Aspects of Biochemical Engineering
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Lecture – 43
Design and analysis of activated sludge process – II

Welcome back, to my course Aspects of Biochemical Engineering. Now, in the last lecture I was discussing about the activated sludge process. How activated sludge process basically it is the CSTR with cell mass recycling. An activated sludge process is mostly used for the wastewater treatment process and I described in the last class that that industrial more than 70 percent of wastewater treatment process that is controlled by the biological means and there is a survey made by central pollution control board in India and they observed that mostly the chemical and biochemical industry that we have in India that posed the that water pollution problem

So, you know that now if you look at the chemical and biochemical industry the wastewater mostly contained the organic material the soluble organic material and this soluble organic material when we discharge in the watercourses the whatever bacteria is there they will grow and multiply and contaminate the water and not only that the secret different metabolites that causes some toxic effect in the water.

So, to safeguard this process we shall have to do the wastewater treatment process and most of the chemical and biochemical industry they adopt this activated sludge process. Now, if you look at; why this biological process is mostly used for waste water treatment process the reason is that if you want to oxidize chemically we shall have to use the potassium dichromate, potassium permanganate and you have to you have to boil with some time. So, that you know whatever organic, inorganic material is there, that will be totally oxidized.

But, but when you do so, that wastewater also in other way increases the heavy metal contamination. As for example, if you treat with potassium dichromate solution the chromium concentration of the water that increases, if treat did with potassium permanganate the manganese ion concentration in the water that increases. So, metal ion heavy metal ion contamination this is another problem that will be will be facing.

So, to safeguard this situation biological process has a some kind of alternative. The reason is that your bacteria can utilize the soluble organism very easily and convert it into the cell mass and then I tried to discuss with respect to carbon balance if you do the carbon balance of the system we find that 50 percent of the carbon usually goes for the cell mass formation and 50 percent to carbon dioxide. Now, carbon dioxide that will go into ahead, but whatever that cell mass 50 percent of carbon converted into cell mass and which is insoluble mass and we can easily separate it out. So, we can we can separate out is easily.

And, I try to discuss that one key organism that is mostly used for activated sludge process is the joglier imigera because they secrete the polysaccharide gel and we know that the size of the bacterial cells is very small. It is 0.5 to 2 microns and since the size is very small it is very difficult to separate out because and since this joglier imigera has the characteristics of secreting the polysaccharide gel they have the agglomeration property the particle they will binds with each other and from the flock that is the bigger particles.

When it from the bigger particle they will precipitate it out and the so, you know that activated sludge process we basic as I told you it is basically CSTR which cell mass recycling and if you look at in this process because I try to discuss previously also the major drawback of the chemo stat at process or CSTR process is the cell mass wasting from the reactor and if your rate of cell mass that is going out of the reactor is more as compared to the cell mass growing in the reactor. So, a time will come there should be no cell present in the reactor if then there is no cell present in the reactor so, we will not get any kind of reaction.

To avoid this kind of situation what we can do, the whatever excess amount of cell mass that is going out of the reactor we can recycle back to the system. So, the cell mass concentration in the reactor will be uniform and rate of reaction with the constant. So, power process we can operate very easily. So, this is the activated sludge process I tried to discuss and we develop kind of equation through which we can find out the cell mass concentration in the activated sludge process also the volume of the reactor how you can calculate.

Now, when you do the recycling of the cells I told you the main purpose is to increase the mean cell residence time. In case of chemo stat process the mean cell residence times is equal to hydraulic retention time. The as soon as you recycle the cells the mean cell residence time should be higher as compared to that hydraulic retention time. So, there again we try to discuss the effectiveness how the sludge settling property can be expressed with the help of sludge volume index.

And, now, today I want to discuss, two numerical problems on this particular activated sludge process and first problem we will discuss the process design and this process design we can not only we know that most of the biochemical processes there aerobic, aerobic fermentation process. An aerobic fermentation process major bottlenecks is the dissolve oxygen concentration because why because microorganism they can utilize the oxygen which is dissolved in the fermentation media.

And sinks oxygen is sparingly soluble in water so that is the major limiting factor in the aerobic fermentation process. So, since activated sludge process the aerobic fermentation process we can extrapolate this process design for normal biochemical fermentation process also and in the next lecture I shall discuss the anaerobic fermentation process. So, we can also we find out how the how we can design the anaerobic digester.

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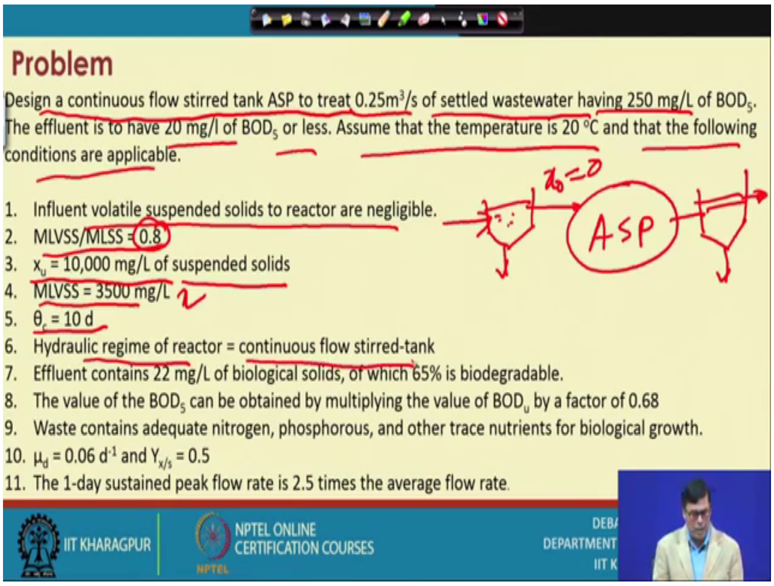

So, let me start this today that with the activated sludge process. Now, if you look at problem that we have here this is if you see that design of a continuous flow stirred tank activated sludge process to treat 0.25 cubic meter per second of settled wastewater. Settled waste water I try to discuss that when wastewater comes to that suppose this is the activated sludge process when it comes first is it comes to the primary clarifier. Primary clarifier this main purpose is to separate down the suspended particles then it goes to the activated sludge process then again is goes to the secondary clarifier. Finally, it goes out like this and suspended solid we can separate out here.

So, this is exactly what is mentioned the design a continuous flow starting activated sludge process to treat 0.25 cubic meter per second of settle wastewater having cod BOD 5 is 250 milligram per liter, effluent has 20 milligram per liter of BOD 5 or less assume the temperature is 20 degree centigrade that the following conditions are applicable.

The influent volatile suspended solids in the reactor is negligible. So, I told you the volatile suspended solid actually that indicate the presence of cell mass because most of the cell mass they are organic mass. So, here we can assume the x 0 equal to 0 and a MLVSS by MLSS is 0.8. I explained in the last lecture MLVSS means the organic that cell mass and MLSS in the total suspended solid and suspended solid comprises of both organic and inorganic matter material. Inorganic material we considered as the inactive biomass.

Now, x u is the settle cell mass concentration, but this is suspended solid. So, this is not a exactly the cell mass concentration, but if you multiply it with 0.8 then we need to get the settled cell mass concentration and this is the MLVS that is the cell mass concentration x equal to 3500 milligram per liter, theta c is the solid retention time or mean cell residence time that is strained is hydraulic regime of the reactor it is continuous flow stirred tank the this thing is very important because the effluent contains 22 milligram biological solid in of which of which the 65 percent biodegradable.

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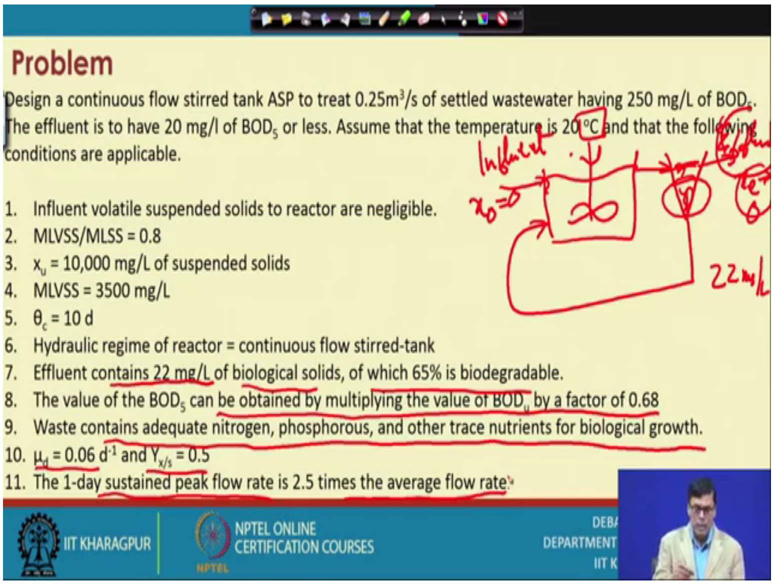

Now, I want to tell you here, suppose this is the activated sludge process and this is the CSTR and here you have stirred and here you have the sedimentation tank, you recycle back to the reactor. The supernatant is this is actually the this is called influent this is called influent and that is called effluent am I right. So, here x 0 equal to 0 and here x c we also this tends to 0, this is also tends to 0, that is we usually assume. We assume that the very less amount of cell mass present.

But, here the problem is like this they are saying that effluent contains 22 milligram per liter of suspended biological solid, that means, due to the inefficiency of the separated some solid material cell mass may overflow and it is comes in the effluent. is 65 percent the value of BOD 5 can be obtained by multiplying BOD u by 0.68. Waste contains adequate nitrogen phosphorous and other trace nutrient for biological growth and the specific death rate of the cell 0.06 d inverse and yield coefficient 0.5. 1-day sustained peak flow is 2 2.5 times the average flow rate. This is the problem that we have.

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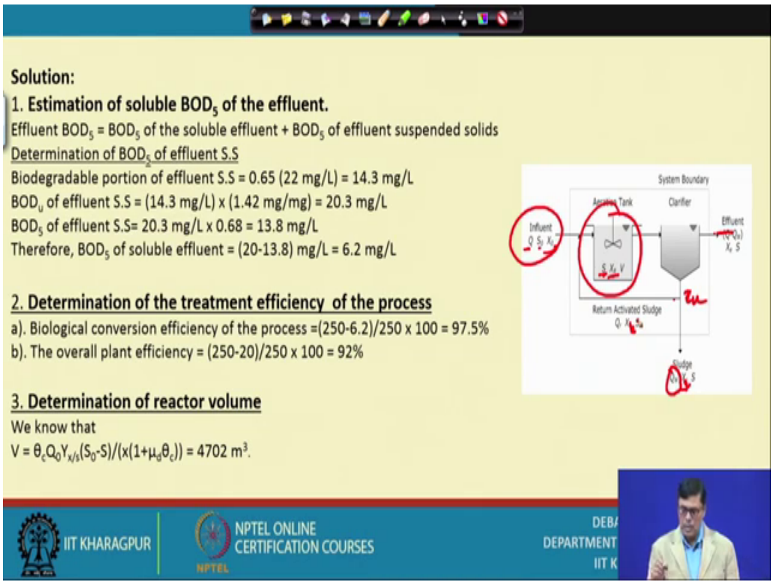

Now, so, what we shall have to do first? The process is like this that you know this is the reactor and we pass the this is the Q is the flow rate Q 0 is the flow rate and S 0 the initial substrate concentration X 0 is the initial cell mass concentration this comes in the reactor and under steady state condition the cell mass concentration is the X X and substrate concentration is S and V is the volume of the reactor.

Then it comes to the clarified or separated where we separate the cell mass and this is the settle cell mass concentration is X u it is it is it is recycle back to the reactor like this and this is an effluent is coming out like this and this is the wasting this flow rate of the sludge and this is the settle said this is X r is given this will be X u we will be using the X u this is wrongly given.

So, now, let us see how we can we can we can solve this problem. Now, here that what is the purpose of this activated sludge process purpose of the activated sludge process is do we remove the soluble organics present in the wastewater. Now, how you can remove that your organism grow in the wastewater and convert the soluble organics to insoluble organists and carbon dioxide. Carbon dioxide will go out of the system and cell mass remain in the system that we can easily separate it out.

So,, so, actually that is due to the inefficiency of the clarified we cannot separate all the cell mass. So, some cell mass remain with the effluent. So, that is not the fault of the activated sludge process. Now, if you want to calculate the actual efficiency of the activated sludge process we shall have to consider the BOD 5 of the soluble organs not the insoluble organs.

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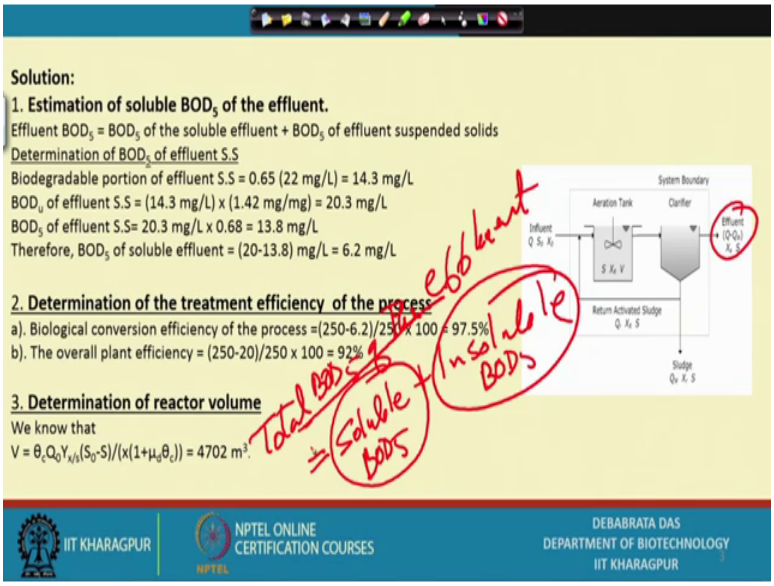

So, the outgoing liquid has two parts, am I right? It has a soluble organics soluble plus insoluble. So, we shall we shall have to calculate what is the BOD 5 of the soluble and BOD 5 of the insoluble. Now, this is equal to the total BOD 5 of the effluent BOD 5 of the effluent, am I right? Now, now if you if you can find out BOD 5 of the insoluble solid material then if you deduct with total BOD 5 of the effluent then we can find out BOD 5 of the soluble liquid.

So, this is exactly what we are doing here. You see that the effluent BOD 5 equal to BOD 5 of the soluble effluent BOD 5 of the suspended solid. Now, now a biodegradable portion of the effluent is we have a 22 milligram per liter of the biological solids of which the 65 percent is biodegradable; that means, biodegradable organic matter is 14.3 milligram per liter that we know that for the oxidation of 1 gram of biomass we required 1.42 grams of oxygen. So, we can find out these are much oxygen will be required for oxidation of the solid material.

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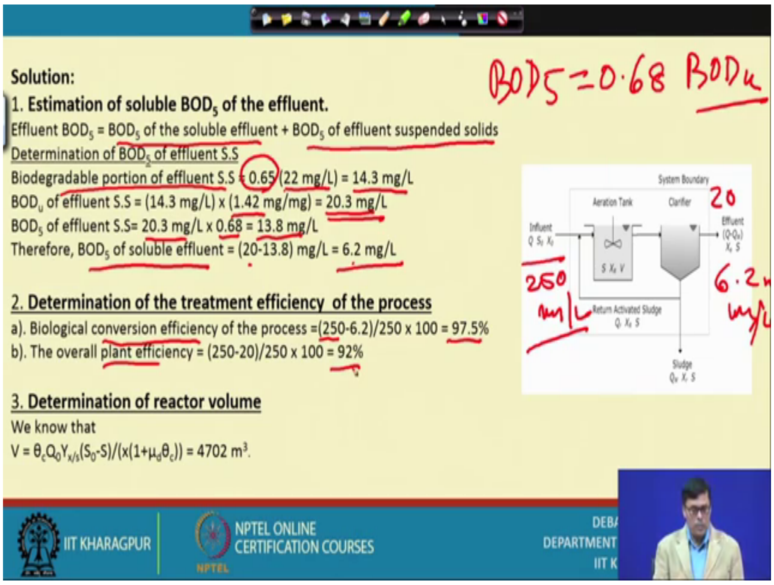

And, then BOD 5 of this material if you multiplied with 0.65 because we have written in this problem BOD 5 is equal to 0.68 into BOD u u, u means that ultimate BOD, the total BOD that we have. So, we can easily find out the BOD 5 of the suspended solid. Then we can we can find out the BOD 5 of the soluble effluent is 20 minus 13.8 that is 6.2 milligram per liter.

Now, when you so, when you when you talk about the process design the of any kind of biological process or chemical process first parameter we shall have to determine that what is the conversion efficiency of the process. Now, here we have seen that we have two type of conversion efficiency; one is overall plant efficiency and there is the biological efficiency of the process.

Now, if you look at the biological conversion efficiency of the process that will be what we that is the BOD of the soluble incoming liquid here is the 250 milligram per liter BOD 5 and here is 6.2 milligram per liter the this is we have we have found out this par[t]-. So, biological conversion efficiency of the process will be 97.5 percent, but overall plant efficiency if you considered. So, it is 250 and here 20. So, that means, 250 minus 20 by 250 is coming 92 percent.

So, this is how we can calculate the plant efficiency. So, when you do any kind of process design first parameter you shall have to monitor that what is the conversion efficiency of the process. Second parameter we shall have to find out what is the volume of the reactor the volume of the reactor is like this.

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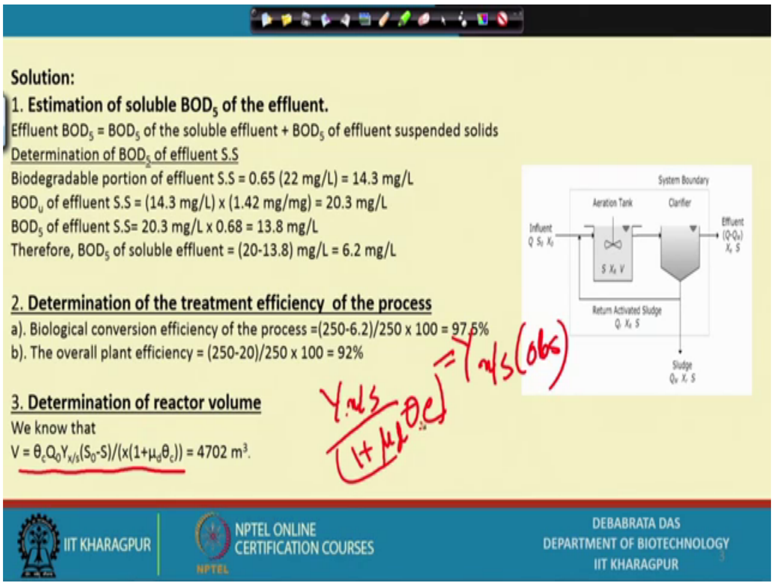

And, in this in this I want to point out that these parameters particularly Y x by s this 1 plus mu t plus theta c. This is considered as Y x by s observe; observe means this is the way we know the suspended material when you talk about the yield coefficient what is the overall coefficient? Gram of cell mass produced per gram of substrate consumed.

Now, this gram of cell mass when you go considered about overall yield coefficient it comprises of two type of biomass one is one is called cell another we call dead cell now when you when cell multiplies on the only the cell cells will multiply this will not multiply. So, observed yield coefficient will be something else, the observed yield coefficient we shall have to consider the rate of the cells and it will come as the Y x by s by 1 plus mu t plus theta c equal to Y x by s, this is observed yield coefficient.

Now, here this is the expression for the volume and we in this problem we have all the parameters, you just put the parameters we can easily find out the volume of the reactor. So, second part of the problem is that how to find out the volume of the reactor, am I right?

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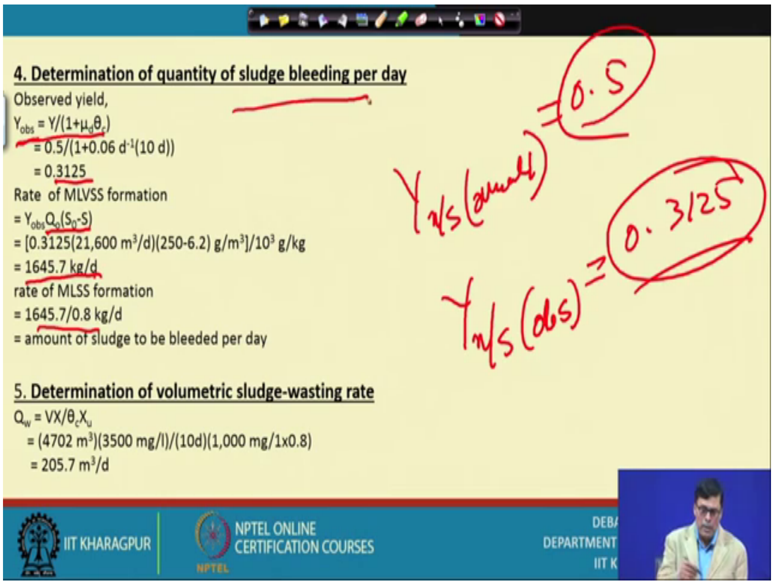

So, now next is that that what is the amount of solid produced per day from the reactor that we shall have to find out. Let us see how you can find out that I first I told you the y observe equal to Y by 1 plus mu t plus theta c this is the observed yield coefficient and this is coming you I can I can tell you actually that we go over all this over all yield coefficient was how much this is was 5, but when you consider the calculate the observed that is coming. So, it is much less than the overall yield coefficient because it comprises of both the dead cell and viable cell then it comes consists of mostly the viable cells.

So, we can so, this is what is this parameter? This parameter to indicate Q 0 into S 0 minus S indicate how much of BOD that is removed. So, if you multiplied by this factor Y observed we you will easily get the how much cell mass is produced this is the cell mass is produced. Now, once we know the how much cell mass is produce this is the volatile suspended solid now if you divide by 0.8 then we will got we will get the mixed liquor suspended solid that is the sludge. So, this is what we have we have what we can calculate how much sludge is producing per day.

Next is that volumetric the sludge wasting flow rate. Now, how you can find out.

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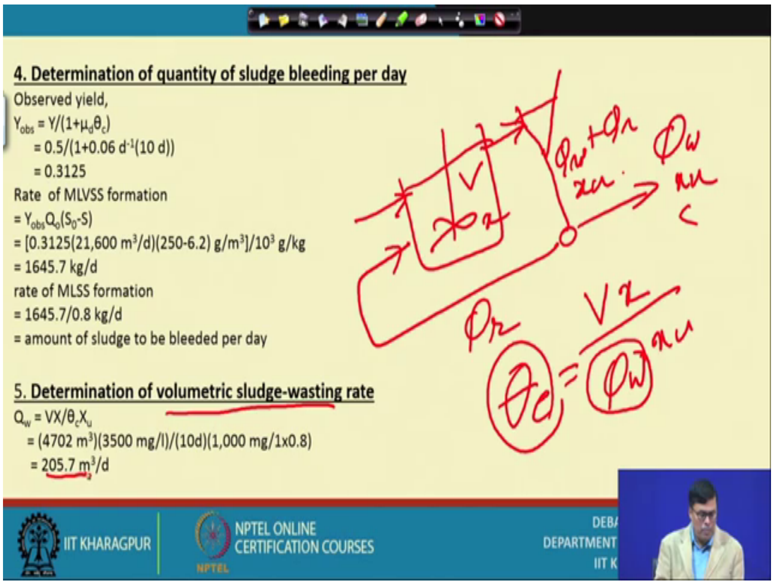

I told you that in this reactor this is like this is coming in and a part you are going out and a part you are recycles back. Now, here you have Q wxu and yes, am I right and here you have what Q w plus Q r and Q r is a recycle flow rate. Here is the cell mass concentration. Now, what is the theta c? theta c is the solid retention time. How you can write this is V is the V is the volume of the reactor x is the cell mass x, V into x divided by Q w into x u, x u that is the how much rate of cell mass wasting from the reactor and this is the how much cell present in the reactor. So, that gives you the what is the solid retention time.

Now, even in this equation we can easily find out Q w. Q w is the volumetric sludge wasting rate if you put all this value we will get 205.7 cubic meters per day.

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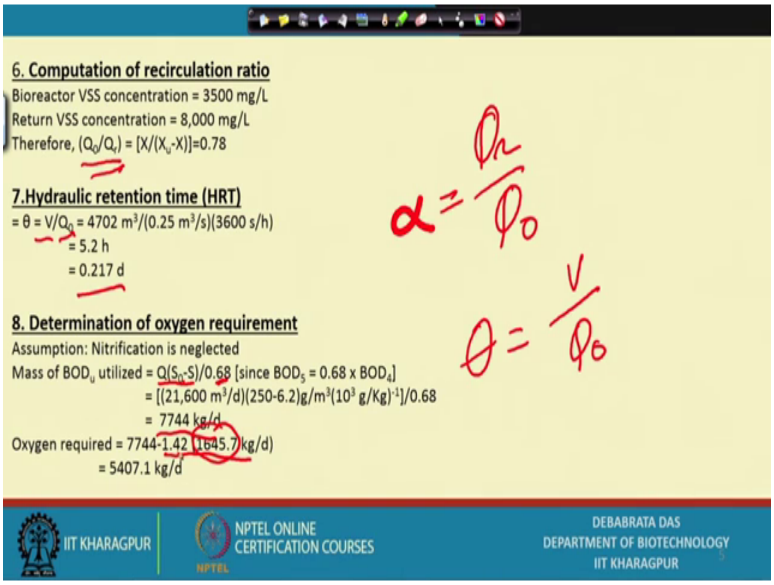

Now, next is that what is the recirculation ratio that we can easily find out recirculation ratio we can find out that this equation that a recirculation ratio usually we find out by alpha, this is alpha is equal to Q r by Q 0. This is the recirculation ratio this is I think there is some mistake we can made the correction. Then this we can find out through the material balance across the reactor we can easily find out that in the in the then we can we can find out that what will be the value of Q r by Q 0.

The hydraulic retention time that is hydraulic retention theta can be easily find out V by Q 0 that is you can you can easily find out then V we know then Q 0 equal you know. So, we can find out the hydraulic retention time. Now, oxygen requirement we can easily calculate how we can calculate the Q into S 0 minus S that is the amount of BOD that is removed and then this is point this is the BOD 5 and 0.68 if you divide then we will get the total BOD that it should be removed.

Now, when your wastewater this much of BOD is removed a part is converting into cell mass that remain in the reactor. So, the BOD equivalent to cell mass that is to be deducted and BOD equivalent to this is the amount of cell mass that is produced and this is 1.42 is the conversion factor for the oxidation of 1 gram of the cell you required 1.4 to gram of oxygen. So, if you derived we can find out the figure that; what is the exact amount of oxygen that is required in this particular process.

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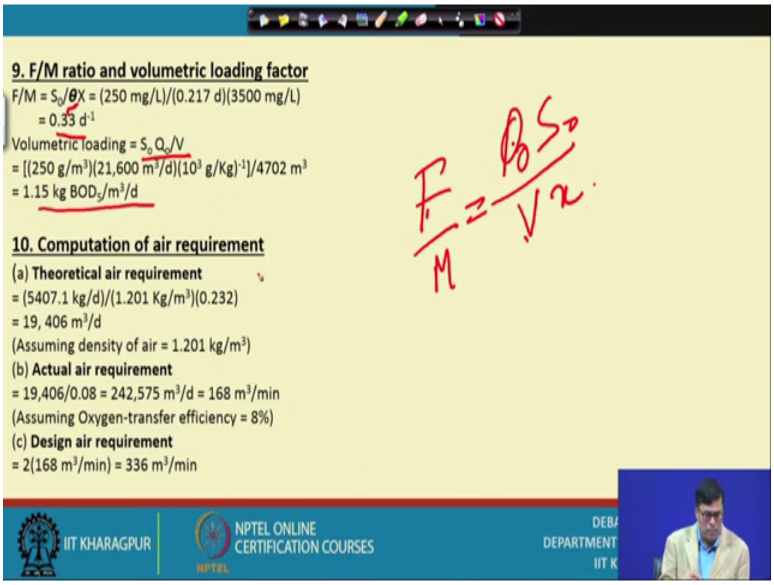

Now, the F F by M ratio that also you can easily calculate what is the F by M ratio F by M ratio is the food and microorganism ratio. What is the food total food is the Q 0 into S 0 and what is the microorganism present in the reactor V into x the. So, we can we can find here because the Q F by F by Q 0 is the 1 by theta. So, if this is the replaced by theta. Theta is the hydraulic retention time. So, you can easily find out what is the F by ratio and then volumetric loading that we can calculate by this is that per unit volume how much BOD is loading, that we can per unit time that we can calculate from this.

Now, how you calculate the amount of air requirement that is very important because previously we have already find out how much oxygen is required this is the amount of oxygen required. Now, air contain 23.2 percent of air oxygen. So, if you divide by 0.232 you will get the amount of air that is required. Now, air has the density of 1.20 to 1 kg per cubic meter. So, you will get the volume of here that is required for this particular process.

Now, now all oxygen present in the air all a all oxygen we cannot be transferred into the liquid. So, there is a some kind of oxygen transfer efficiency that is we considered about 8 percent. So, if you divided by 0.08 we will get the exact amount of oxygen that is air that is required for this particular process and for designing purpose always we consider some kind of factor of safety. Here we can consider 2 is the factor of safety. We can find out that what should be the air requirement has about 333 36 cubic meter per minute.

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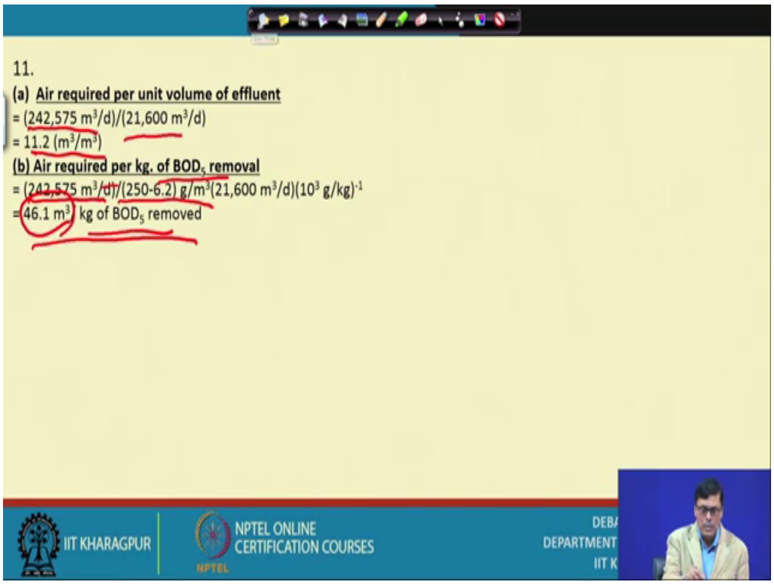

And, here we can say air requirement per unit volume of the effluent. This is the amount of effluent is to be treated, this is the amount of air is required. So, we can find out cubic meter per cubic meter of that effluent that that we can calculate, air requirement per kg of BOD removal that also we can calculate with very easily. So, if you know that this is the a amount of air requirement and this is the amount of that BOD that is to be removed and then we can find out what the per kg of BOD removal how much air is required.

So, this is considered as the process design. The process design basically we have been that for running for operation of the process whatever parameters we shall have to monitor that is to be estimated that is called process design.

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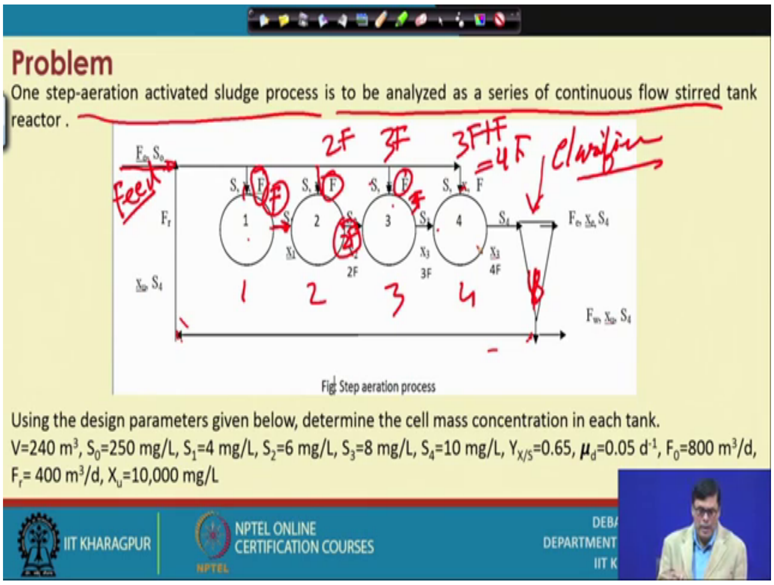

Now, second problem also very interesting, if you look at that one step-aeration activated sludge process is to be analyzed as a series of continuous flow stirred tank reactor. Now, this is the four tanks. This is 1, 2, 3, 4 this is the activated sludge process their continuous stirred tank reactor they are attached with each other in series.

Now, then this is the clarifier this is the clarifier where you separate out the cells and if cell you recycle back to the system. Now, if you look at the flow diagram these cells it comes in contact with the with the flow stream that is the feed this is the feed or wastewater that is coming in. So, they are mixing together and then they are equally distributed in the 4 different reactor, am I right? You can see that this is distributed like this.

So, then here the liquid is coming and then after the contusion is a continuously operation then the liquid is entering into the second reactor and here is coming and then this is now here I want to point out one thing that if you look at the flow rate of the how much word what flow rate the incoming liquid coming in the first reactor that is F, am I right? Now, in case of second reactor we have two flow rate here F and here F. So, overall flow rate is 2F. So, here you have 2F am I right. So, the this in the third reactor this what is the flow rate 2F plus F that is 3F. So, here it is coming 3F, am I right? This 3F is entering and fourth reactor will be 3F plus 4F that is 4F. So, this is the overall flow rate in the in the in the fourth reactor.

So, this is let me see how we can solve this problem.

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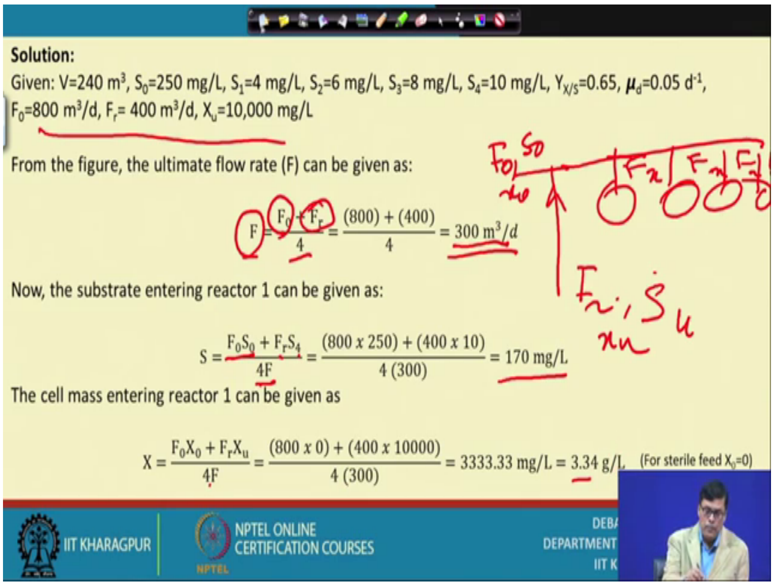

And, I told you that whenever we you want to solve the problem you try to write down all the operational parameters that we have you can write it down and now let us see how we can find out the overall flow rate of individual tank.

So, F 0 is the is the is the is the incoming flow rate am I right this is F 0 and this is F r this is your F 0 and F r and then it is divided into 4 different reactors like this equally it divided it like this, am I right? So, basically it is the F 0 by F r divided by 4. So, the flow rate of individual reactor here it will be 300 cubic meter per day.

Now, question come what is the value of S? Now, here the S 0 values is the substrate concentration S 0 and here substrate concentration is S, am I right? Now, S 4 because it is coming from the fourth reactor. So, we can write F 0 into S S 0 plus F r into S 4 divided by F 4 F then we will get the this value; that means, 170 milligram per liter. So, S value you can find out similarly we can find out the value of X also what is coming in here X here X here X all this X value you can kind of F 0 into X 0 this is the X 0 and here this is your X u, am I right? The F r into X u divide by 4F you calculate 3.3 grams per liter that will be getting.

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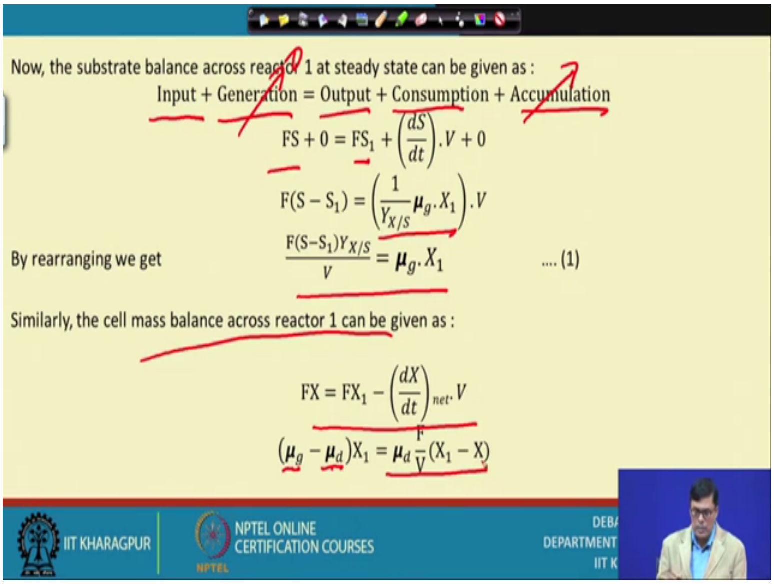

Now, when we do the substrate balance in the first reactor, then how we can write? The substrate balance is the rate of input of the substrate of generation of substrate output consumption and accumulation. Now, this will be equal to 0, in case of substrate and rate under steady state condition accumulation will be 0. So, we can write F into S, F into S 1 dS by dt into F. Now, dS by dt we can write in this form. So, this we can write in this form they into S minus S 1, Y X by S by V equal to mu g into X 1.

Now, if you go if you write the cell mass balance also we can we can we can come across this equation. So, this is what is the what is the net growth of the cells is mu g into mu d. The mu g is the growth of the cell mu d is the death of the cells into X 1, this is equal to this.

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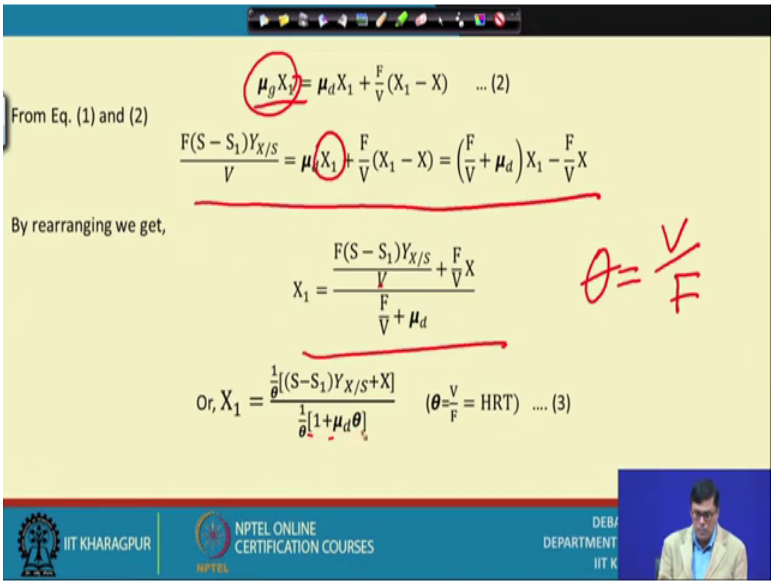

Now, this equation we can write in this form. This is the and then from equation 1 and 2 if you look at this equation we have we have written in this form the mu mu g into X 1 and this equation also we find out the expression for mu g. So, the 1 or 2 that one side is the same. So, we can equilibrate the equation we will come across this equation and then the this equation you can write we have to find out the value of X 1 and where our equation will come and X 1 will be equal to that F by V is equal to what, 1 by theta, because we know theta is the hydraulic retention time is equal to V by F, am I right?. So, this we can write in this form Y by X s. This is F by V, I can take common and this also we can take common and we can take 1 plus mu d into theta.

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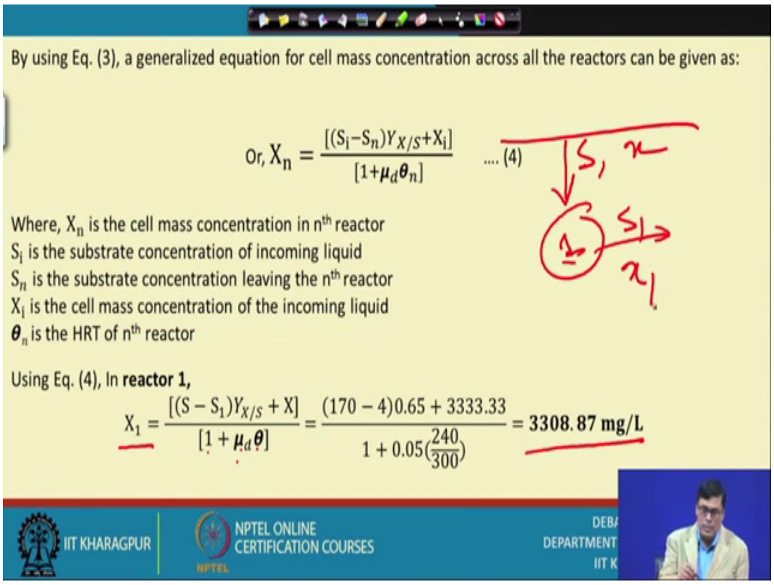

Now, then from this we can we can we can write a generalized equation that X n equal to S i into minus S n Y X by S plus X i will divide by y 1 plus mu d plus theta n. Now, what do you mean by theta n? theta n is the hydraulic retention time of the n tank, X i is the cell mass concentration of the incoming liquid X n is the substrate concentration leaving the nth tank and S i is the substrate concentration of the incoming liquid X n is the cell mass concentration of the n-th reactor.

So, what we can do that after writing this generalized equation now, we can consider the first reactor. In the first reactor what we can write that X 1 equal to this S will be that S that you know the reactor that S is coming this is with the main stream the S minus S 1; S 1 is going out late from this is the number 1 reactor I can I can write that this is X is the here is the value of X that is the incoming liquid and 1 plus theta into mu d into theta. So, if you put all these values we can find out the cell mass concentration here is like this.

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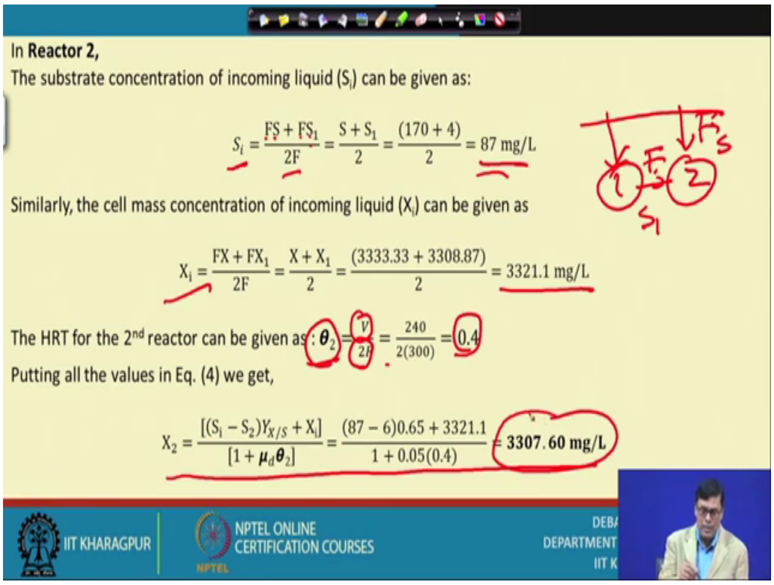

Now, similarly we can find out the S i. S i value and X i value and X 2 value that we can find out. In the in the second reactor, how we can find out; in the second reactor that in the second reactor if you consider in the second reactor suppose this is the main stream and this is the first reactor this is the second reactor and this is coming like this. So, here there is the F is the flow rate, this is F is the flow rate, this is this one this is S, am I right?

So, we can write the S i the incoming substrate concentration the F into S plus F into S is 1 divided by 2F will give you 87 milligram per liter. Similarly, X i also we can calculate we find this. The theta theta 2 the hydraulic detention level this is the volume of the reaction that the total flow rate is F plus F is 2F. So, we can find out 0.4. So, they if you put this value in this equation we can get the value of X 2.

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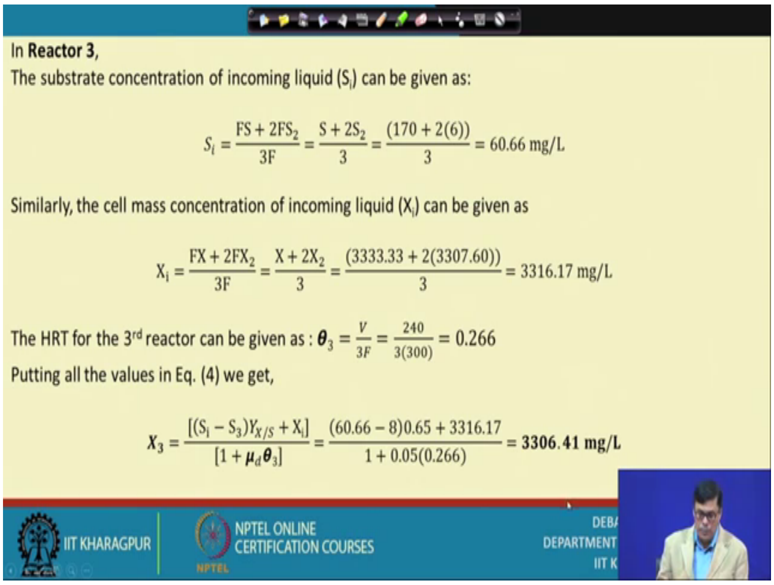

Now, similarly we I can I can solve for the reactor 3 and reactor 4.

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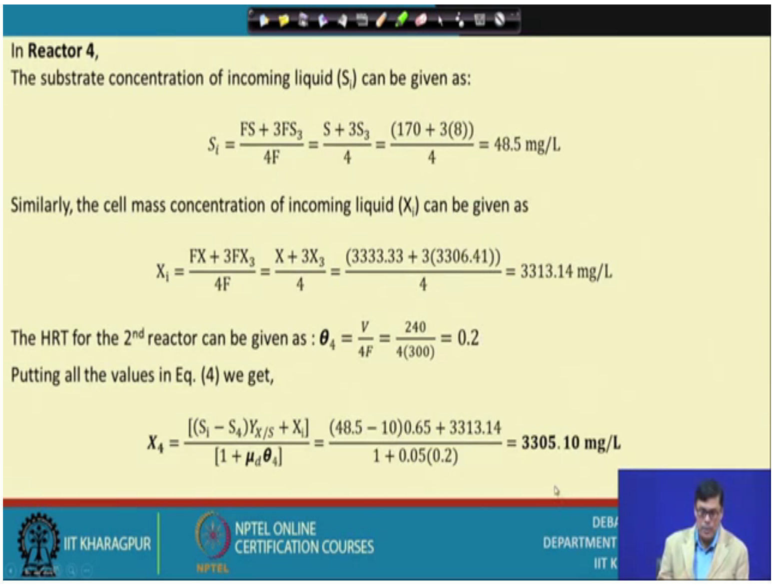

Similarly, the same solution we can get and so, what are you in conclusion what I want to tell that that in it is very easy to do the process design of activated sludge process. We can find out first we shall have to find out the conversion efficiency of the process and then we shall have to find out the volume of the reactor, then we can we can find out how much sludge is producing per unit time. Then, we can calculate that that what is the hydraulic retention time, what is the solid retention time, what is the flow rate wasting flow rate of the of the sludge. Then, we can find out the exact amount of air that is required for this particular activated sludge process.

And, I tried to tried to solve some kind of step variation process just to find out that how to the cell concentration in after different reactors when they are they are connected in series.

Thank you very much.