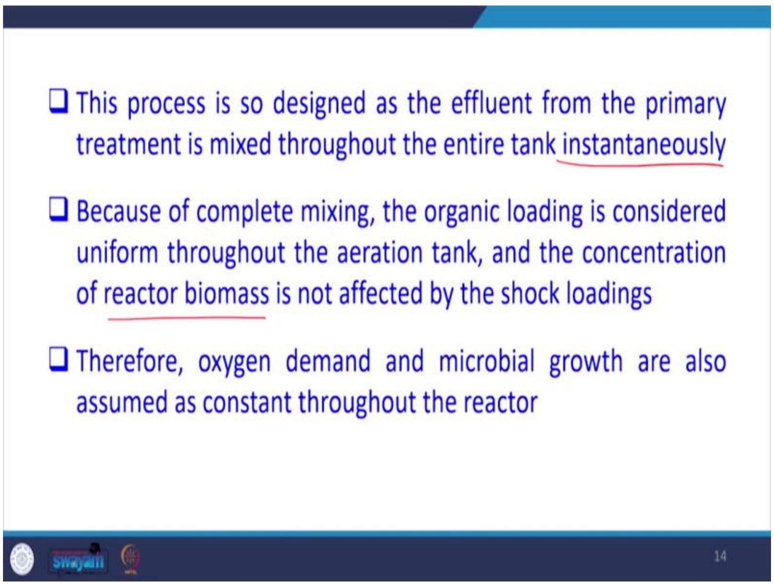

So, in this process is so, design as the effluent from primary treatment is mixed throughout the entire tank instantaneously. So, we have instantaneous mixing of the primary treated wastewater with the return sludge because of the complete mixing the organic loading is considered uniform throughout the aeration tank and the concentration of the reactor biomass is not affected by the shock loadings so, this is there.

Therefore, oxygen demand and microbial growth are also assumed constant throughout the reactor. So, this is the now there are major design considerations in the activity slug process. The design of the activated sludge process requires the consideration of following significant aspects.

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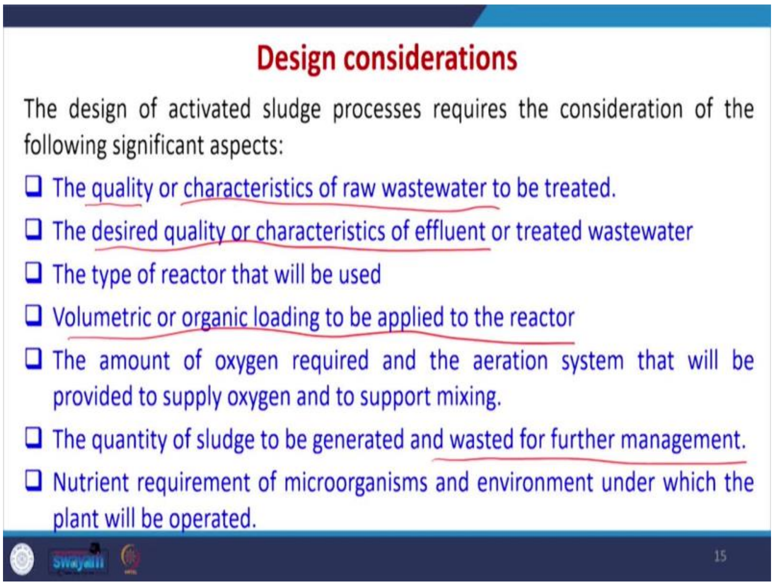

One of them is what is the quality or characteristic of wastewater which has to be treated after the primary treatment or we are going directly for the activated sludge process. What is the desired quality which is actually required as per the industry requirements or as per the standard requirement? So, what is the desired quality or characteristic of effluent which is desired?

The type of reactor that will be used whether it will be conventional or completely mixed, then we have volumetric or organic loading to be applied to the reactor. So, we always decide beforehand that what should be the organic loading under which the reactor will be designed, the amount of oxygen required and the aeration system that will be provided whether it is diffused aeration or surface aeration that is also decided.

And which of them will supply the essential oxygen and how it will support the mixing the quantity of sludge to be generated. So, we also tried to see that how much amount of sludge will be generated and wasted for further management because we have to manage the sludge which is generated all inside the wastewater treatment system. So, it may be primary sludge the secondary sludge which is generated here.

So, everything has to be managed it will come in the biological treatment systems itself. So, this management is very essential, what are the nutrients requirements for microorganism and environment under which the plant will be operated? So, this is also major design consideration.

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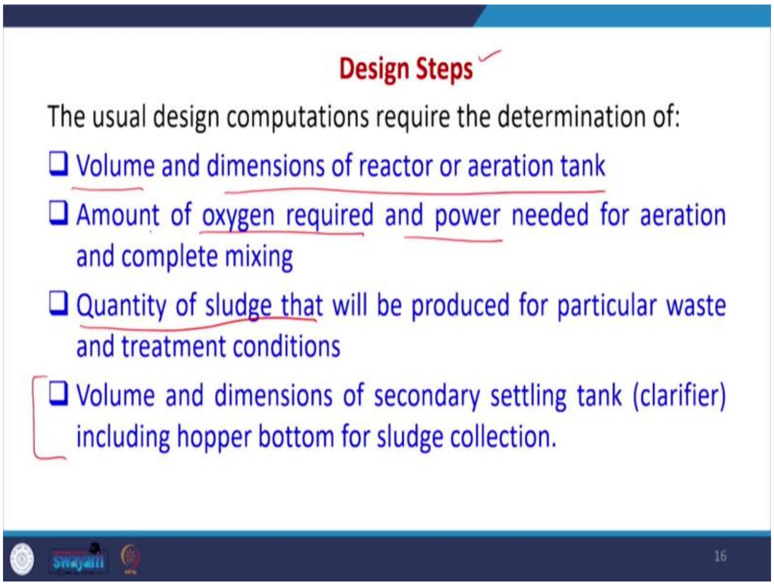

Now, the user design computation require the determination so, what are the design steps, so, when we are telling that we have to design an activated sludge process. So, what are the some of the essential things that have to be calculated one is that what is the volume and dimension of the reactor aeration tank amount of oxygen which is required and the power which is needed for the aeration and complete mixing this is there.

The quantity of sludge that will be produced and for particular waste and treatment conditions. So, this quantity of sludge that will be produced that also has to be calculated. Volume and dimension of the secondary settling tank clarifier including hopper bottom of the sludge collection. So, this also has to be done. So, this we have we studied in the sedimentation section. So, we will be a little bit studying regarding this activated sludge process.

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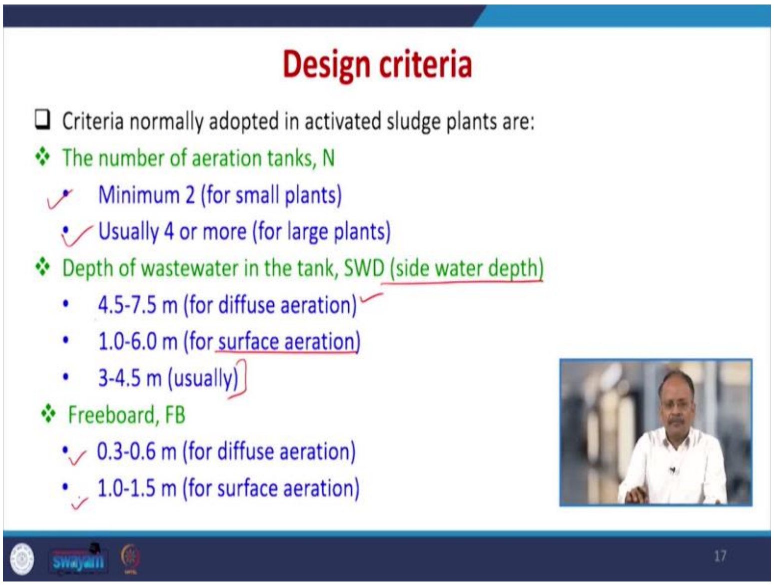

Some of the design criteria which is used commonly are given here, the number of aeration tanks minimum 2 for small plants usually 4 or more for larger plants. So, we are using then that depth of wastewater in that tank what is the side water depth. So, that is it maybe 4.5 to 7.5 meter for diffused aeration, but if we are going for surface aeration it is around 1 to 6 meter maximum. Usually 3 to 4.5 meter depth is the system is designed in this range. Now, the freeboard region is for diffused aeration it is around 0.3 to 2.6 meter and for surface aeration it is 1 to 1.5 meter.

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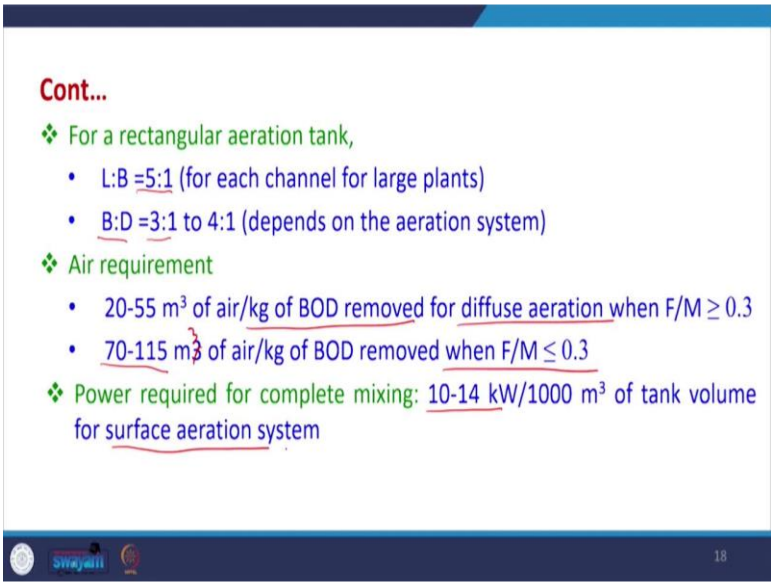

For a rectangular aeration tank so, the length the breath ratio generally is taken for each channel of large plant 5 is to 1 and breadth to depth ratio is from 3 to 1 to 4 to 1 depending upon the aeration system. The air requirements now, which are there, they vary from 20 to 55 meter cube of air per kg of BOD removed for diffused aeration when the food to microorganism ratio is greater than 0.3, but when the food to microorganism ratio is less than 0.3 the air requirements increase and they may be in the range of 70 to 115 meter cube of air per kg of BOD removed.

The power which is required for complete mixing in the range of 10 to 14 kilowatt per 1000 meter cube of tank volume for surface aeration systems. So, these are some of the design that which are commonly used. Now, we will try to solve some problems related to one problem related to activated sludge system. So, but before going for that, let us study the how the different things can be modeled in the activated sludge system.

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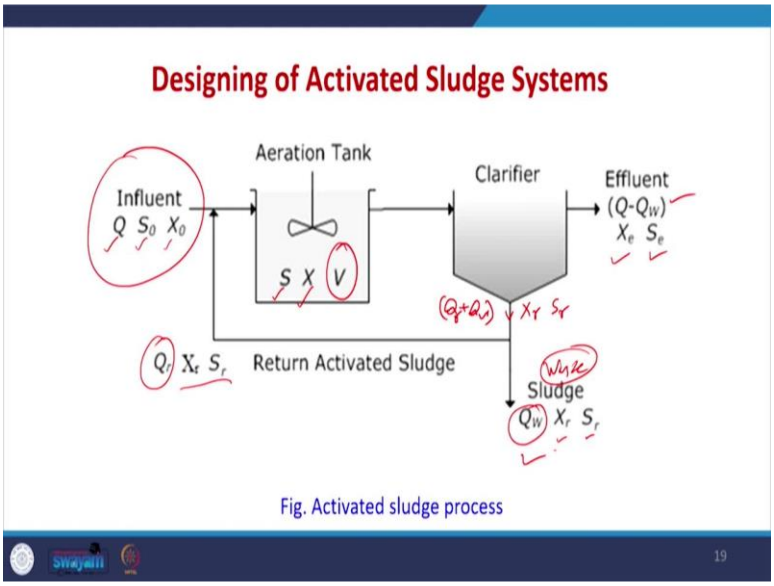

So, we have some influence which is coming with the flow rate of Q having a substrate concentration of S_0 that means, the organic loading or BOD loading is S_0 and it may be contained in some microorganism or not, but we are assuming that it is containing some microorganism which is X_0. Now, inside the aeration tank, the respective concentrations are with respect to substrate as S.

The MLVSS are the biomass concentration is X and the volume of the aeration tank which is completely mixed reactor is taken as V. Now after treatment it is going to the clarifier and from the clarifier we have two streams which are coming one is the wastage sludge which is going out. So, wastage sludge is having flow rate of Q_w X_r S_r the respective concentration of biomass and substrate S_r and Xr Sr are same for the return activated sludge.

Because after from here both the concentration will be same, so, X_r S_r and the flow rate here will be mix of Q_r plus Q_w. So, this is being divided into two sections we have the return sludge is having flow rate of Q_r.

Now, after treatment, it is assumed that the effluent is flowing at the rate of Q minus Q_w so, whatever is the wasted sludge. So, here Q minus Q_w is the flow rate X_e and S_e, S_e are the concentration of biomass and substrate respectively. Now, we can apply lots of few material balances etc., to calculate any of the design parameters.

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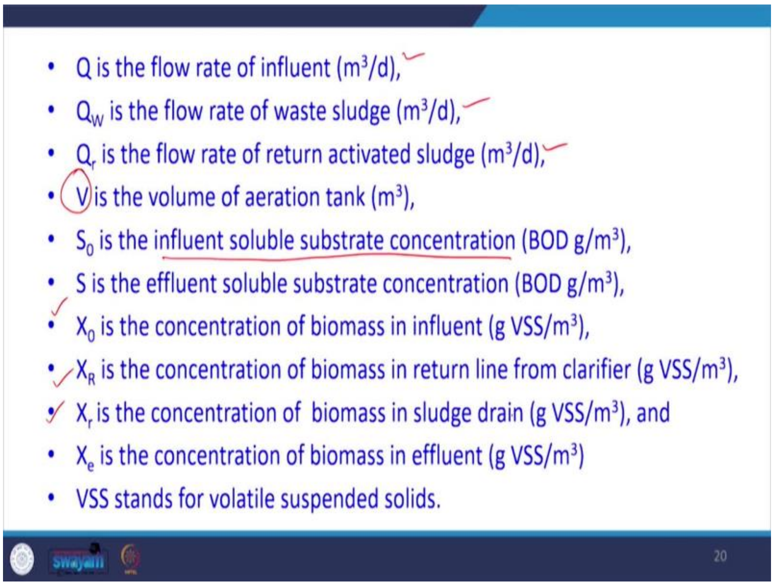

So, let us see, so, all the flow rates and other things are defined here already I have discussed the Q is the flow rate of the influent Q w is the flow rate of wasted sludge Qr is the flow rate of the return activated sludge, V is the volume of the aeration tank, S_0 is the influence soluble substrate concentration which is BOD per meter cube some amount, S is the effluent solid substrate concentration then X_0, X_r, X_r is the capital return line then this is for the sludge drain. So, we have different concentrations.

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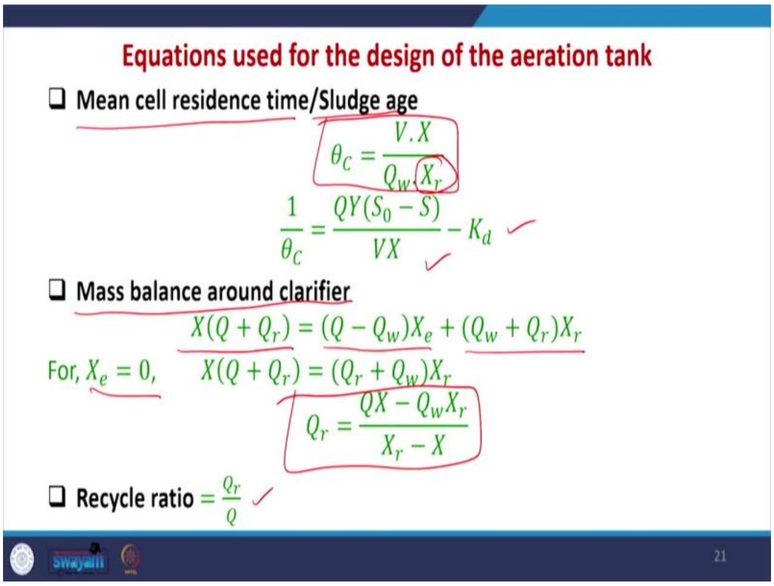

Mean cell residence time/Sludge age:

$$\theta_c = \frac{V.X}{Q_w.X_r}$$

$$\frac{1}{\theta_c} = \frac{QY(S_0 - S)}{VX} - K_d$$

Mass balance around clarifier:

$$X(Q + Q_r) = (Q - Q_w)X_e + (Q_w + Q_r)X_r$$

For, $X_e = 0$, $X(Q + Q_r) = (Q_r + Q_w)X_r$

$$Q_r = \frac{QX - Q_w X_r}{X_r - X}$$

Recycle ratio

$$= \frac{Q_r}{Q}$$

Now the equation which can be used for design of aeration tank. One is the what is a mean cell residence time or sludge age. So, we have already studied regarding this earlier. So, from this equation we can find out the sludge age. So, sludge age is like how much amount of the sludge is there inside the reactor. So, this is multiply and how much sludge is being wasted. So, from this data we can calculate.

So, X into V is the amount of sludge inside the reactor and this is the amount of sludge which is being wasted from this line. So, that is why it is Q_w into X_r, we can manipulate this equation to convert this into this form using certain conditions. So, for this we use the X_r and different other parameters, we can convert this into this form and we have already studied regarding this.

Then the mass balance around clarifier can be done and around this clarifier if we tried to do the mass balance, so, this is given here. So, the amount of biomass which is entering the clarifier is X into Q plus Qr. So, this is if you see yet what will be the amount here, here X is the amount, but the flow rate will be sum of Q plus Q_r, the flow rate is Q plus Q_r. So, this is the flow rate and so, for this balance is being done.

Now, this is the amount which is going after the treatment from the clarifier and this is going into the sludge. So, we can solve this equation to get this particular equation assuming for X is equal to 0 and the recycle ratio is Q_r by Q we can calculate this. So these equations can be used for design of activated sludge system.

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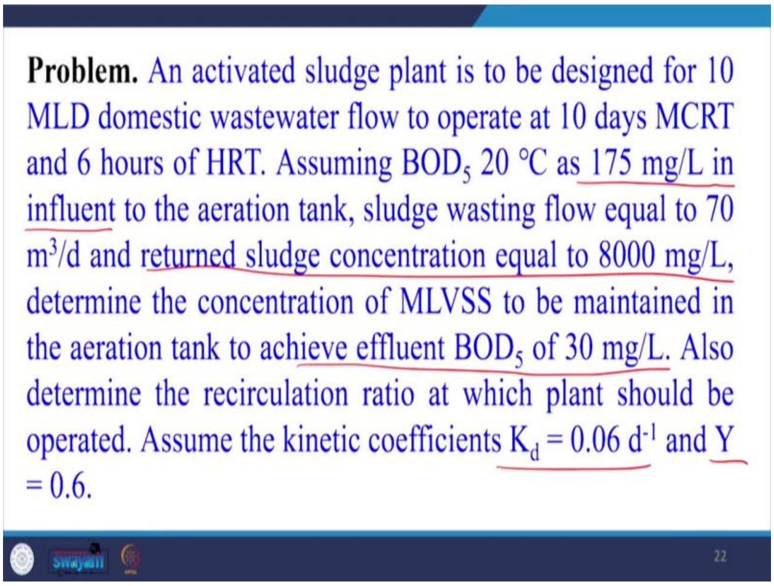

So we will try to solve a problem to further understand how it is done. So here in this Question and activated sludge plant is to be designed for 10 MLD domestic wastewater flow to operate at 10 days MCRT and 6 hours of HRT assuming BOD 5 at 20 degrees centigrade is 175 milligrams per liter in the wastewater which is to be treated in the aeration tank, the sludge wasting flow rate is equal to 70-meter cube per day, the return sludge concentration is equal to 8000 milligram per liter.

So, this is defined already known, determine the concentration of MLVSS to be maintained inside the aeration tank to achieve the effluent BOD of 30 milligram per liter. Also determine the recirculation ratio at which the plant should be operated. Assume that the kinetic coefficients K d for indigenous respiration and why the yield coefficient is 0.6 this is required in this equation. So this is known from the literature.

So, in this question, actually, in the actual scenario, we will be only given one thing that the flow rate of water is this and the water contains a BOD of this and we want to achieve a BOD of 30 milligram per liter. So, this is the actual design condition which is which will be given by any person to us for designing the activated sludge process.

So, the three things will be generally be given the flow rate of water, the initial BOD and the final BOD which is desired after that we assume certain things so, as to design the reactor under those conditions.

So, here it is assuming that we are going to have a 6 hour HRT and 10 days MCRT we are also assuming that the sludge concentration the return slide will maintain around 8000 milligram per liter it may be something else, we can redesign the system from the literature we have to find out the value of k_d and Y this also we can do in the smallest scale lab also we can calculate this for this sort of particular feeding on this particular activity sludge. So, these parameters have to be determined. Now, let us go ahead.

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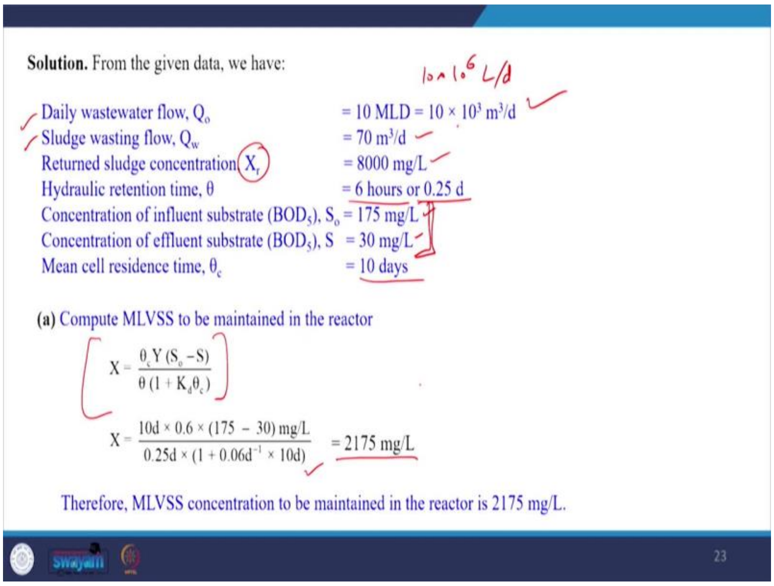

(a) Compute MLVSS to be maintained in the reactor:

$$X = \frac{\theta_c Y (S_o - S)}{\theta (1 + K_d \theta_c)}$$

$$X = \frac{10d \times 0.6 \times (175 - 30)\ mg/L}{0.25d \times (1 + 0.06d^{-1} \times 10d)}$$

X= 2175 mg/L

So, we have the daily wastewater flow rate is 10 MLD that means 10 into 10 into 10 raise to 3-meter cube per day because it is million liters. So, that way it is we can also write 10 into 10 raise to 6 liters per day. So, if we are writing liter per day, so, it is meter cube per day. Now, the sludge wasting flow is 70-meter cube per day, return sludge concentration which is X_r is given us 8000 milligram per liter, the hydraulic retention time HRT is 6 hour which is equivalent to 0.25 per day.

The concentration of influence substrate S_0 is 175 and desired is 30 the mean cell residence time has been taken as the 10 days. So, we have means cell residence MCRT as 10 days. So, these are the parameters which are given. The essential things are these are these are the two parameters which will be given by the any vendor which will be coming to us for designing the system.

Now, we have to find out what will be the MLVSS that has to be maintained. Many times we fix the MLVSS first because from the general idea, it is known that what amount of MLVSS will be good enough. So, under these conditions under which this data is given, we can little bit change the equation and little a bit after manipulation of this particular equation, we can find out the value of X in terms of all other parameters.

So, the equation will be this, once we feed all the values in unit so that all they cut each other. So, we will be having these particular values which we have to be feeded and after that, we get the value that 2175 is the 2175 milligram per liter 2175 is the MLVSS concentration that has to be maintained inside the reactor for getting the concentration of after treatment to be 30 milligram per liter.

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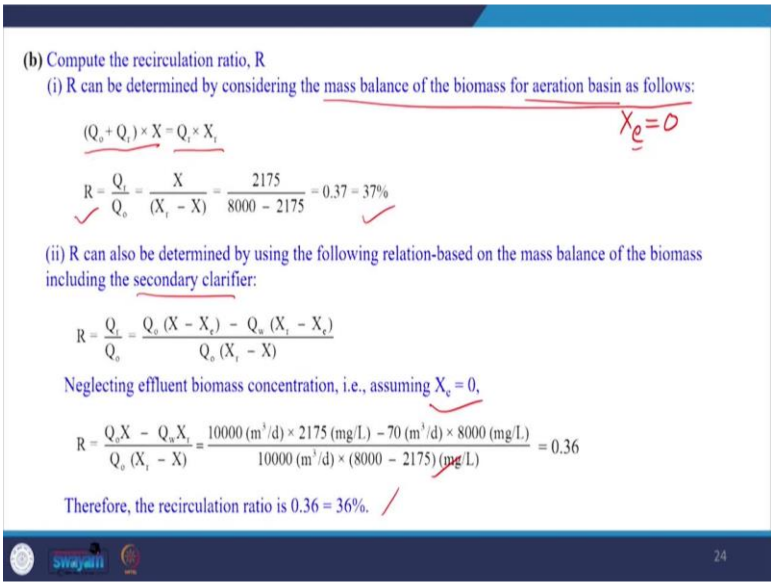

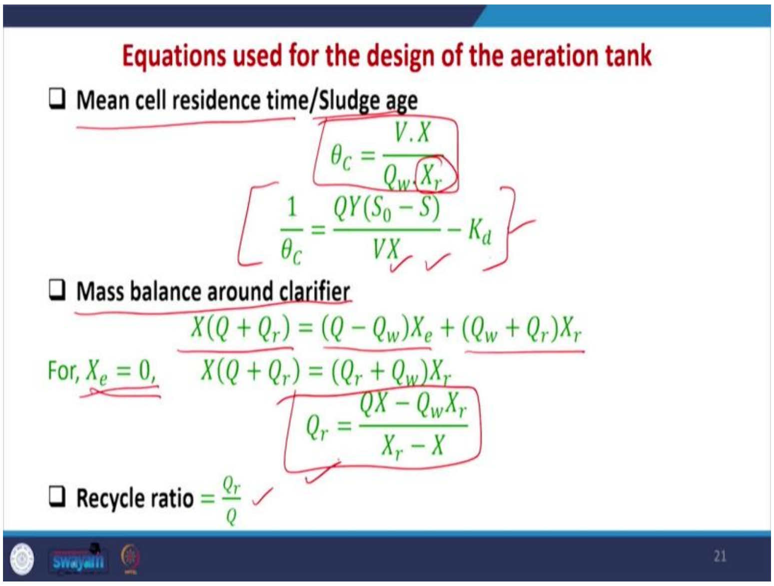

(b). Compute the recirculation ratio, R. (i). R can be determined by considering the mass balance of the biomass for aeration basin as follows:

$$(Q_o + Q_r) \times X = Q_r \times X_r$$

$$R = \frac{Q_r}{Q_o} = \frac{X}{(X_r - X)} = \frac{2175}{8000 - 2175} = 0.37 = 37\%$$

(ii). R can also be determined by using the following relation-based on the mass balance of the biomass including the secondary clarifier:

$$R = \frac{Q_r}{Q_o} = \frac{Q_o (X - X_e) - Q_w (X_r - X_e)}{Q_o (X_r - X)}$$

$$R = \frac{Q_o X - Q_w X_r}{Q_o (X_r - X)} = \frac{10000\ (m^3/d) \times 2175\ (mg/L) - 70\ (m^3/d) \times 8000\ (mg/L)}{10000\ (m^3/d) \times (8000 - 2175)\ (mg/L)} = 0.36$$

Now compute the recirculation ratio R, now for that R can be determined by considering the mass balance of biomass for aeration basin. So, already we did and here it is assumed that that there is no biomass which is going in the effluent so X_e is equal to 0. So, remember, this was the equation but we assume X_e is equal to 0. So under that Q_r value can be determined easily. So, the same equation is being used.

So, the balance assuming X_e is equal to 0 so, this is going into the sludge, this is going into the settling chamber and this is going out as a settling chamber. So, if you calculate this, this will be the recycle ratio, which is coming out to be 37 percent. R can also be determined using the relationship around the secondary clarifier which was given earlier. So, assuming X_e is equal to 0, we can solve this or we can solve this by putting the balance around the aeration basin.

So aeration basin also we can put this balance and we can solve. So we are getting the same answer virtually in both places at 37 percent should be the recycled ratio. So this is how we can determine, we can determine volume also or other parameters if they are not given depending upon the requirements. So we can calculate with the volume we can calculate back the dimension we can calculate back the aeration. But this is beyond the scope of this lecture. So we will, thus we will end the activated sludge process now. Thank you very much.