Aspects of Biochemical Engineering
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Lecture – 42
Design and analysis of activated sludge process – I

Welcome back to my this lecture that is on Aspects of Biochemical Engineering and last couple of lectures, we try to discuss the that you know microbial system for substrate utilization product formations cell mass formation by using different microbes and we made a detail analysis on the process.

Now, this lecture is something related to that, but little bit advancement of the chemostat process. We know that major drawback of the chemostat process will say the cell mass wasting from the reactor because we know that because when you consider any kind of continuous stirred tank reactor there is a inflow of substrate there is the outflow of product and when since we have it to the continuous stirred tank reactor we assume that whatever cells that present in the reactor that also remain in suspension. So, it is also going out with the outgoing liquid.

Now, if the rate of cell mass that is going out of the from the reactor is more as compared to cell mass growing in the reactor then what will happen is situation will come when there will be no cells present in the reactor. So, this is the major drawback of the chemostat process the and you know we have I will try to explain the situation that the ap cell has the generation time and we know that 1 by d is equal to hydraulic retention time.

Now, suppose you operate a system and very high dilution rate and you know one and so that their the retention time of the liquid in the reactor much less than the generation time. So, before your cell multiply you are taking out the cell from the reactor naturally you will not get any cell in the reactor though this kind of situation can be overcome by two different approaches.

One is if you recycle the cell back to the whatever excess cell you are taking out from the reactor if you recycle back the cell to the reactor then naturally your cell mass concentration will remain constant there will be the situation cell wash out and second situation is that I told you if you immobilize the cell on a solid matrix so that you hold the cell like this and you pass your substrate like this though there is a less possibility of cell wash out.

Now, this particular that lecture we try to discuss the process with the CSTR with cell mass recycling and we have taken this with respect to one particular process what we call activated sludge process which is largely used for waste water treatment process.

Because the we know that it there was a survey in India that you know long before 15 years before by the central pollution control board and they observed that the most of the chemical and biochemical industry in India they are contributing the waste water pollution program and it is mandatory for all the industry. They should before they dispose the waste water to the watercourses that should be treated properly so that they should not have any kind of harmful effect on the environment.

Though this, the activated sludge process is largely used for the wastewater treatment process. So, this I said I am going to discuss this in the lecture and also I am going to discuss how we can do the process design because you know that that you know we try to develop the equation maybe in the next lecture I shall give you more detailed information how can do the detailing of the process design.

Process design means to run the process whatever parameters we shall have to calculate with the how what are the different parameters we should calculate we should determine or running a particular process that I shall show you in the next lecture, but this lecture we will try to analyze the activated sludge process.

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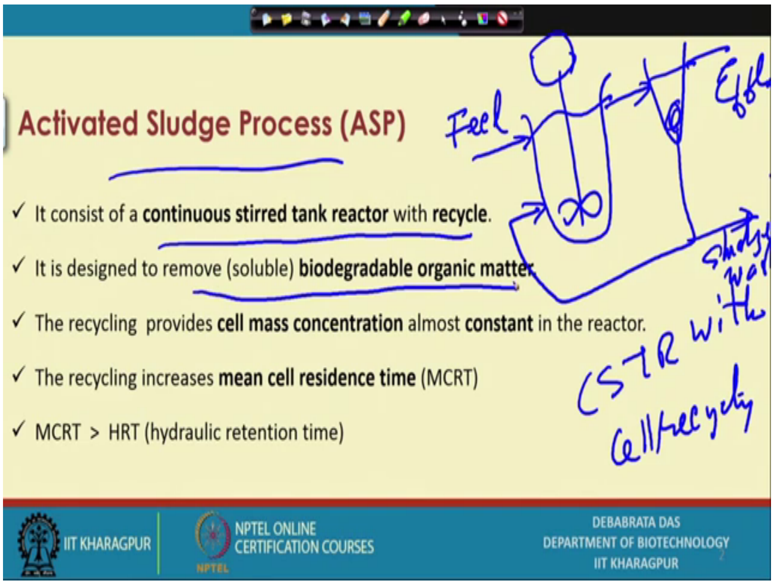

Now, if you look at the first the activated sludge process what is the, what do you mean by activated sludge process? Activated sludge process is the continuous stirred tank reactor with cell mass cycling; that means, the we know this is a continuous stirred tank reactor am I right there is the inflow and outflow then with cell mass recycling; that means, there will be some kind of cell separator a part of the cell you recycle back in the system.

So, this is called CSTR with cell recycling with cell recycling am I right. So, that they so activated sludge process is nothing, but this is the feel and this is a effluent this is the effluent and this is sludge wasting sludge wasting. Now, it is designed to remove the soluble biodegradable organic matter because here let me explain that because you see that you know when the waste water contains some kind of organic matter how we can remove.

Now, if we use any kind of chemical process we shall we shall have to use some kind of chemicals we said the oxidizing property as for example; potassium dichromate, potassium permanganate. So, you know that the that we use if you if you treat this waste water with this oxidizing agent then all the carbonaceous matter that will be converted to carbon dioxide and water.

But, the problem is that when you use any kind of chemicals for the oxidation of organic matter. So, first of all it is a energy intensive we have to heat it and high temperature at the same time we have to use lot of chemicals, but now when you use these chemicals particularly heavy metal toxicity of the water that will be increased.

As for example, potassium dichromate if you treat the wastewater; that means, chromium concentration of the water will increase; The potassium permanganate that if you use the manganese concentration in the water that will increase, that is undesirable.

So, in but if you look at the biological process in other way that if there is the any kind of soluble organics present in the wastewater our bacteria can easily utilize this organic matter for the growth and multiplication. When they grow there is a soluble organics can be converted with the convert to in insoluble biomass and this insoluble biomass which is the insoluble we can easily separate it out. If you separate it out how do you will find it the clear liquid and that is why that the activated sludge process largely used for the wastewater treatment process.

The recycling provide the cell mass concentration almost constant in the reactor I told you the main purpose of recycling we want to maintain the cell mass concentration uniform so that rate of reaction in the reactor should remain constant and recycling is necessary increases the mean cell residence time.

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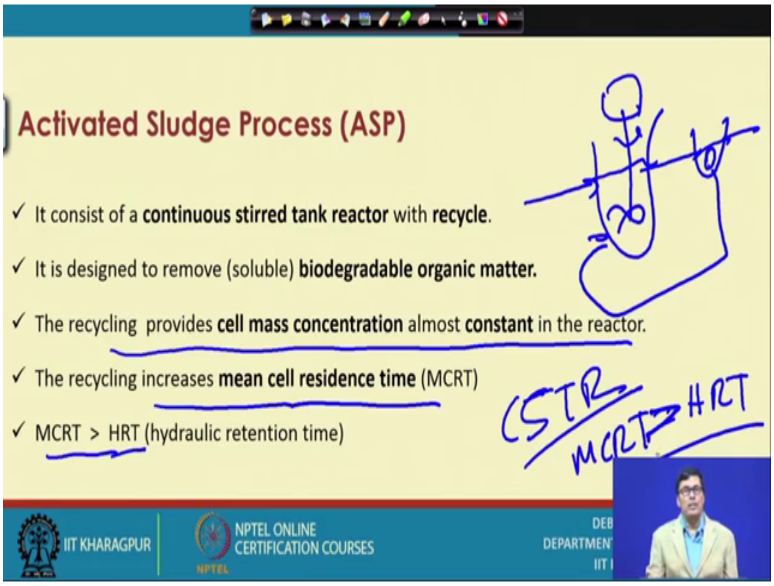

Now, since in this reactor if you do the recycling then what will happen the recycling that means, what I say they cell cells we are recycling back ; that means, the cell retention time in the reactor that will increase that is why that is exactly. So in that case, the mean cell residence time should be higher than hydraulic retention time.

Now, in case of CSTR; CSTR or chemostat what is happening the mean cell residence time is equal to hydraulic retention time, am I right, but way as soon as you do the recycling then the mean residence time is higher as compared to hydraulic retention this is the main purpose of recycling.

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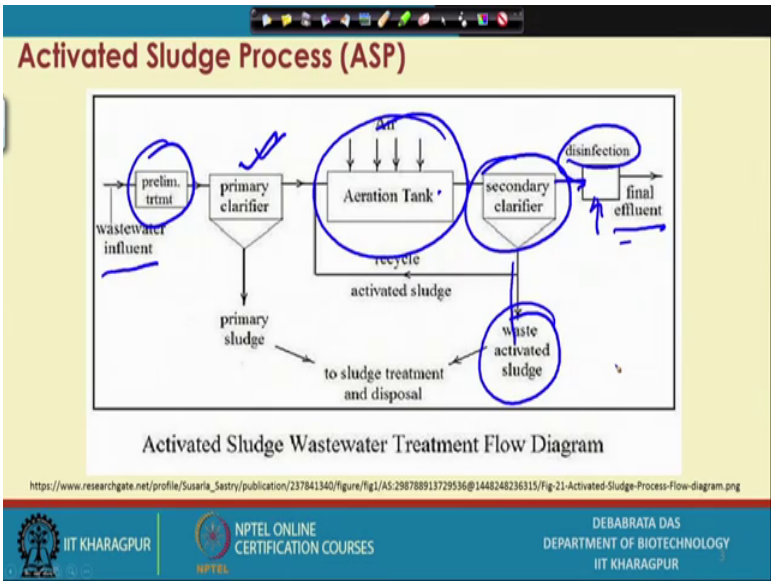

Now, this is how this the process diagrammatically I can explain this is wastewater that is it first we have the preliminary treatment. Preliminary treatment it has a might be having some floating matter it may be the bigger particles that is usually separated out by the settling process and then we have primary clarifier where that you know that smaller particles suspended particle that will be separated out.

After that is passes this is the activated sludge process where what we call it a aeration tank; where the aerobic organism will grow and utilize the soluble organics for their growth and metabolism.

Then this cell mass is the insoluble mass, that is separated by the secondary clarified system and then this cell mass we separated out this is the waste activated sludge and the clear liquid is take it out and we use some kind of disinfection like chlorine treat and finally, we dispose to the watercourses this is how the process is operated. So, basically our activated sludge process is the CSTR with cell mass recycling this is the process that we have.

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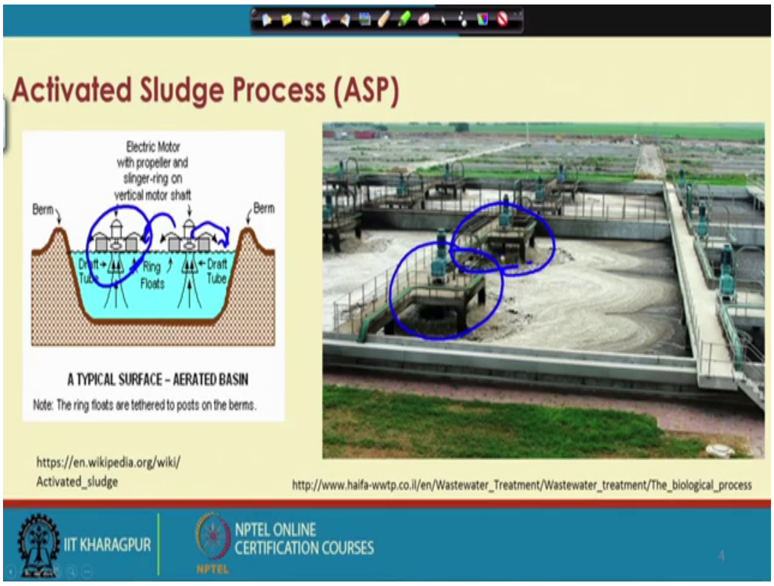

Now, in if you look the in a that you know how it is in practice in the industry it is like the like this that you know this is the surface aerator this is called surface aerator. The surface aerator that flowed at the top of the liquid now, here you can see that how the surface aerator happens? It is located in the actual activated sludge process it was located.

So, what they do they the throw the water out you can see that it is this is the throwing the water out. So, that when you throw the water out then air will come in contact with the water and more air come in contact with the water that dissolve oxygen concentration in the water will increases.

So, that if the dissolve oxygen increases then the your organism will grow more and they can utilize more soluble organic material for their growth of the organism and the degradation of the organic matter will be more which is most desirable.

Because, in case of aerobic fermentation process major limitation factor is the dissolve oxygen concentration because we know the microorganism can utilize the oxygen which is dissolved in the liquid not like human beings we all human beings we can take the oxygen which is present in the air, but microorganism they can utilize the oxygen which is dissolved in the water and since oxygen is sparingly soluble in water so, you would the that is the limiting factor or the growth of the aerobic organism.

So, we shall have to increase the dissolve oxygen concentration of the in the liquid. So, that we our organism can grow very fast and it utilize the substrate at the faster rate. Now, this is that is why we put the surface aerator here and then. So, this is how it looks.

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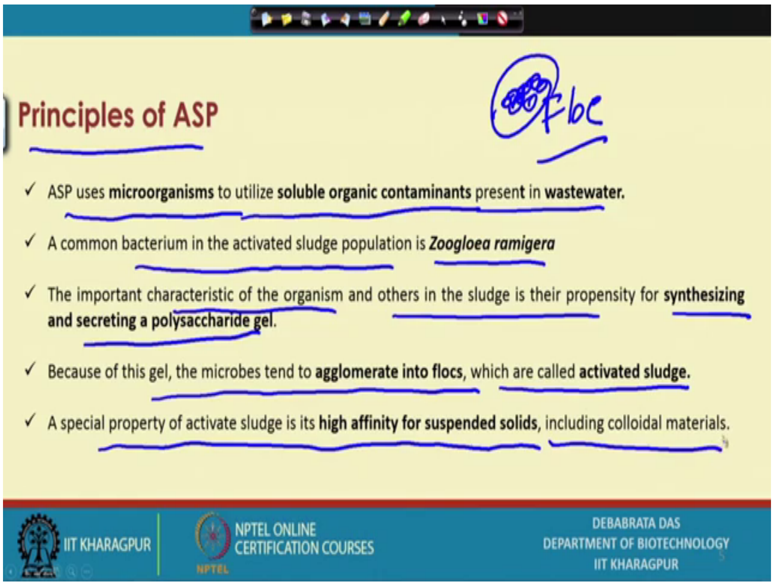

So, question comes what are the principles of activated sludge process. Now, activated sludge process uses the microorganism to utilize the soluble organic contaminants present in the wastewater. The, what I just now I will try to point out the soluble organic converted to the insoluble biomass. Then common bacterial space that use in the activated sludge process is Zoogloea ramigera.

This is the typical type of key organism that is used in the activated sludge process. The important characteristics of this organism is that is synthesizing or it produces secreting the polysaccharide gel. Since the organism because we know bacterial what is the size of bacteria? Size of bacteria varies from 0.5 to 2 microns and they are very tiny particles and very difficult to settle down.

So, that is the major problem because whenever we handle any kind of bacterial process the major problem we face that is the separation of the cells and this organism has the characteristics of secreting the polysaccharide gel and since in secreted polysaccharide gel that cell they will be they will be they attach with each other and they will form the floc they will form the floc can this is called floc formation and the then the particle size will be big and as the particle size is big to it will settle down.

The because of this gel the microbes agglomerate into floc and which is called activated sludge the special property of the activated sludge is the high affinity for suspended solid including the collegial biomass. So, that you know that this suspended mass what will be some the small particles that present the wastewater they adsorbed on the surface of the this cell surface and your wastewater do you will find the clear water.

Because I can I can tell you that my personal experience that I when I was at the at the IIT, Delhi I visited the oculus waste treatment plant and if you are if you visit the oculus I do not know how it now how it is now, but I visited in the year 1983 then I found when I took the water in my hand I found immediately that that cell that settle down and we I get the clear water at the top. So, you know this kind of experience that I had.

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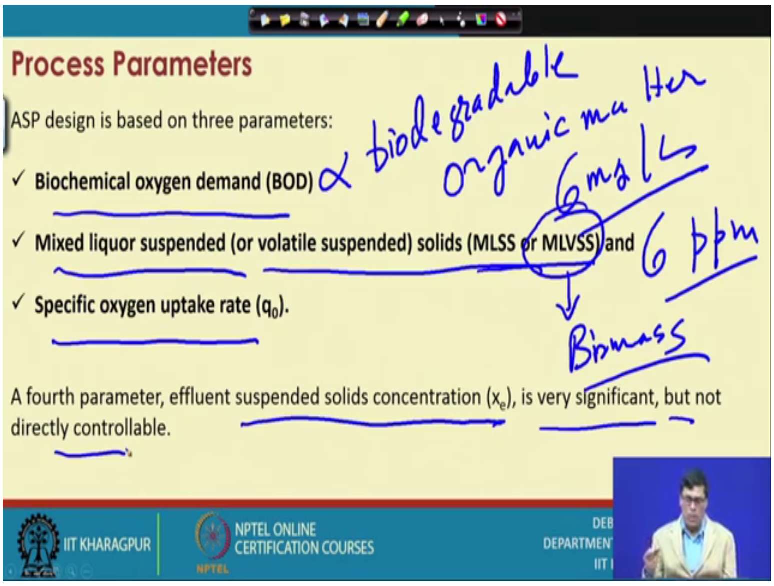

Now, for ASP design base out three different parameters one is biochemical oxygen demand. Now, what is the what do you mean by biochemical oxygen demand; biochemical oxygen demand means as I told you for when the organisms grow and multiply they required the dissolve oxygen am I right.

So, to more the organisms grow more will be dissolve oxygen consumption. So, biochemical oxygen demand means amount of oxygen required for the oxidation of the biodegradable organic matter.

So, this BOD is directly proportional to bio degradable organic matter is directly proportional to the why it is so? Suppose, the if the BOD that is high that means, this has more biodegradable organic matter if a BOD value is low that we know that is a less biodegradable. In this connection let me tell you that the our drinking water we know you know the drinking water as per World Health Organization WHO the BOD of the waste that drinking water should be less than 6 milligram per milligram per liter am I right what you call 6 ppm. So, this is this should be less than 6 ppm.

Now, the mixed liquor suspended solid and mixed liquor volatile suspended solid MLSS and MLVSS that is very important that you know that suspended solid we understand the suspended solid. How you do what you call sludge how you define the sludge? Sludge is the kind of insoluble solid material it may comprises of both inorganic and organic, am I right. So, it is similarly that you know that when we have the mixed liquor suspended solid it has one in suspended another is volatile suspended solid.

Now, what do you mean by the volatile suspended solid? Now, if you burn it at our 600 degree centigrade then whatever organic matter is there that will convert into carbon dioxide and all the oxides sulfur dioxide nitrogen will convert nitrogen oxide metal will convert into metal oxide, but you know that metal oxide that remain in the form of gas in the in the in your in your system, but gas will go out of the system, gas always remove you can go out of the system.

So, whatever things is converted to the gas that we call it volatile matter you get may the volatile matter indirectly it tells the organic content of the solid material. So, since our biomass or cell mass comprises of mostly the organic matter that is a volatile mix liquor volatile suspended solid what you call MLVSS this we usually considered the biomass or cell mass. This we usually we express as biomass or cell mass because when you burn it produces a carbon dioxide and carbon dioxide sulfur dioxide nitrogen also that will be go out of the this is the organic material.

And, specific oxygen uptake rate; This is very important the reason is that since it is the aerobic process question comes there are how much oxygen is required what the oxidation of the sample. So, that is why this is very though. So, you know these are the things there are other parameters like you know that suspended concentration of the cells and outgoing liquid that they effluent is the significant, but not directly controllable. Though we assume the outgoing that cell that cell that effluent should not count in much of cell mass because most of the cell mass we assume that is usually separated in the clarified.

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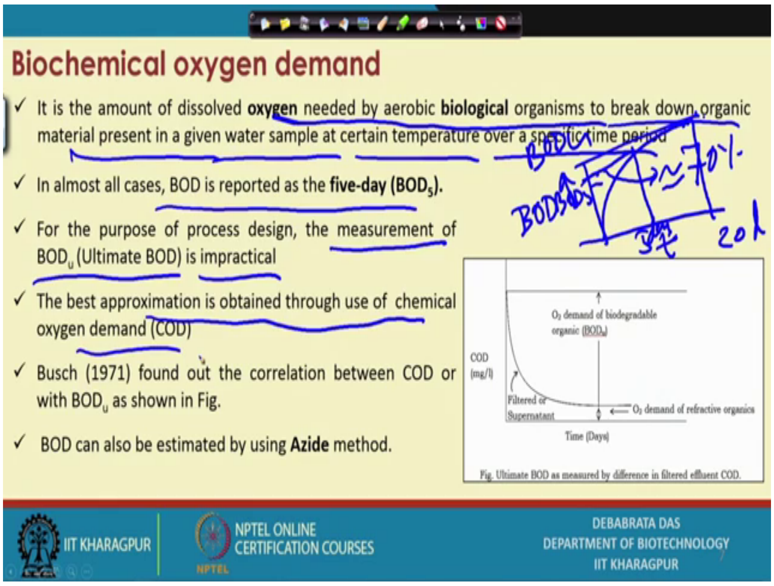

Now, now question comes that that what do you mean by biochemical oxygen demand is the amount of dissolved oxygen that needed by the aerobic bio biological organism to break down the organic material present in a given water sample at the certain temperature over a specific period of time.

Now, usually we consider five-day BOD. Now, why we consider five-day BOD? Now, if you would look at BOD to the biochemical oxygen demand, am I right? BOD versus t that is like this now this is called this is five-day's and suppose this is 20 day am I right? All the here, all the organic matter that would be oxidized. Now, here 5 day we have observed that approximately 70 percent organic matter will be oxidized.

Now, since it is the operating parameter naturally we are interested that you know that in the how this parameter can be monitored very short time that is why we express this 5 time 5 day in the BOD. Now, for the purpose of that process design the measurement of BOD u what we call ultimate this is call ultimate this is called BOD u and this is called

BOD 5. So, this is the impractical because then you have to wait for 20 days that is not visible.

Now, based approximation is obtained through the use of chemical oxygen demand because why the chemical oxygen demand is very good because chemical oxygen demand is the amount of oxygen that is required chemically for the oxidation of the sample and this can be done within 2 hours.

You will just take the sample and deflects with potassium dichromate for 2 hours all the organic matter all the inorganic matter that will be oxidized. Then you through titration you find out how much potassium dichromate has been exiled that consumed. So, from that you can find out the COD value.

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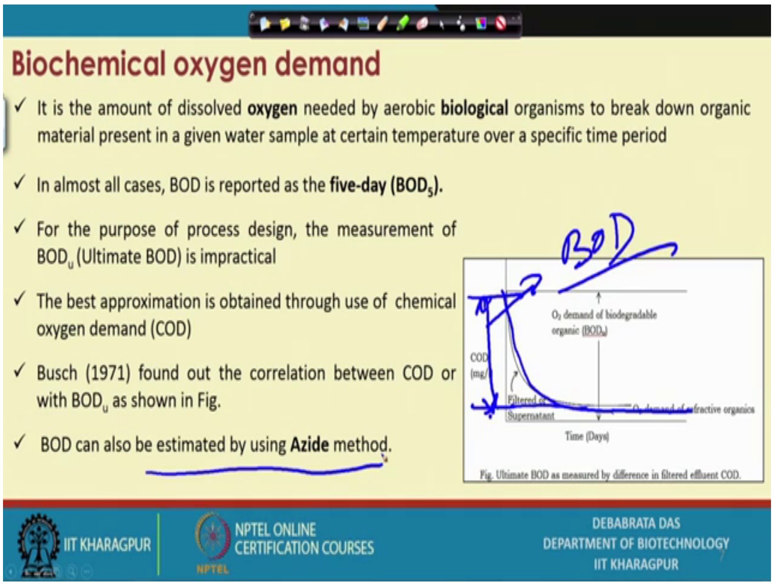

Now, the COD of a sample if you see here this will keep on decreasing with respect to any treatment process will keep on decreasing a time will come when it is constant. Now, this when it is constant and this a, this is the input and this is the final value and this difference is this is actually the BOD value.

So, from the COD value we can easily we can also find out extrapolate the BOD value with the help of this particular curve and BOD estimate by the Azide method. The dissolve oxygen concentration can be estimated by the two methods one is by using the or dissolve oxygen probe another by the chemical method what we call the azide method we can use that.

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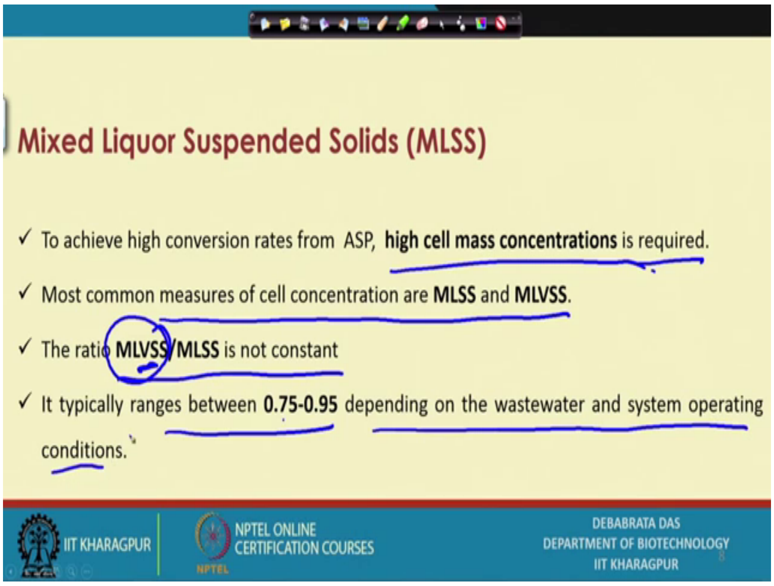

Now, mixed liquor suspended solid to achieve the high conversion obvious the high cell biomass concentration is required and most commonly measures the cell the ratio of this is very is not constant, but ratio plays very important role. MLVSS, I told you MLVSS indicate that how much volatile suspended solid is there; that means, volatile suspended solid indicate that how much cell mass is there.

Now, if that ratio is more that means, your suspended solid content more cell mass, if the ratio is less that means, suspended solid contains less amount of cell mass that is inactive material. So, that is undesirable. So, typical range of MLVSS by MLSS is 0.75 to 0.95 depending on the wastewater and system operating conditions.

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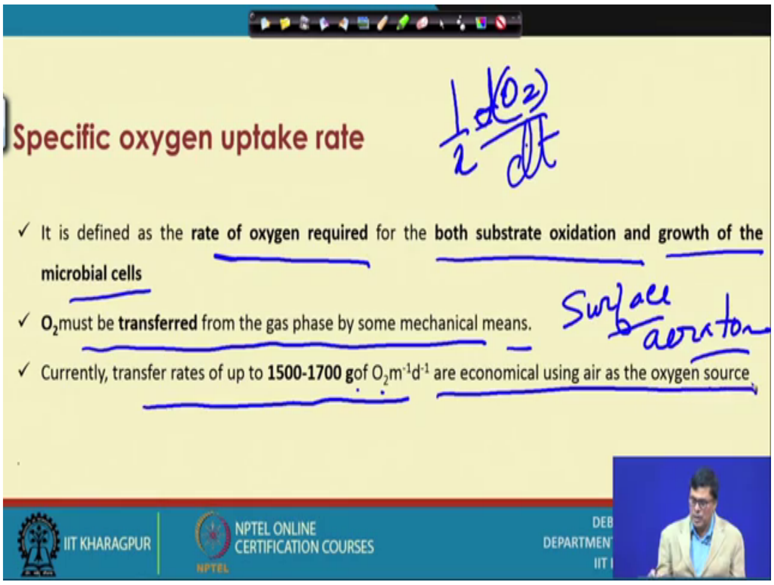

Specific oxygen uptake is defined as the, that rate of oxygen required both for substrate observation and growth of the cells. Now, specific oxygen uptake I told you this is equal to 1 by x do 2 by dt, am I right? The this is the rate of oxygen consumption and this is 1 by x is called the specific oxygen uptake rate.

So, this is we can like that the oxygen must be transformed from the gas phase to by some mechanical means; I told you surface aerator I told you surface area I show you aerator is use to transferred the oxygen present in the air from the air to the water and currently transferred rate is 1500 to 1700 grams of oxygen per meter square meter per day are economically used for air the oxygen source.

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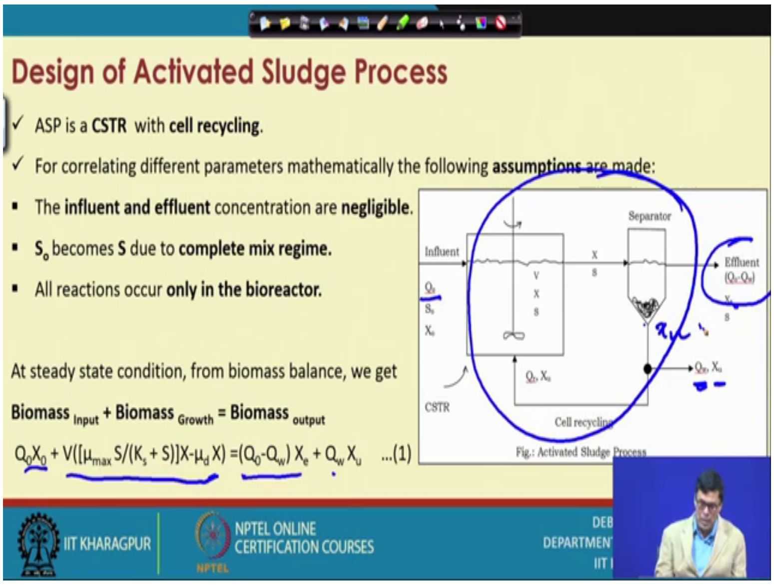

Now, this is the activated sludge process let us see how we can design that in case of activated sludge process I told you it is the this is the CSTR and this is the settling tank separated and you recycle back the cells here. So, it is CSTR with cell recycling.

Now, here three assumptions remind the influent, this is influent and this is the effluent am I right? Influent and effluent concentration is negligible S 0 becoming S this S 0 becoming S as well as this fold in the reactor due to the complete mix regime and all the reaction occurred only in the bioreactor not in the pipeline not separator.

Now, if you have this then we can write at the steady state condition biomass balance is what is X Q 0? Is the flow rate Q 0 is X 0 is the input cell mass then what the biomass growth what is generation is the, we can write this. This is this is the growth of the cell; this is the death of the cells into V this column we have to consider and biomass output. What is the output of the biomass? There is a output is going out here because we want to do the balance across the this system not across the reactor.

So, the there is a two outlet this is Q o 0 into X e and the, and this is the X w is the wasting flow rate and X u is the settle cell mass concentration here is the X e.

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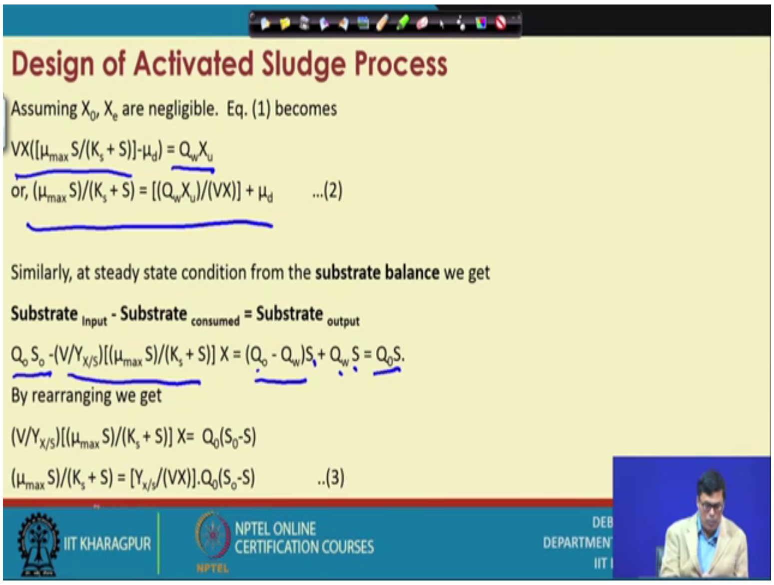

Now, assuming because in this problem we have made certain assumption that influent and effluent influent and effluent the concentration of cell mass is negligible. Am I right?

So, if we if we assume that influent and effluent cell mass negligible then we can write this equation in this form. This is the V equal to this is equal to and this equation I can write in this form that is mu max S by K s plus S equal to Q w, X u by V into X into plus mu d and then if you do the substrate balance in the similar way Q into X 0 is the rate of substrate that you know input and substrate consumed is this one and substrate.

What is the output one is with the effluent that is a Q 0 into S and Q w into S then this is a if we put this will be Q 0 into S and if you simplify we will get this particular relationship.

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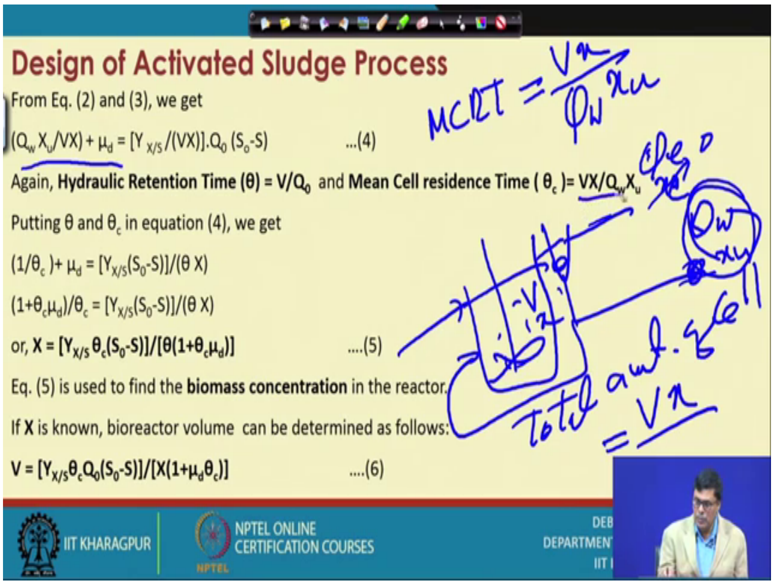

Now, we considered both the equation 2 and 3 then we will get this equation. We will get this equation that you know Q w equal to Q Q w into X u VX mu d equal to this.

Now, here I as I told you the main purpose of recycling is to increase the cell residence time. Now, in the reactor what is the cell present in the reactor? This is the volume of the reactor and X is the cell the total amount of cell is amount total amount of cell is how much is V into x, am I right?

And, what is the cell wasting from the system we assume most of the cell is going out from the recycle tank and this is coming in. So, this is what Q w and X u that this here we have we have qe into X e, but this we assumed to be 0, am I right? So, we assume most of the cell that is wasting from the, this wasting line.

So, so, what we can write that mean cell residence I mean cell residence time is equal to what equal to V x divided by rate of that you know the cell that is wasting from the from the from the system. So, these will the unit will be time. Though this is exactly what we have written here you can see this is written here like this and if we put this value and this is equal to theta c.

Now, we can put this theta c here 1 by theta c and then finally, we will come across this equation X equal to this equation and this equation we can write we know theta.

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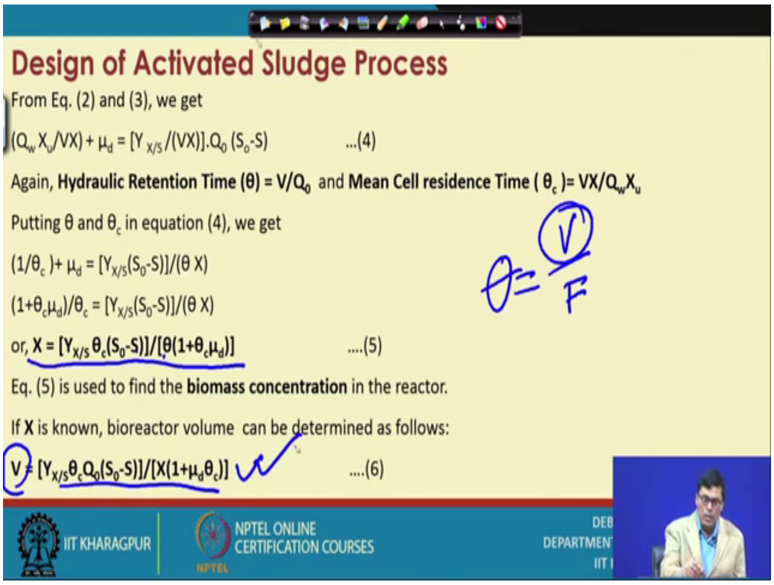

What is theta? Theta is the hydraulic retention time V by f. Am I right? So, we can we can easily find out the volume of the reactor. So, we can V equal to from this equation we can find out this (Refer Time: 28:11) the. So, we can easily find out the volume of the reactor.

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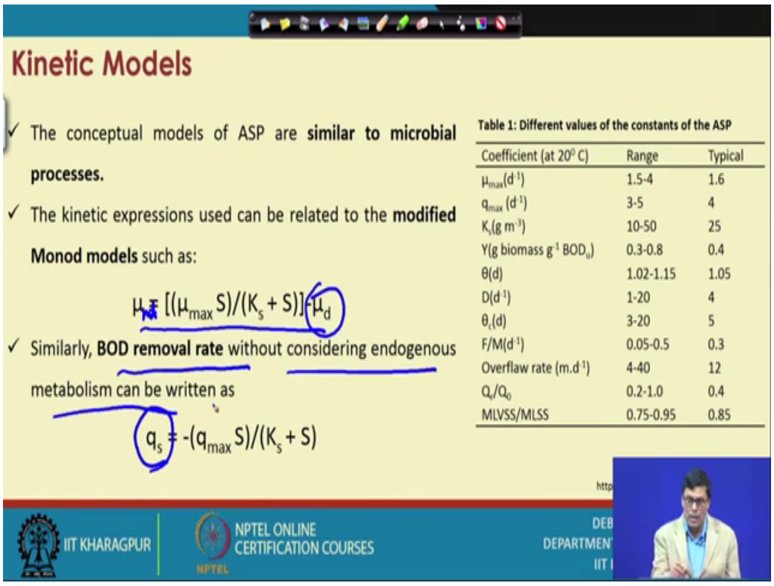

Now, for the computational model asp is similar to the microbial process and the monod equation we use for the and monod equation; this is the modified monod equation. Monod equation is this one mu equal to mu max S K s plus S, but when model because cell death is occurred in a particular my in a living population. So, actual the net growth of cell equal to growth of the cell minus the death of the cells.

The BOD removal rate we can write q s equal to q max S by K s plus S this is the without considering the endogenous metabolism of the cells. Now, these are the different constant value I that is shown here this we quoted from this reference. So, these are the different range is like this and typical values are given here.

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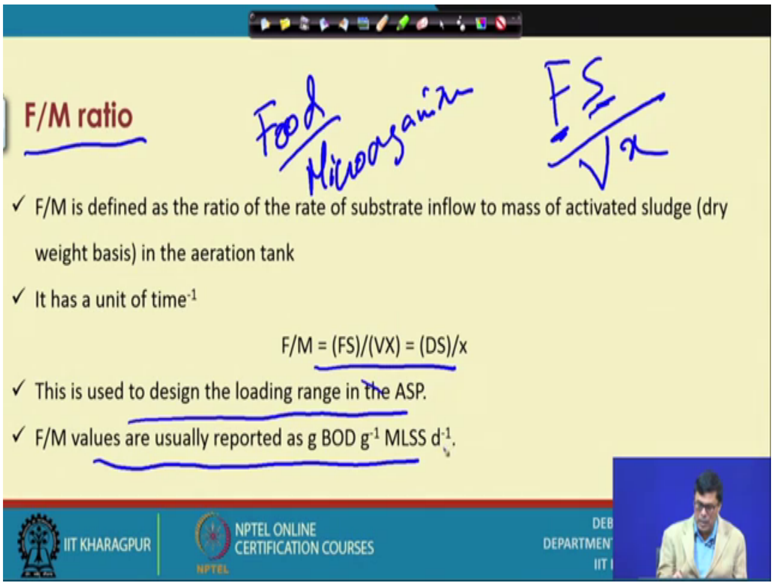

Now, here we have come across a new term what we call F by M ratio. What is the F by F F is stands for food and M stands for microorganism ratio now how you can find out what is the food the F into X F F is the volumetric flow rate s is the substrate concentration and what is the microbes present with the V into X.

So, this is the distance called food by microorganism ratio these how the unit is time inverse. This is used to designing the loading of the ASP, the F M ratio usually reported at BOD per gram of MLVSS per day.

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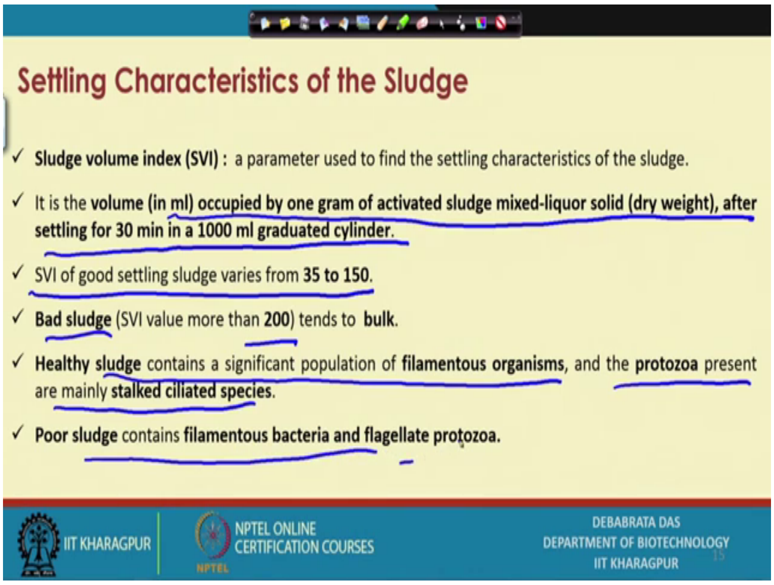

So, this is another very important problem of the activity sludge process I told with the separator. Separated where the cell mass is separated that is the sludge volume index with the kind of the important parameter that determined the settling characteristic of the sludge. Now, here we can find out that a sludge volume index is the volume occupied one gram of activated sludge of the mixed liquor solid after settling 30 minutes in 1000 milliliter graduated cylinder.

Now, if the sludge volume is the 35 to 150 then it is a good settling sludge. If it is more than 200 this is it is called bad sludge and healthy sludge contains significant population of filamentous organism and protozoa of present are mainly stalked ciliated species. The poor sludge content filamentous bacteria and flagellate protozoa. So, these are the problem. So, the sludge characteristics also plays very important role.

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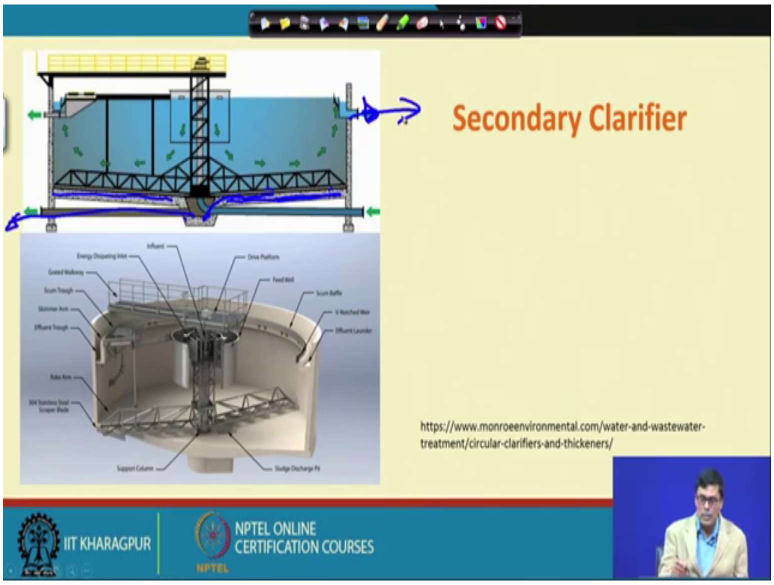

Now, this is this is the how the clarified loops. This is the you can see they the here the sludge that will settle down at the bottom and this is little bit inclined and this is scrapper and you know this scrapper it is it loaded very low speed and scrapped in that the way, in the manner show that all the sludge will come here and then we can take this take this out on this in this direction.

So, and that you know the solve that clear liquid is usually comes out from the top, this is how the clarifier looks.

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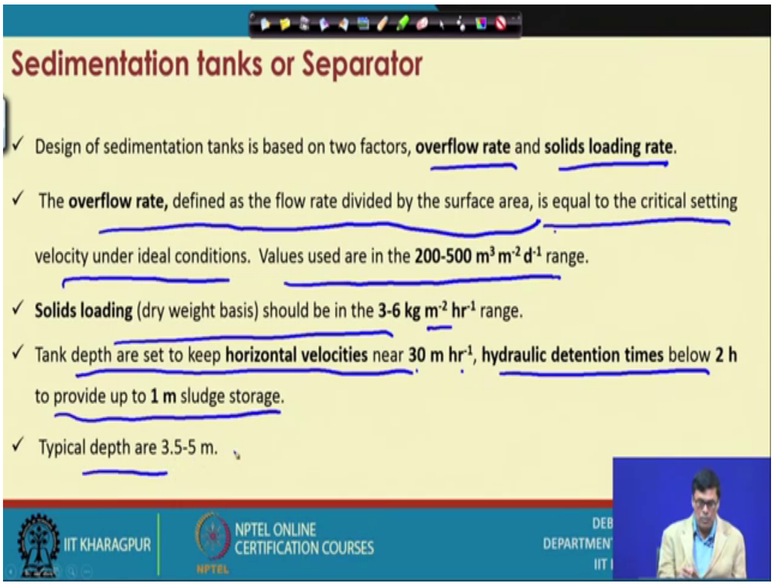

Now, sedimentation stirred tanks the designed of sedimentation tank is based on two factor overflow rate and solid loading rate. Overflow rate defined as the flow rate divided by the surface area is equal to the critical settling velocity under the ideal condition values are in the range of 200 to 500 cubic meter per square meter per day range and solid loading is 3 to 6 kg per square meter per hour per day our range and depth of the horizontal velocity is the that you know 30 meter per hour and the hydraulic retention time is a retention time is 2 hours to provide 1 meter as sludge storage the typical depth is 3.5 to 5 meters.

So, in this particularly presentation I try to discuss that what do you mean by activated sludge process. I told you that activated sludge process is a process through which you can remove the soluble organic present the wastewater and also it is a process through which the drawback. One of the major drawback of the chemostat process that is a cell mass wasting from the reactor is can be already know that what problem that we face that it is cell wash out that problem can be overcome.

So, how to analyze this system that I will try to explain and also I will try to find out that mathematical correlation just to find out how we can determine the cell mass concentration in the in the activated sludge process, how you can find out the volume of the activated sludge process and I told you whenever you do the recycling of the cell means purpose is to increase the retention time of the cell. So, in this case the solid retention time or mean cell resident time will be more than the hydraulic retention time.

And, also I will try to discuss that the settling characteristics of the sludge, I told you if the values lies in between 550 to 150 then it is good settling are use more than two hard lines the best sludge so, and how the clarify looks. So, this I will try to explain here. I hope in the next lecture, I try to discuss the process design of the activated sludge process.

Thank you.