Water and Wastewater Engineering
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Activated Sludge Process (continued)
Lecture-23

Last few classes we were discussing about biological processes for water and wastewater treatment. We have seen that how the biological processes are working and how the organic matter whatever present in the water and wastewater is getting removed by the microorganisms and we have seen in detail what is an activated sludge process and what are the process modifications. We also discussed about the excess sludge production and what is the loading rate we can adapt for the activated sludge process. We have seen about what type of a process we have to adopt for a particular type of wastewater.

For example, if the wastewater is having colloidal particles and rich in organic matter then it is always advisable to go for contact stabilization tank and for small communities we prefer to have extended aeration system or oxidation ditches. So today we will see what is the oxygen requirement in an activated sludge process or in any aerobic process and what is the nutrient requirement for the microorganisms and other factors which affect the biological processes.

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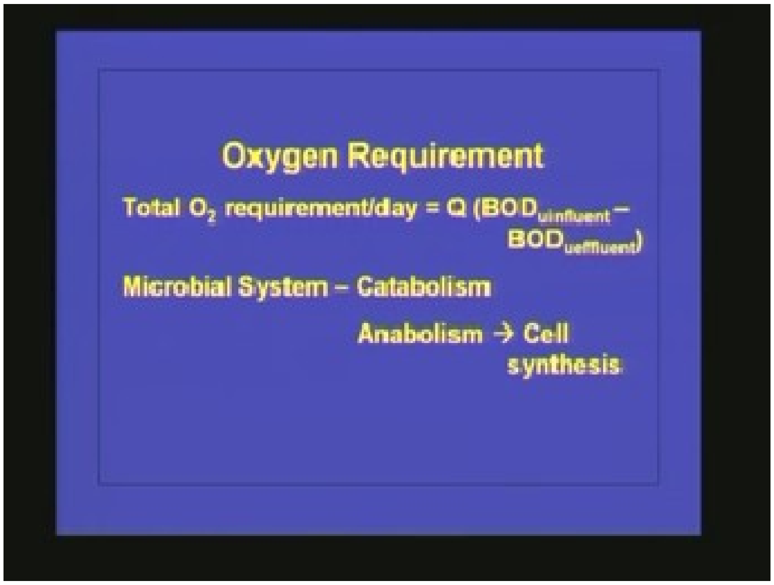

Why oxygen is required in a biological process?
The process itself is like that. The microorganisms are utilizing the organic matter whatever is present in the wastewater so because of the air supply the organic matter is getting oxidized to carbon dioxide and water and more and more new cells will be generated. So the oxygen requirement or the oxygen consumption rate is much more than

whatever can be got by natural **replenation** because the system is open to the atmosphere so definitely natural oxygen transfer will be taking place from the atmosphere to the wastewater or the treatment system. but that oxygen transfer is very very less compared to the oxygen requirement in any system.

How can we supply this oxygen?
We have to supply externally or by some mechanical means we have to supply the oxygen. Thus, if you want to design any mechanical system for the oxygen supply or oxygen transfer we should be able to tell what is the oxygen requirement per unit time in the system. How can we find out that oxygen requirement? We can find out the total oxygen requirement by using this formula; q into BOD influent minus BOD effluent. BOD is nothing but the biochemical oxygen requirement. So if you know what is the influent BOD and what is the effluent BOD so whatever is the difference between the influent and effluent that will be consumed or that much oxygen is consumed during the process. So we have to supply that much of oxygen. q is the flow rate. That means this much of meter cube of water per day or per hour is coming to the system.

We also discussed that in any microbial system there are two processes. One is catabolism and another one is anabolism. In catabolism what will happen is the microorganisms will be utilizing the organic matter and that organic matter will be undergoing a series of oxidation reduction reactions and the energy will be liberated. This energy will be utilized for the cell maintenance or the energy liberating reactions of the cell that is known as catabolism and anabolism is the one which utilizes the organic matter or the carbon available in the waste and the microorganisms will be creation or generating or synthesizing new cells.

The energy required for this one is coming from the catabolism process because of a series of oxidation reduction reactions. Or in the substrate level oxidation reduction so much of energy will be liberated and this energy will be stored in the cells in the form of ATPS. And by hydrolysis of this ATP the energy will be liberated and this energy will be utilizing for the cell synthesis. So any microbial process we will be having this catabolism and anabolism. Because of the anabolism more cells will be synthesized.

Therefore, when we talk about the oxygen requirement the organic matter whatever is getting converted to new cells will not be getting oxidized so, for that one oxygen is not required. How can we find out the total oxygen requirements in an activated sludge process? We can find out what is the net biomass production in the system. At steady state we assume that net biomass production in the system is zero that means amount of biomass synthesized for the given amount of time is equal to amount of biomass wasted from the system. That is the steady state condition.

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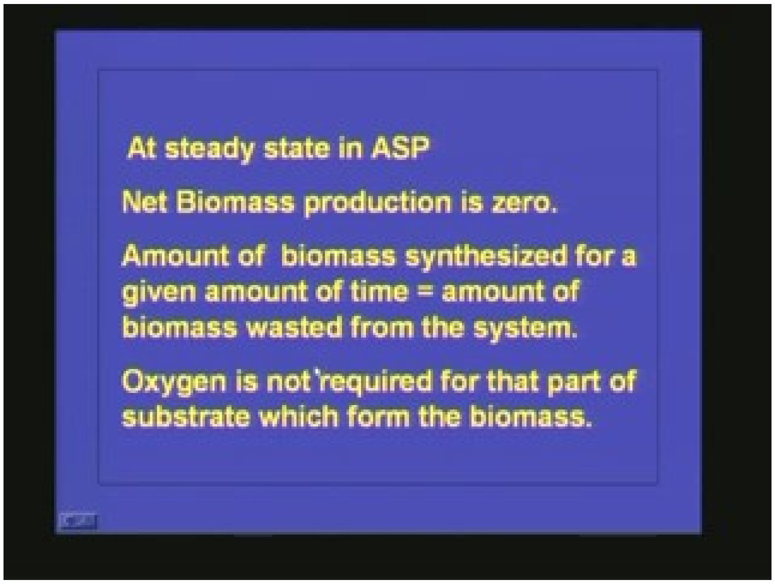

Oxygen is not required for that part of substrate which form the biomass because that is not undergoing any further oxidation, it will be getting more complex and the biomass will be generated. So how can we find out what is the portion of the organic matter that is going for cell synthesis. That we can get from the yield coefficient. Yield coefficient is nothing but per unit substrate consumption, what is the biomass yield that is the yield coefficient.

We know that some portion of the organic matter is going to be used for the cell synthesis. How can we find out, what is the oxygen that is not required for this cell synthesis? We were told that the oxygen requirement is nothing but q into BOD influent minus BOD effluent. From that one we have to detect this portion whatever is going for the cell synthesis? So, for that one we have to find out what is the general formula of a cell and from that one we can find out what is the oxygen required for the complete oxidization that organic compound and if we know that, that much is going as cell we can detect that amount exactly from the oxygen requirement if the entire system is going to get oxidized. So the empirical formula for biomass is reported like this; $C_5H_7NO_2$. So how can we get this one (Refer Slide Time: 7:35) this is based upon the CHNO analyzer, Carbon Hydrogen Nitrogen Oxygen analyzer.

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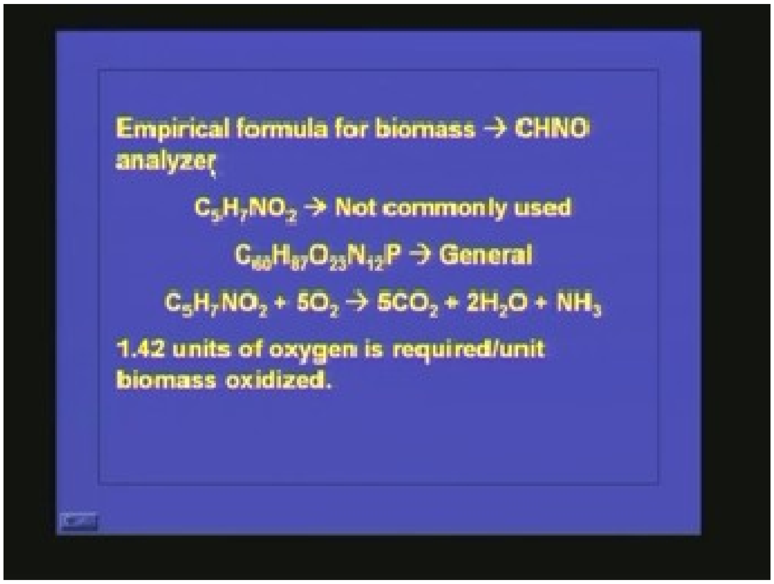

So you take the cell or the biomass and analyze for what is the percentage of carbon present, hydrogen present, nitrogen present and oxygen present using the CHNO analyzer then we can make an empirical formula. This is the simplest formula available for a biomass C5H7NO2. But this is not very commonly used because we know that phosphorus is a high essential element for the microbial cell. In this formula there is no phosphorus available. So the most commonly used formula is this one; C60H87O23N12 and P. That means one biomass cell or one microbial cell will be having 60 carbon molecules, 87 hydrogen atoms, 23 oxygen, 12 nitrogen atoms and 1 phosphorus.

So, if you take the simple formula for the microbial cell that means C5H7NO2. You can find out what is the total oxygen required for the oxidation of the cell because we have incorporated this oxygen requirement also in the initial formula that means q into BOD of the influent minus BOD of the effluent. So if we can find out what is the oxygen required for the complete oxidation of this one that much we can detect from the initial value then we will be getting the total oxygen requirement in the system.

So if you want to find out what is the total oxygen required for a complete oxidation of the system what we have to do is we have to convert carbon completely to carbon dioxide, hydrogen to water, nitrogen to either ammonia if we are stopping at the carbonaceous stage. But if you want to go for complete oxidation that ammonia has to be taken or converted to nitrate. So this will be the final formula; $C_5H_7NO_2$ plus 5O2 will be giving five carbon dioxide plus $2H_2O$ plus ammonia. Here we are considering only up to this stage we are not going for the nitrification. So if you see this one around 1.42 units of oxygen is required per unit biomass oxidized.

If you take the molecular weight of this one this is equivalent to 5 into 32 so from this one we can find out around 1.42 unit of oxygen is required per unit biomass oxidized.

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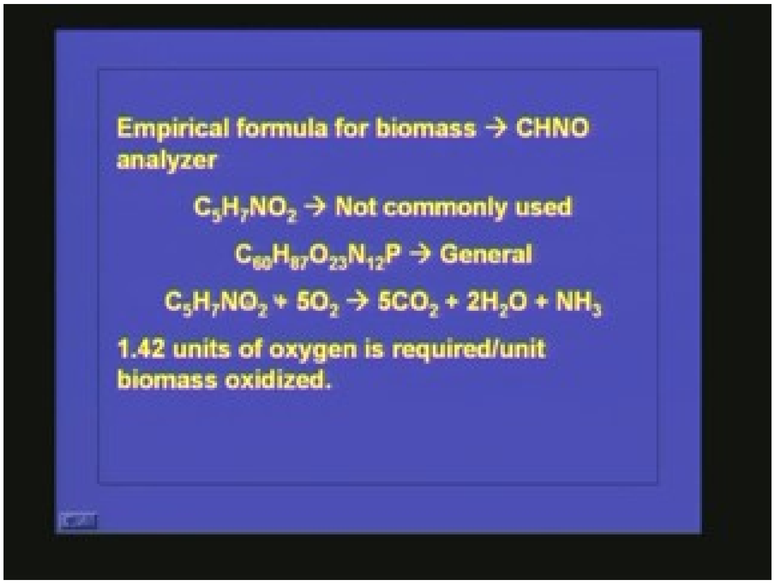

So in any system if you want to find out the net oxygen requirement that is equal to total oxygen required minus 1.42 times total biomass present in the system. In the last class we saw what is the total biomass produced in the system so delta O2 means the oxygen requirement in the system is nothing but q into S0 minus Se S0 is the initial BOD; Se is the effluent BOD minus 1.42 times delta x. Or this one we can write again this; q into S0 minus Se minus 1.42 into y observed which is the observed yield coefficient.

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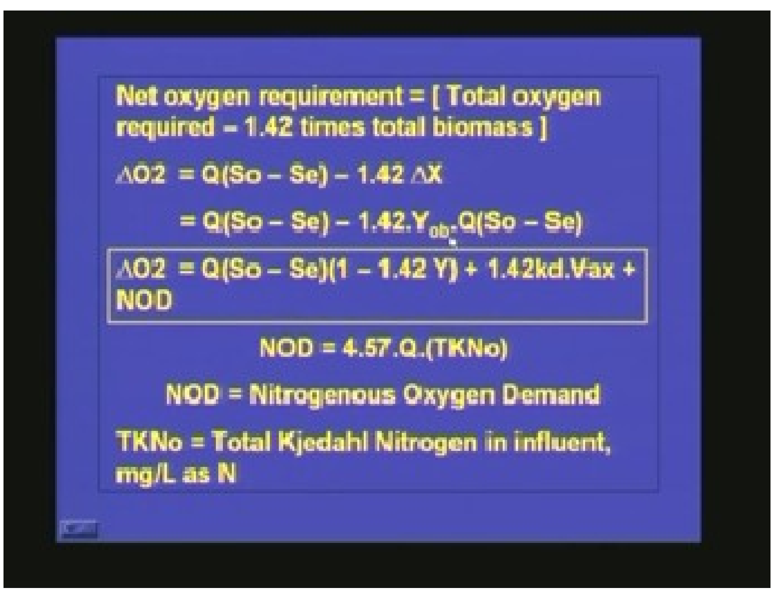

That means total yield coefficient is there, we are taking care of the decay part so that will be the observed yield coefficient. So, y observed into q into S0 minus Se. Or we can write in another way; delta O2 is equal to q into S0 minus Se into 1 minus 1.42 y. So we take it as yt plus 1.42 into kd into va into x plus NOD. So this formula shows we are considering the y total here. That means what is the actual yield coefficient plus this one (Refer Slide Time: 11:30) again we are taking because kd into vax is the amount of biomass that is undergoing decay or endogenous respiration. That means the biomass is getting oxidized. So the same formula whatever we have seen earlier we can use the same thing.

If we want to oxidize the particular amount of biomass then we have to supply 1.42 units of oxygen per unit of biomass that is why this is coming like this and NOD is nitrogenous oxygen demand. Nitrogenous oxygen demand is ammonia. When ammonia is oxidized in the presence of certain microorganisms then the final end product will be nitrate. So, for that one if you have one unit of ammonia we need 4.57 units of oxygen. This we will see in detail when we talk about nitrification and denitrification. We will be seeing in detail about what is the nitrogenous oxygen demand.

The total oxygen demand is nothing but q into S0 minus Se into 1 minus 1.42 yt this is the total yield coefficient plus 1.42 kd vax kd is the decay coefficient plus NOD. NOD is the nitrogenous oxygen demand, and TKNo is nothing but the total Kjedahl Nitrogen in the effluent which is expressed in terms of milligram per litter as nitrogen. So if you know the total nitrogen present in the system and total BOD that means influent BOD effluent BOD and if you know the bio kinetic parameters like yt and kd we can find out the total oxygen requirement.

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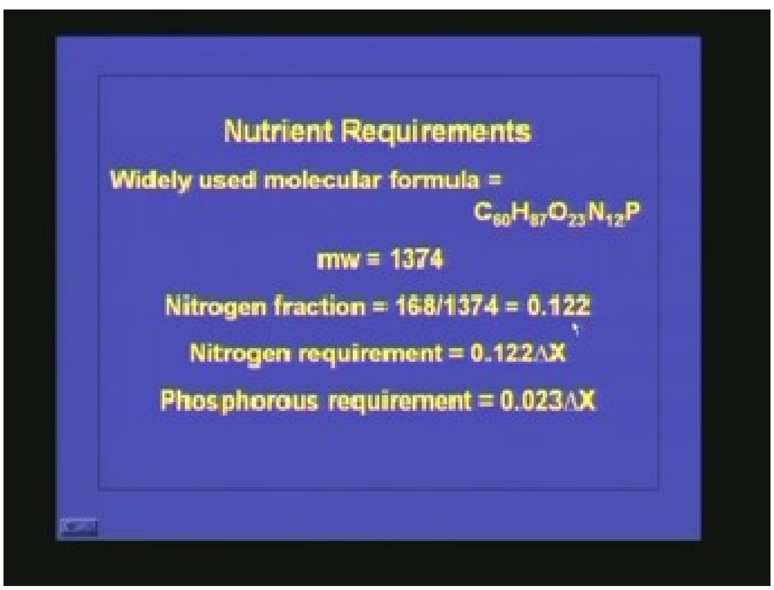

Whenever we go for any aerated design that aerator should be able to supply this much of oxygen to the system at any time that is the basic design criteria. Now we will see that any biological system for the growth of microorganisms should have nutrients. We should supply enough nutrients to the system because in the empirical microbial formula itself we have seen that carbon is present, nitrogen is present, oxygen is present and apart from that one nitrogen and phosphorus are there. And if you take the biomass and if you burn it we will be getting around 6 to 14% ash. This ash mainly contains phosphorus, sodium, potassium, calcium etc or chloride because all these nutrients or all these elements are present in micro or macro quantities in microorganisms.

So if the microorganisms have to grow properly we have to supply these nutrients that are adequate for the cell growth. And whenever we take the microorganism or the sludge if you burn it all the carbon will be converted to carbon dioxide nitrogen will be converted to nitrogen gas and hydrogen converted to H_2O so the remaining ash whatever is present is the micro and macro nutrients present in the system.

How can we find out what is the nutrient requirement in the system?
Here also we have to use the empirical formula for the microbial system. The most widely use molecular formula as we have already seen is $C_{60}H_{87}O_{23}N_{12}P$. So if you find out the molecular weight of this one that means 60 into 12 plus 87 into 1 plus 23 into 6 plus 12 into 14 plus phosphorus we will be getting 1374. The molecular weight of this compound is 1374 grams. And if you want to find out what is the nitrogen fraction it is nothing but 14 into 12. So nitrogen fraction we can find out 14 into 12 divided by the total molecular weight that means 0.122. That means if you take 1 gram of the biomass it will be containing 0.122 grams of nitrogen.

That means if you want to generate cells in the system apart from carbon and hydrogen and oxygen we are supplying anyway we have to supply enough nitrogen and phosphorus to the system otherwise the cell growth will not be proper or cell growth will not be taking place. So if the wastewater is not having the nitrogen we have to supply nitrogen in this ratio. That means per gram of biomass generated we have to supply 0.122 grams of nitrogen or nitrogen requirement for the entire system is equal to 0.122 into the total biomass that is going to generate in the system.

Similarly we can find out what is the phosphorus requirement. So here we can take the molecular weight of phosphorus divided by 1374 we will be getting 0.023 and total phosphorus requirement is nothing but 0.023 into delta x because delta x is the entire biomass that is going to be generated in the system. So, whether the nutrient requirement in a system is always a constant? It is not. Whether we have to supply these nutrients externally all the time? The answer is no because whenever we talk about the wastewater especially the domestic wastewater it will be containing lot of nitrogen and phosphorus most of the times in excess of the requirement of the microorganisms so we do not have to supply any nitrogen or phosphorus to the system.

But whenever we go for industrial wastewater treatment especially the system which does not have any nitrogen or phosphorus we have to supply nitrogen and phosphorus externally, that is why the ratio is very very important. We have seen that the ratio is 0.122 and 0.023 and we should know whether it remains constant in a particular system, most of the time it will not remain as a constant because it is a function of the biological sludge retention time. When we were discussing about the process modification of activated sludge process we have seen that in certain systems the cell generation or the net cell production is very very minimal. But in certain other system the cell generation is very high.

For example, in high rate activated sludge process the cell generation is so high. More than 50% of the organic matter whatever we are supplying to the system is getting converted as microbial cells. But when we talk about extended aeration system the net cell production is zero or the mu of the specific growth rate of the system is zero. That means the net production is zero, ultimately no microorganisms is generated in the system.

If there is no microorganism generation in the system naturally the nutrient requirement will be almost zero because whatever nutrient is available in the system initially the microorganisms will be utilizing them for the synthesis of the cells and those cells whatever is generated will be undergoing auto oxidation and again the nutrients will be released to the system and for the new cells synthesis the same nutrients will be available. So the net nutrient requirement for the system will be 0. That is what this graph shows.

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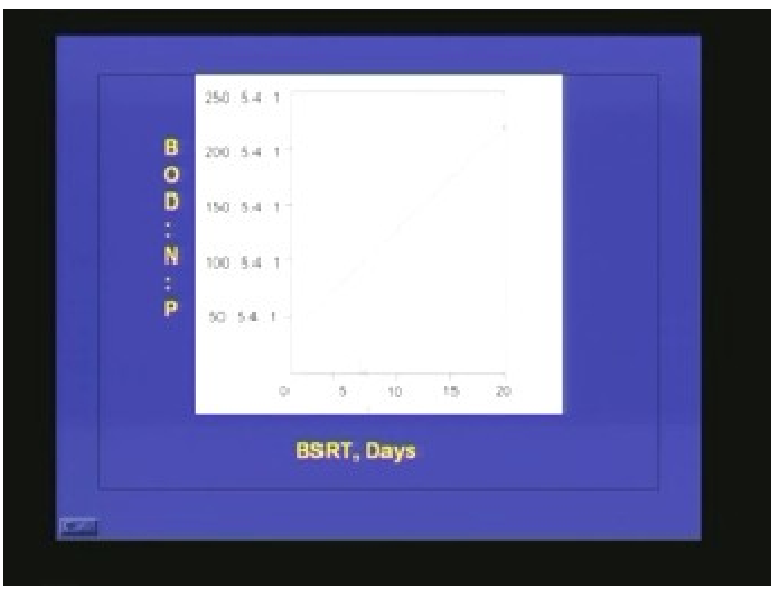

How the nitrogen phosphorus and BOD ratio changes with respect to the biological sludge retention time?
As the biological sludge retention time increases we can see here BOD is to nitrogen is to phosphorus ratio also increases. If the BSRT is very very low that means just like a high rate activated sludge process the BOD is to nitrogen is to phosphorus ratio is 50 is to 5.4 is to 1 that means we have to supply more nitrogen and phosphorus compared to the BOD. But as the BSRT increase we can see that it is coming to 100 is to 5.4 is to 1 then 150 is to 5.4 is to 1 and 200 is to 5.4 is to 1. So depending upon the process modification

or depending upon the nature of the process we are choosing, the nutrient requirement also will change. So when we talk about the nutrient requirement and the nutrient present in the system depending upon the requirement we can select the process according to our convenience. What I mean is, if some industrial wastewater is there and there is not sufficient nutrient present in the system and external addition of this nutrient is costly so we can go for a system which requires least nutrients that means extended aeration system. So, depending upon the nutrient availability and the requirement we can make the choice according to our convenience. Now we will talk about the solid liquid separate process in activated sludge process.

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We have seen that in an activated sludge process unless the solid liquid separation is there we cannot call it as treatment process because in aeration tank only the conversion of soluble cod or soluble BOD to colloidal solids or colloidal BOD is taking place. Because the organic matter whatever is present in the system is getting converted to new microbial cells and that new cells will be remaining in the system. So, if you take the BOD of the sample from the aeration tank it will be almost same as that of the influent.

Some reduction will be there because whatever is getting oxidized for the catabolism process whatever is converting to carbon dioxide and water during the catabolism process that much of reduction will be there in the BOD. But whatever is converted into a cell will be remaining the system and that will be contributing to the BOD. So if you not have a sedimentation tank after the aeration tank your treatment efficiency will be very very less in an activated sludge process. So, solid liquid separation process is very very essential in an activated sludge process.

We have seen that the microbial growth stage is also important for this solid liquid separation process. Because if the microorganisms are in the low growth phase what will happen is they will be staying as discrete particles or the flocculation of the particle is almost impossible. But if they come to the stationary phase or endogenous respiration phase or the end of the stationary phase the microorganisms start secreting or producing extra cellular polymers that will be acting as natural biopolymers which enhances the flocculation of the system or flocculation of the microbial cells. Once the flocculation take place then it is very easy for the solid liquid separation process.

Now we will see in detail on how we can design a solid liquid separation system for an activated sludge process. When we come to the sedimentation tank design of for an activated sludge process or the secondary sedimentation tank design we have to meet two criteria; one is to produce clear effluent to meet the effluent discharge standard, the second one is to concentrate the biological solids to minimize the quantity of sludge that must be handled.

So whenever we go for design these two objectives should be satisfied. So how can we satisfy these two objectives? The **tarification** is based upon how fast the particles are settling but the thickening is entirely different from that one because it will be settling but if the settled sludge volume is very high then the sludge handling will be so difficult. Moreover, whatever sludge is generated in the activated sludge process it is active biomass so we cannot discharge them into the sludge drying beds but we have to go for further treatment which can stabilize the sludge. Therefore it is always advisable to have the minimum volume of the sludge then we can reduce the volume of the sludge digester or any further treatment whatever we are proposing to take care of the sludge.

Now we will see in detail how can we go for the design of the secondary sedimentation tank to meet these two objectives that means clarification as well as sludge thickening. In the initial classes we discussed that the settling can be classified into four different categories; one is type one settling, second one is type two settling, the **zone** settling and compression settling. So whenever we talk about the secondary sedimentation tank of an activated sludge processes the sedimentation tank or the settling is coming under zone settling and compression settling.

Zone settling is taking place when we talk about the clarification and compression settling is coming into picture when we talk about the sludge thickening. Here zone settling is taking place because the particles whatever is present or whatever is coming to the secondary sedimentation tank is flocculent in nature. And if you see the concentration of the particle it is very high. We discussed already that the MLSS concentration in a conventional activated sludge process varies from two thousand to five thousand milligram per liter so the concentration of the suspension is relatively high and the particles are flocculent in nature.

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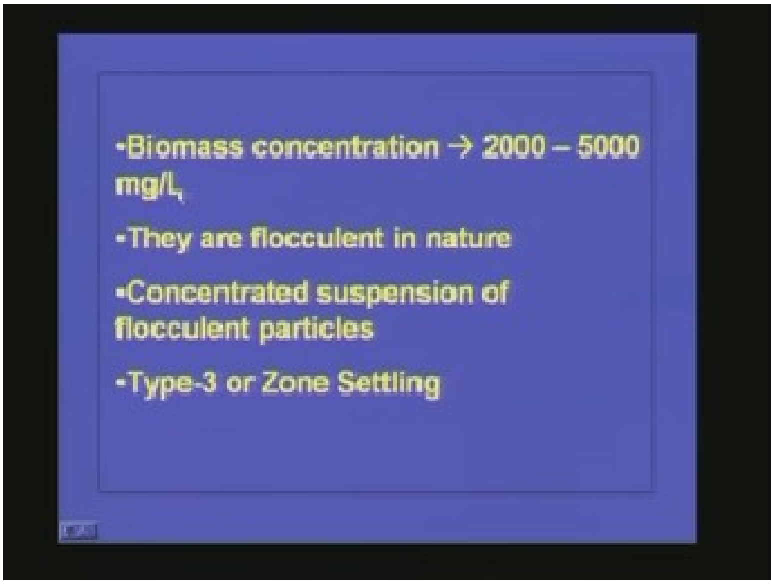

- Biomass concentration varies from 2000 to 5000 milligram per liter
- Flocculent in nature
- Concentrated suspension of flocculent particles
- It is coming under type 3 or Zone Settling

How can we go about for the design?
Here also we have to conduct the batch analysis.
How can we conduct the batch analysis?
The batch analysis can be conducted in measuring cylinders or small settling column. This is the settling column so what we have to do is first fill the settling column with the sludge which is having the same concentration as that of the activated sludge process say two thousand to five thousand milligram per liter. Hence, the sludge we are taking here and this is the time (Refer Slide Time: 26:35) so what we have to do after that is with respect to the time find out what is the position of this sludge.

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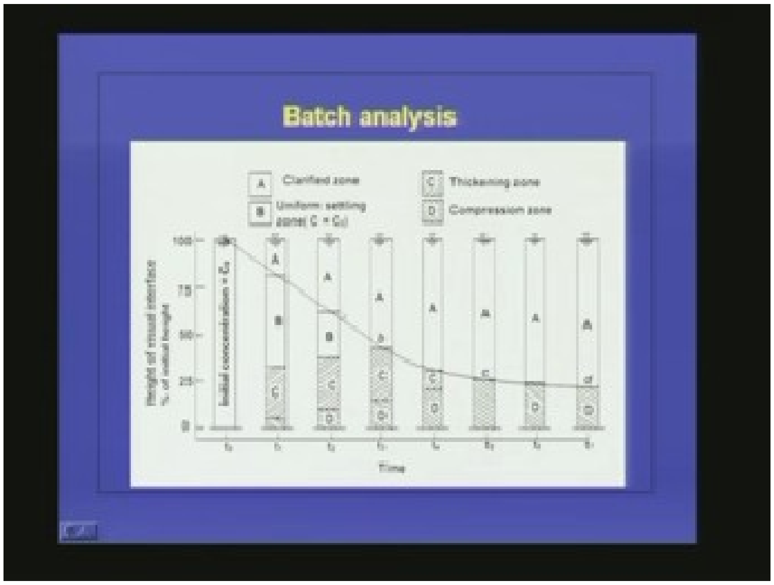

So we will be observing different zones in the settling. This is the air portion this is the clarified **zone** and another zone will be there which will always maintain the same concentration of the sludge whatever we have introduced in the first column and we will be having a compression or thickening zone here and the bottom most portion is the compression zone.

So with respect to time we have to find out what is the depth of this clarified zone. That means we will be having a very clear zone as well as a zone which is having the same thickness of the particles as we have introduced. So we will be taking the depth of the clarified zone with respect to time till there is no increase in the depth or there is no increase in the depth of the clarified zone. So here it is very very clear. This (Refer Slide Time: 27:40) is the initial stage when the initial concentration of the particle is equal to C0.

After time T1 the clarified zone is coming out up to here and entire sludge is settling as a blanket that is why it is known as zone settling. So the clarified zone is coming up to here so we know what is the height of the clarified zone then at T2 again we are taking the height of the clarified zone and like that we are going on and after sometime we can see that this depth is not increasing considerably or the curve is becoming almost flat so this information we can use for the design of the clariflocculator.

That means this portion this (Refer Slide Time: 28:26) clarified zone represents how we can get the clear effluent from the settling tank and this portion will tell us how much concentrated sludge we can produce using the settling column or using the sedimentation tank because we are using the same data for the design of the sedimentation tank so it will be able to tell us what is the effluent quality or what is the area required for getting

the effluent quality and what is the area required for getting the desired sludge concentration. Now let us go into the detail of the analysis.
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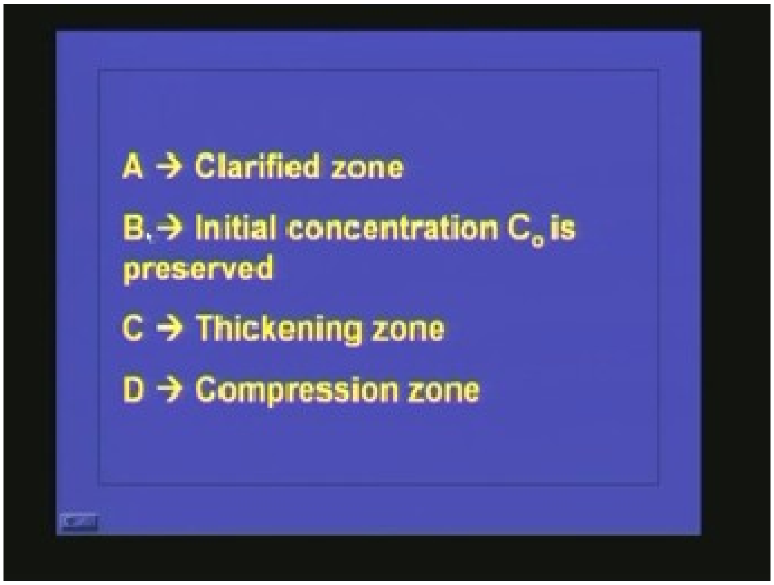

I have already discussed about the different zones visible in the settling column analyses. A is the clarified zone; B is the zone where initial concentration C_0 is preserved. That means always the same concentration will be there and C is the thickening zone and D is the compression zone.

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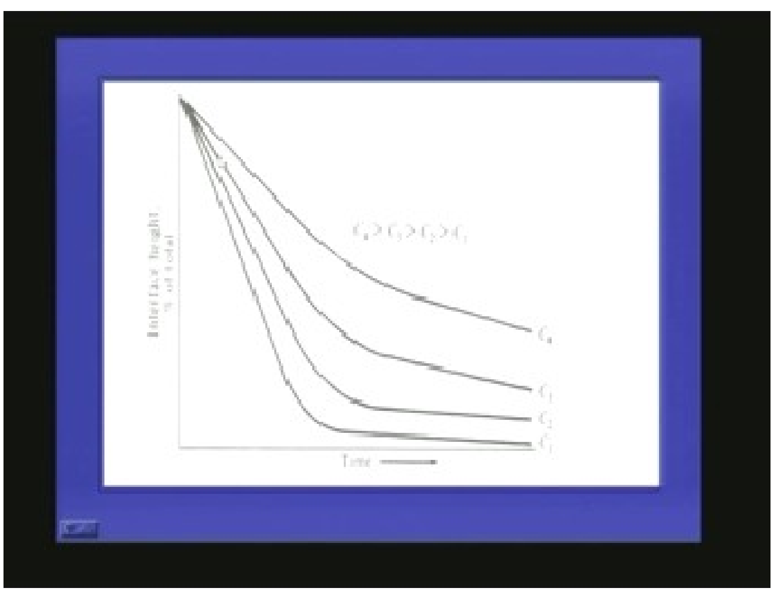

Therefore if you put different concentrations of the sludge in the settling column because as I have told you whatever sedimentation tank we have to design we have to take the same sludge concentration of that in the aeration tank for which we are going to design the sedimentation tank. We have seen that the sludge concentration can vary from two thousand to five thousand. So what will happen if the sludge concentration varies? The settling column experiments or the curve's nature will be something like this (Refer Slide Time: 29:58) if the concentration is very low the initial settling will be very fast so we will be getting a curve something like this and as the concentration increases the curve will be coming like this.

Here we can see C_4, this is having maximum concentration and C_1 is having the least concentration. So if the sludge is having less concentration the clarification will be very very fast because this is the slope that gives the settling velocity of the particle. Now if you have the settling column analysis data, and since we will be doing the experiment with a particular concentration finally we will be getting a curve something like this (Refer Slide Time: 30:38) and this is the portion where the compression is taking place and it will be becoming asymptotic to the x axis. So what we have to do is draw tangents to this straight line portion and this asymptotic portion. That will be acting at a point say here O.

Here the O point is coming by drawing tangents to the top portion where it is a straight line and draw a tangent to this portion and draw tangent to this asymptotic portion that will be meeting at a point here say point O then draw an angular bisector to this point that will be meeting the curve at point A then draw tangent to this line, tangent to this curve through the point A. This is the tangent.

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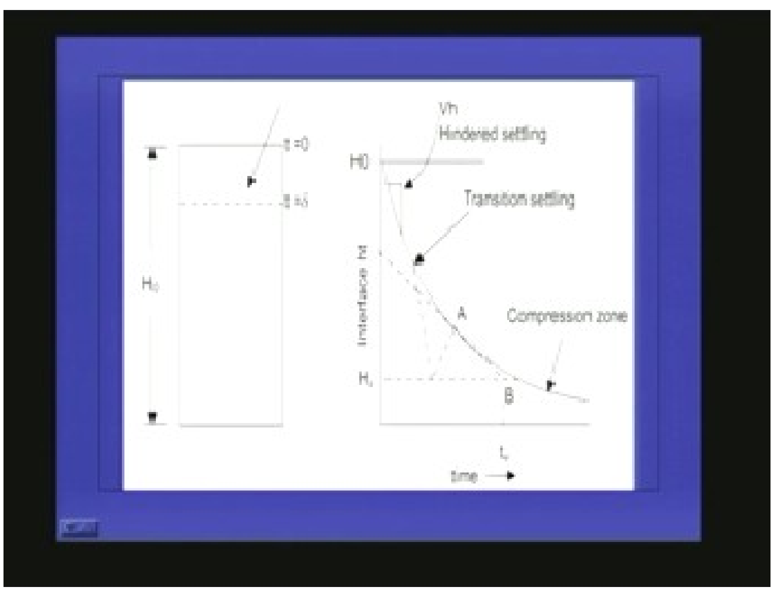

Now using this information how can we design the system? In this curve itself we can see different portions. This portion the straight line portion gives the hindered settling, or if you take the slope of this portion that will give you the hinder settling velocity Vh. This velocity is very very important for the design of the sedimentation tank for clarification purpose and this is the transition zone (Refer Slide Time: 32:07) and this is the compression zone.

Now we have this point A and we have the tangent and we have the initial height of the settling column. Now how can we go about it? The area of the clarifier is nothing but Q by Vh that is the area. So, Q is the flow rate and Vh is the index settling velocity so we can find out what is the area required.

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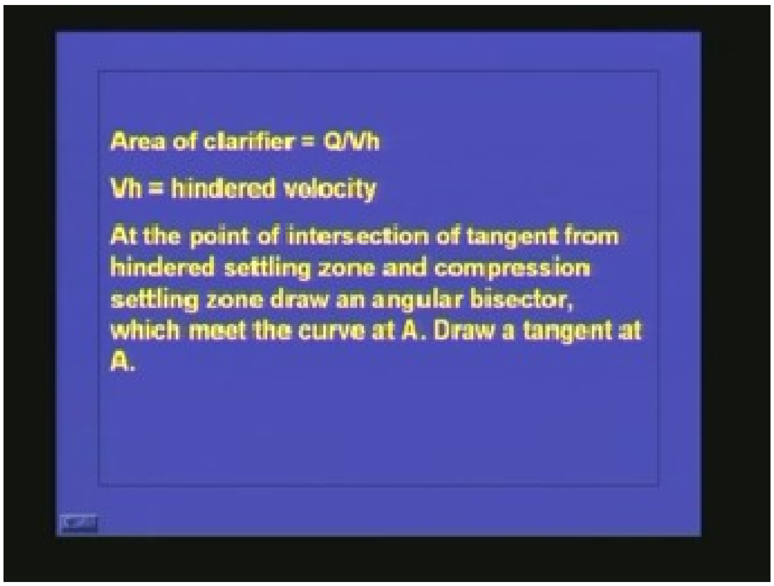

At the point of intersection of tangent from the hinder settling zone and compression settling zone draw an angular bisector which meets the curve at A. This has been already discussed. Now how can we go ahead? We have to make the mass balance of the entire system. We know that initially the concentration of the sludge was C_0 that means say it is between 2000 to 5000 milligram per liter and the total height of the sludge volume is say H0 that means that is the height of the settling column. But after a particular time what is happening the entire zone will be settling or entire sludge will be settling and you will be getting a considerable amount of clear water and entire sludge will be occupying only a small volume say Hu that we can find out from the system and Cu is the concentration at that time so how can we find out Hu. Therefore Hu is equal to C0H0 by Cu. because at any time C0H0 is equal to CuHu. We are not removing anything from the system the total sludge volume will be remaining as a constant.

How can we get cu? Here Cu will be your design sludge concentration. So, from this one we can find out what is the Hu value where Hu is nothing but C0H0 by Cu and Cu is the desired sludge concentration we need from the secondary clarifier.

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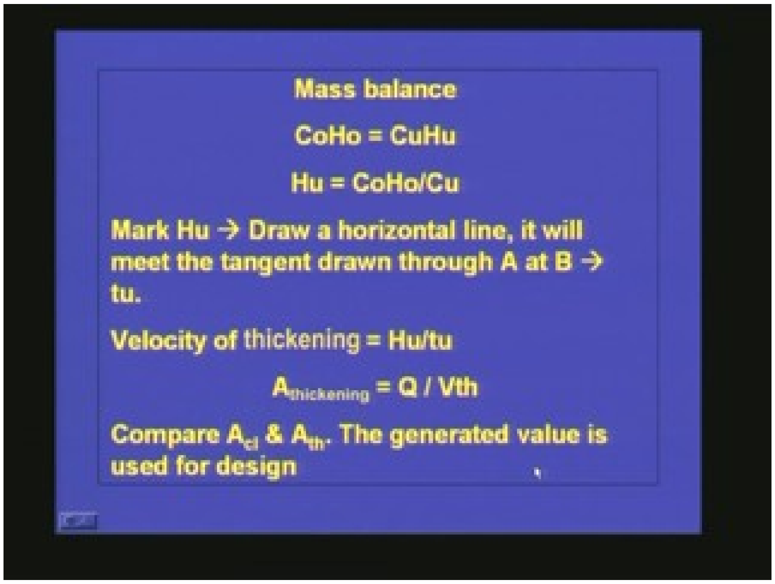

So Hu is available, this is your Hu so you mark it in Hu then draw a horizontal line through Hu and we will be getting a point where the tangent which has gone through this A meeting this horizontal line say B. From B drop a perpendicular that will be meeting your time axis at Tu, so this is the time required for that much of sludge thickening to take place so you can find out the velocity of thickening. We have seen what is the hindered settling velocity and what is area required for the clarification purpose.

Now we have to find out what is the area required if you want to get a particular amount of thickening. So the velocity of thickening or thickness is equal to Hu by Tu because Hu is the high and Tu is the time available. So velocity is nothing but the distance by time so we get the Vth this is nothing but velocity of thickening so we can find out what is the area of thickener. The area of thickener is nothing but Q divided by velocity of thickening. so we have got two areas; one is A for thickening and another is A for clarification so two areas are there. You can compare these two areas and if you want to meet both the purposes we have to provide the area which is maximum then only we will be able to meet both the criteria.

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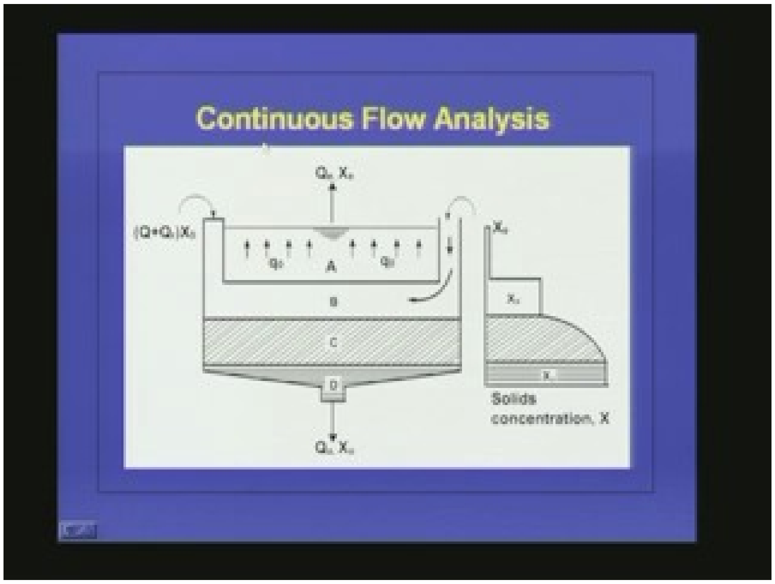

Another way of finding the area is continuous flow analysis, because in batch system we are not considering any under flow. but in any conventional activated sludge process we take, the sedimentation tank will be operating in a continuous mode and the sludge will be withdrawing in a continuous mode so always the effluent will be going from the system and the sludge will be collected always from the bottom of the tank so two forces are acting on the sludge. Because of this withdrawal of the sludge there will be some velocity in which the sludge will be coming down and another one is the weight of the particle or because of the gravity force some thickening will be taking place. So if you want to take both the things into account we can use the flux theory for the design of the secondary sedimentation tank.

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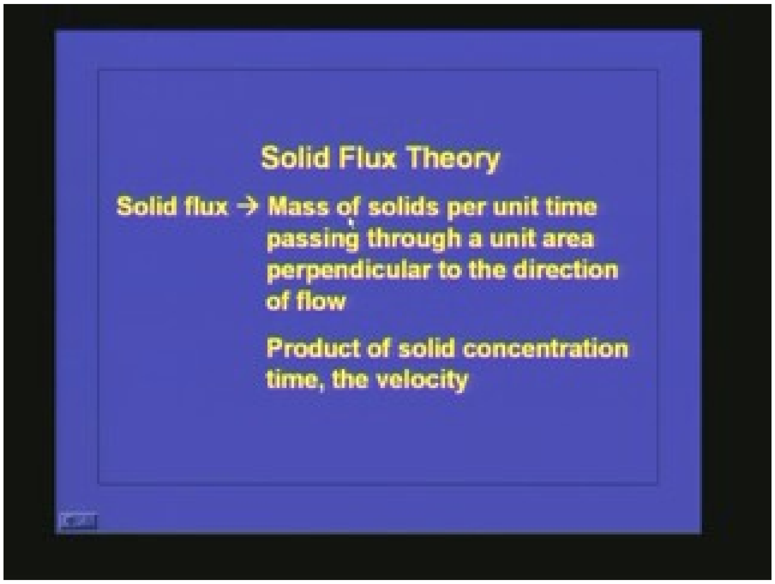

What does this solid flux theory says?
Before going into the solid flux theory we will discuss what solid flux is. Solid flux is nothing but the mass of solids per unit time passing through a unit area perpendicular to the direction of flow. That means the amount of particle or mass of the particle passing perpendicular to the cross sectional area at a given time is known as the solid flux. So, whenever we talk about a sedimentation tank which is having underflow constantly then the flux will be because of the under flow velocity as well as because of gravity. So we have to consider both the things together. So product of solid concentration and velocity gives you the solid flux.

Downward velocity is having two components the transport velocity due to the withdrawal of the sludge and the gravity settling of the solids relative to the water. So transport velocity is a function of underflow rate and area of the tank. This is because your sludge withdrawal pipe will be having much lesser diameter compare to the sludge thickener so the underflow concentration will be depending upon the underflow velocity because velocity will be calculated based upon the pipe diameter with which we are withdrawing the sludge and the area of the clarifier because the flux is nothing but what is passing through a unit cross sectional area in the perpendicular direction so if the clarifier area is more then flux will be less.

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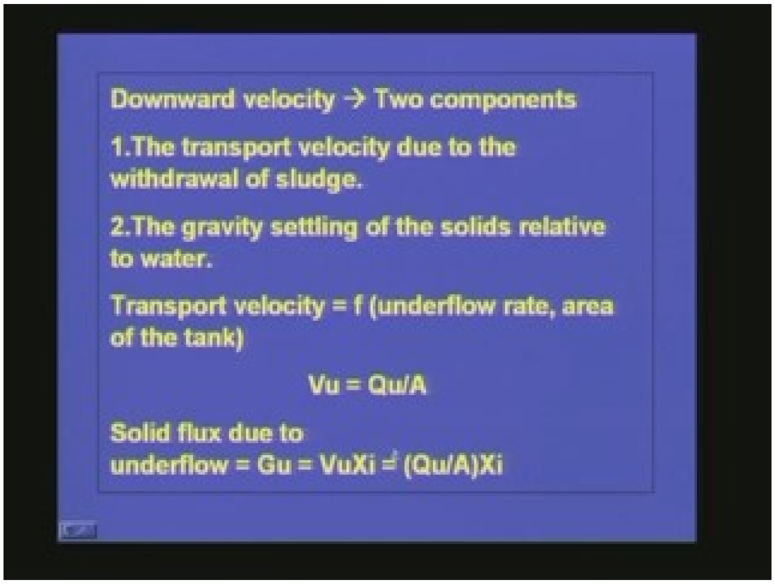

The transport velocity vu we can calculate using this formula Vu is equal to Qu divided by area where Qq is the underflow rate. So solid flux due to underflow we can write like this; Gu is equal to Vu into Xi that is nothing but Qu by A into Xi where Xi is the concentration of the sludge whatever is present in the tank and Qu is the flow rate and A is the area of cross section.

We have already seen that solid flux due to gravity we can calculate using this formula; Gg is equal to vVg into Xi and Vg is the velocity because of the gravity. So total solid flux Gt is equal to Gu plus Gg.

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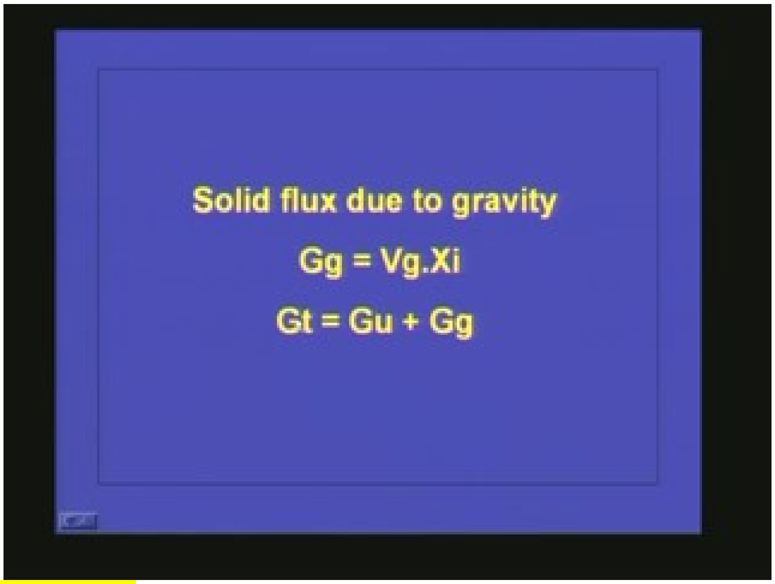

I will explain once again.
We have a clarifier where the underflow is also taking place and we know what is the rate at which the sludge is withdrawing from the sedimentation tank and the sludge is settling down and because of the sludge weight itself there will be some settling velocity that is known the gravity velocity. So whenever we consider the sludge settling there are two components; one is because of the underflow and another one is because of the gravity. So whenever we consider a particular cross section the total solid flux is the sum of the solid flux due to the underflow and the solid flux due to the gravity.

Solid flux due to gravity can be calculated using this formula Vg into Xi where Vg is the velocity due to gravity and Xi is the concentration of the sludge and Gu is nothing but Vg into Xi and VG is nothing but the underflow velocity that is Qu by A. Now how can we go around for the design?

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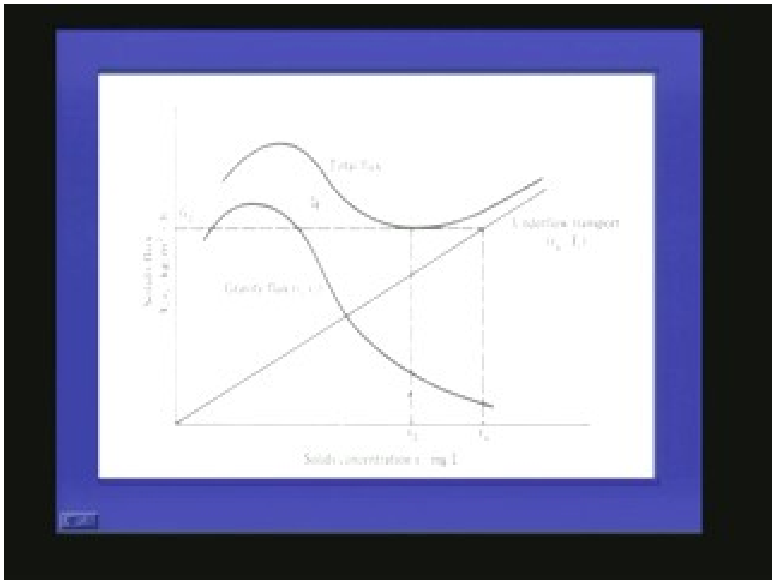

We can use the graphical method. There is analytical solution also to find out what is the area required to achieve a given sludge thickening. So here the y axis gives the solid flux. Solid flux is nothing but the sum of the gravity flux and the flux due to underflow. And here (Refer Slide Time: 40:55) we can get the solid concentration. This line here gives the solid flux due to underflow because V is a constant and Xi keeps on increasing so you will be getting a line something similar to this one. And this is the solid flux due to gravity.

So what will happen? Initially it is low then it is increasing then it is decreasing. Why this particular shape is coming is because initially the concentration of the solids are relatively low compared to these portions but the settling velocity or the gravity velocity is high. The flux is nothing but the product of concentration and the velocity. so here the value will be relatively low but as the concentration increases the reduction in the velocity is not so considerable compared to the increase in the concentration so naturally the product will be high so that will be continuing for certain extent for a particular value of Xi then afterwards what will happen is though the concentration of the sludge increases the velocity with which it is compressing it will be decreasing. The reason is the sludge is so thick so it is not able to compress it much more. So the velocity with which it is compressing or with which it is settling will be very very less so naturally the product of Vi and Xi is coming down as you see in portion and finally it will be becoming almost asymptotic like this.

Now we will see how the total flux will be looking like. So this is the flux due to underflow transport because Vu is remaining as a constant and Xi keeps on increasing so you will be getting a straight line as something like this and this is the gravity flux. So the total if you take the gravity flux plus underflow transport we will be getting this point here and that corresponding to this distance plus this height is the total flux so we will be getting a total flux curve as something like this (Refer Slide Time: 43:04). Therefore, how can we use this data for the design of a secondary sedimentation tank.

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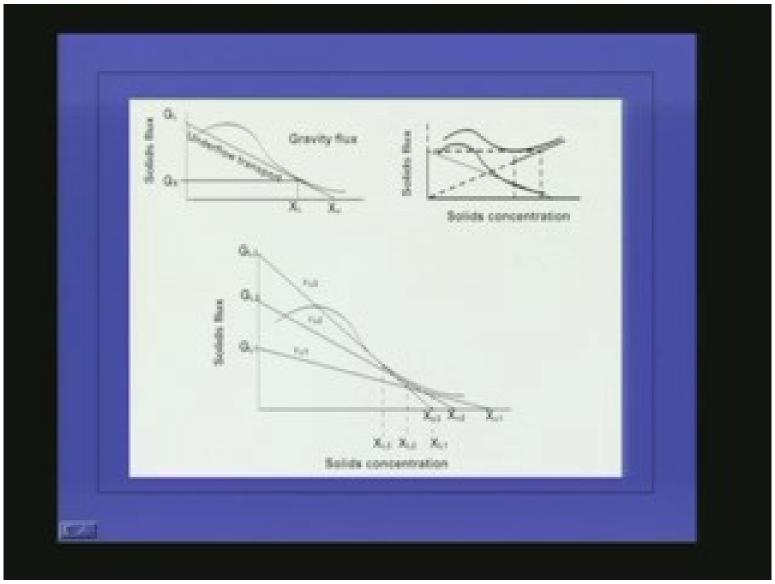

Yoshika suggested an easy graphical solution method for this solid flux using graphical method. What he has done is he has taken the gravity flux alone by considering the similar triangle theory. So your gravity flux is coming as something like this and the flux due to underflow is coming like this. And if you take the sum of these two things we will be getting the same thing. So here the triangle was like this and your gravity flux was like this so take the same triangle this side so you will be getting underflow transport like this and the gravity flux like this.

Now how to use this information for the design. We want to get an underflow concentration of Xu1 that means this much is the sludge concentration we need when we withdraw the sludge from the thickener. So what we have to do is you have the gravity flux line here so draw a tangent to this gravity flux line so it will be touching this point and it will be cutting the solid flux line at some point. For different concentrations we will be getting different points. For Xu1 you will be getting Gl1 and Xu2 you will be getting Gl2 and Xu3 you will be getting Gl3. So this Gl1 Gl2 Gl3 is known as the limiting solid flux that is the maximum flux we can get for that underflow concentration.

Therefore, using this information we can find out what is the area required for the secondary sedimentation tank. We know what are the total solids coming to the system. We know what is the flow rate Q and we know what is the sludge concentration in the influent so we can find out what is the total solid loading to the sedimentation tank. Thus, if you know the total solid loading to the system and unit of the solid flux is kilogram per hour per meter square that means kilogram per time and area so if you know total solids loading and the limiting solid flux we can find out the area required.

One interesting thing from this graph is we are drawing a tangent here and where the point is where this line is meeting the gravity flux curve. If you find out what is the solid flux corresponding to that one that will give you the gravity solid flux and this portion will give you the solid flux due to underflow. This is very very important this is the gravity solid flux and this is the solid flux due to underflow so we can find out what is the area required and the area required for the clarifier for the clarification purpose we can get from the hinder settling velocity.

Here is the summary of this secondary clarifier design. The important objectives are effluent clarification and the sludge thickening. Conduct laboratory experiments and get necessary data and based on this do the design.

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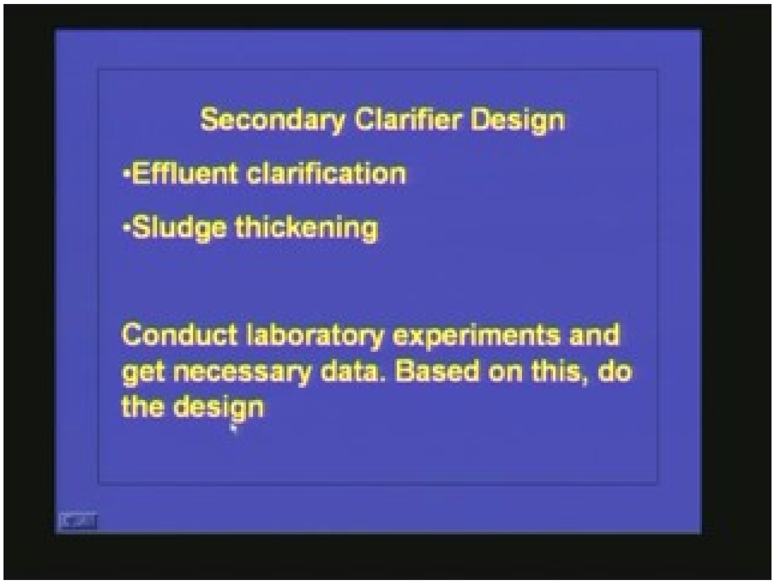

Now we have seen now what the nutrient requirement is, what is the sludge production and what is the loading rate requirement and how much oxygen required and how we can separate the solids and liquids in an activated sludge process. Now we have to discuss about how we can supply the oxygen required for the activated sludge process because unless enough oxygen is supplied to the system the system performance will be coming down drastically. We have calculated the total amount of oxygen required that is nothing but Q into So minus Xe that means the flow rate multiplied by the BOD removed in the system minus whatever is converted into the biomass. So what is the requirement of the aeration?

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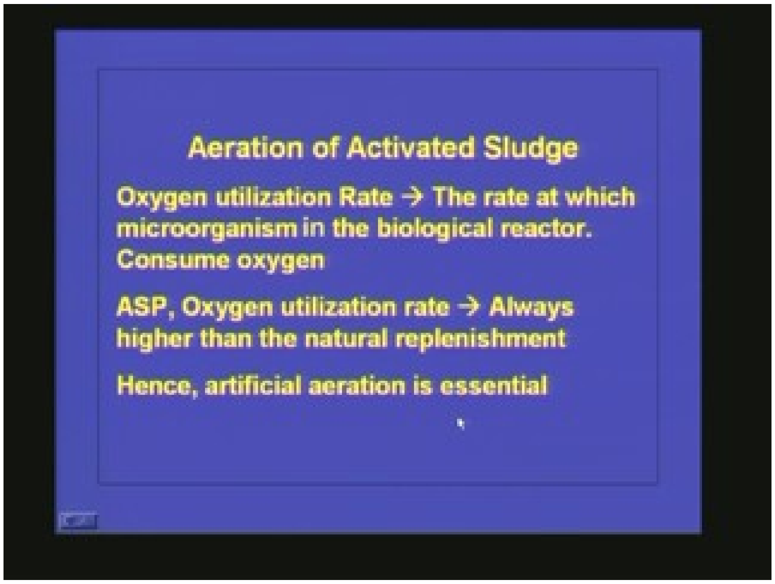

Oxygen utilization rate of the activated sludge process is much higher compared to the oxygen whatever is transferring into the system. The rate at which the microorganisms in the biological reactor consume oxygen is known as Oxygen utilization rate or it is known as OUR. In any activated sludge process oxygen utilization rate is always higher than the natural replenishment rate hence artificial aeration is essential. We have to meet the oxygen utilization rate in whatever way we can to get the maximum efficiency so natural aeration will not be able to provide that rate then what is the other way is we have to go for some mechanical devices. We will discuss in detail about what are the requirement in oxygen for different systems of activated sludge process or different modifications of activated sludge process.

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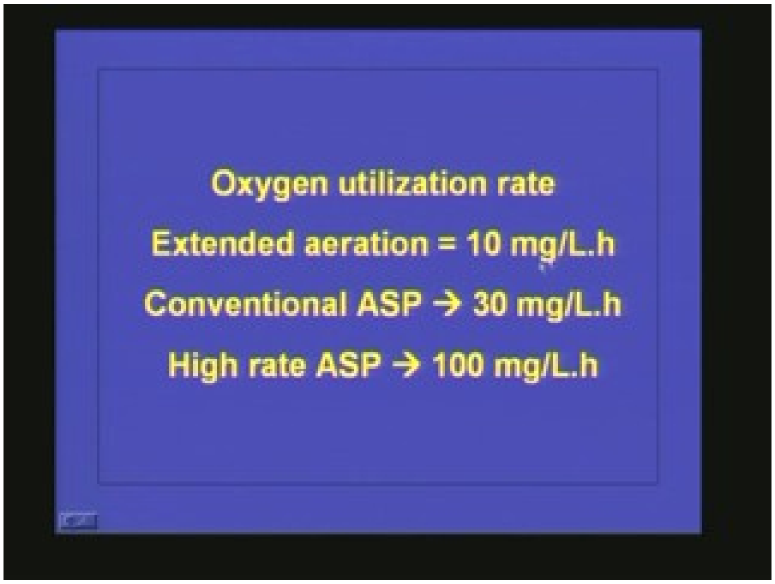

When we talk about extended aeration system we have to supply around 10 milligram per liter per hour oxygen. That means oxygen consumption rate per time is less in extended aeration system. In conventional activated sludge process oxygen utilization rate is 30 milligram per liter per hour and in high rate activated sludge process the oxygen utilization rate is 100 milligrams per liter per hour so we should provide the system which is able to supply this much of oxygen in the given time. For this purpose we are using aerators.

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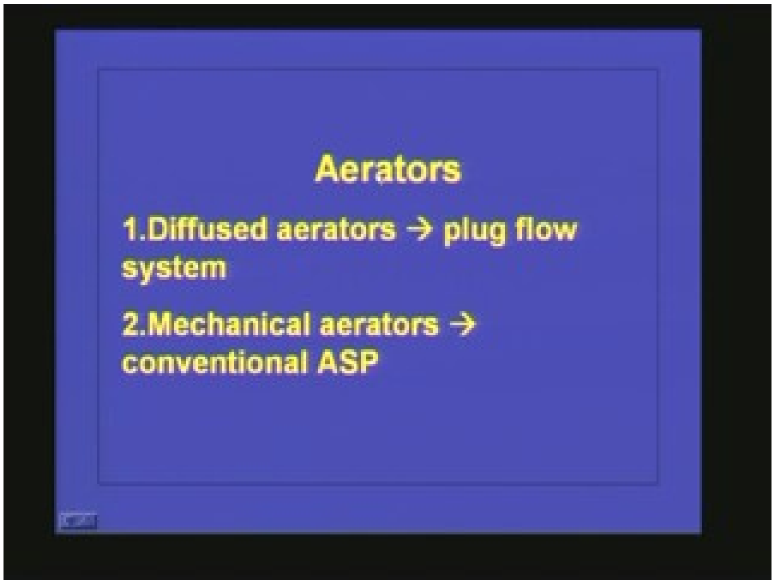

Aerators are mechanical devices which can supply the require amount of oxygen for an activated sludge process. Aerators can be of two different types; one is diffused aerators and another one is mechanical aerators. We usually go for diffused aerators in plug flow system and mechanical aerators in conventional activated sludge process where it is a completely tired tank reactor system.

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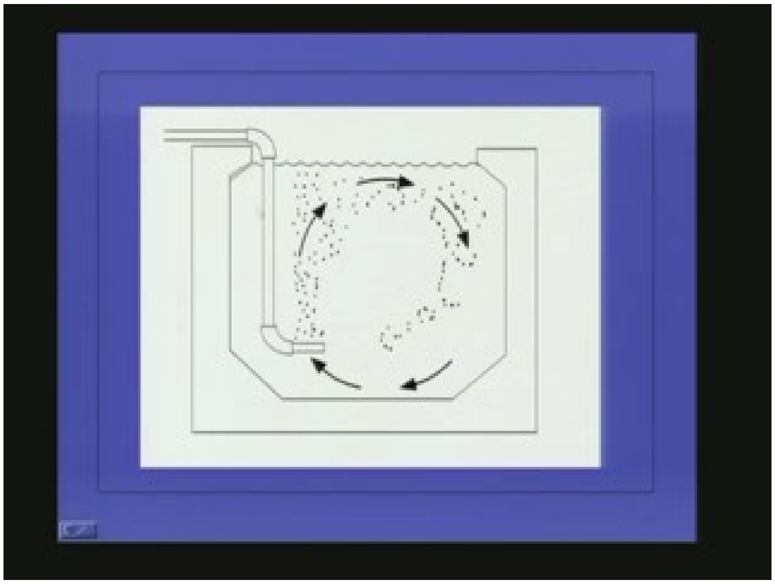

These are the pictures of certain aerators. This is the diffused aerator. We can see that oxygen is coming out from the diffuser and it is going like this and it is taking a part something similar to this one. It is going like this and coming like this so entire area will be getting oxygenated. This shows a surface aerator. We can see that this is the surface aerator and the water is getting mixed thoroughly here.

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The turbulence available here is much much higher compared to the plug flow or the diffused aerator. Here well mixing is taking place moreover oxygen transfer is also taking place. So, in any activated sludge process aeration tank we provide a series of aerators here, we can see one two three aerators. So depending upon the oxygen requirement and oxygen transfer rate of these aerators we can design or we can find out how many aerators we have to see and depending upon the influence zone of the aerators we can find out how we should place the aerators. These are also some other pictures of aerators.

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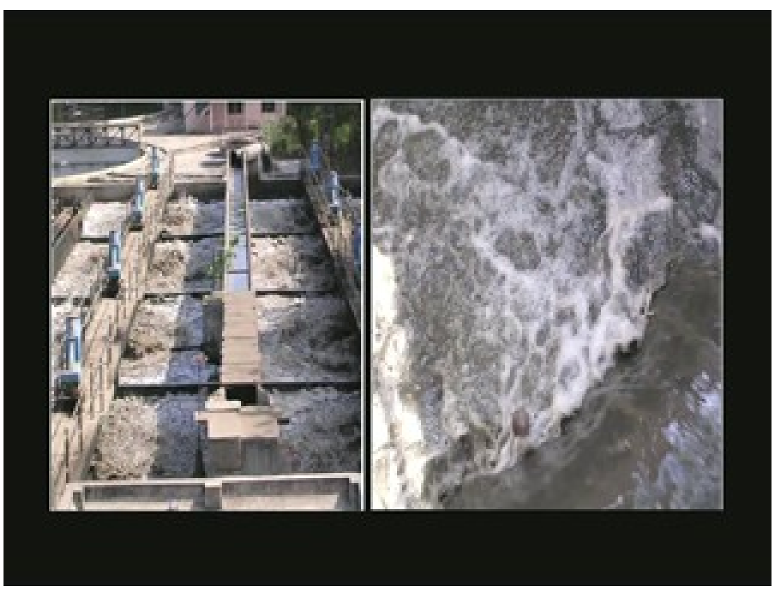

Therefore, how can we design the aeration facilities?
The objective of the aeration facility is to provide calculated oxygen demand and to provide adequate mixing. The D.O concentration in aeration tank; in conventional

activated sludge process we are supposed to maintain a dissolved oxygen concentration of 0.5 to 1 milligram per liter whereas in extended aeration system we are supposed to maintain a dissolved oxygen concentration of 1 to 2 milligram per liter. So your aeration facility whatever you are going to provide should be able to give this much of dissolved oxygen concentration in the system.

Now, when we talk about the aerators the aeration itself is very very important and how the air is getting transferred from the atmosphere to the water. There are many limiting steps present and there are many factors affecting the transfer of oxygen from the atmosphere to the wastewater. The most important things are the turbulence, the temperature, the wastewater characteristics. All these things are very very important.

Another one is the saturation limit. If the wastewater oxygen content is very low and your atmosphere oxygen content is very high and if the concentration gradient available is very very high then naturally the oxygen transfer will be very fast. Similarly, if the temperature is low oxygen transfer will be high and if the temperature is high oxygen transfer will be low. Another parameter is the wastewater characteristics. In wastewater there are many compounds or many pollutants present in the wastewater so some of these compounds are hydrophilic in nature and some are hydrophobic in nature.

Hydrophilic molecule will always have a tendency to be in the liquid or be in the water and hydrophobic particle will be trying to come out of the system. If the hydrophobic particles are more in the system what will happen is it will be forming a thin layer of these particles above the liquid surface so when that liquid surface layer is there naturally other molecule transfer will be hindered. So, if the wastewater is having a lot of solids or lot of hydrophobic solids then naturally the aeration rate will be getting affected.

The fourth important point is turbulence. If you create more and more turbulence the oxygen transfer will be more. If the turbulence is very less or the water surface is quiescent then the oxygen transfer will be less. We will discuss about this aeration in the next class. Now we will see what are the things we have discussed today.

We have seen that how we can calculate the oxygen requirements in an activated sludge process. That is nothing but the BOD consumed in the system but we do not have to supply oxygen for cell synthesis. So whatever amount of waste is converted into cell mass that much oxygen requirement we can detect from the system so total oxygen is the sum of the BOD removed minus 1.42 times the cell synthesis plus 1.42 times whatever is the cell decayed in the system plus whatever is the oxygen required for nitrogenous substances. Because, if organic nitrogen or ammonia nitrogen is presented in the system that will require some oxygen for the complete oxidation and ammonia will be getting oxidized to nitrate. So each unit of ammonia requires around 4.7 units of oxygen for the complete removal.

Then we were discussing about what is the nutrient requirement because the microorganisms requires micronutrients and macronutrients for their growth. In wastewater, most of the times, these nutrients are present in plenty so we do not have to supply them externally. But when we talk about some wastewater which is especially coming from industries they may not be having all these nutrients now we should know what is the nutrient requirement for the system. We have also seen that this nutrient requirement is not a constant; it depends up on the type of or the modified activated sludge process which we have selected. If the BSRT is high then BOD is to nitrogen is to phosphorus ratio is high. That means the nitrogen phosphorus requirement is less but if the BSRT is less it means more and more cells will be synthesized in the system so at that we have to give more and more nutrients. That is why high rate activated sludge requires more nutrients compared to extended aeration system.

Then we have seen how to design a secondary sedimentation tank for an activated sludge process. It is based upon two concepts or two objectives have to be satisfied. Those are clarification and sludge thickening. The area required for the clarification can be calculated based up on hindered settling velocity and area required for the thickening can be calculated based upon the batch column studies or by flux theory. In flux theory we are considering the flux due to underflow as well as gravity and using the graphical methods we can find out what is the limiting solid flux and for a system we know what is the sludge loading per day or per hour so by dividing the limiting flux we will be getting to know what is the required area.