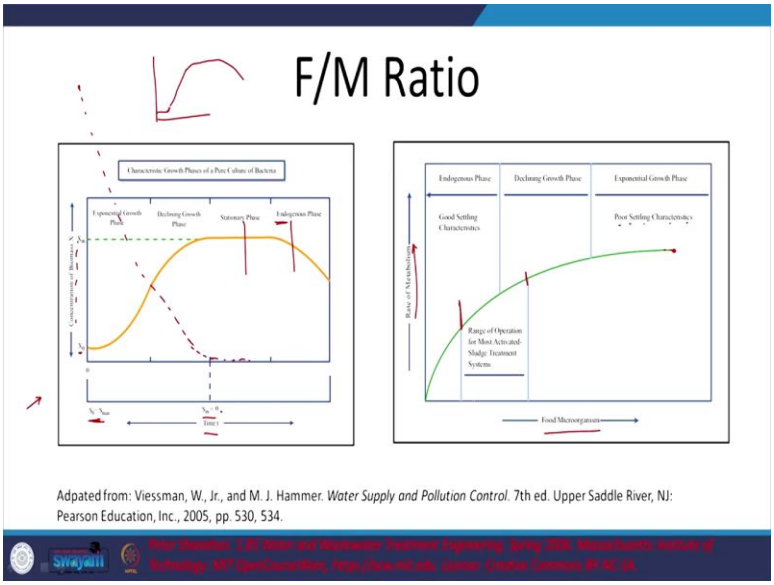
Water and Waste Water Treatment
Prof. Bhanu Prakash
Department of Civil Engineering
Indian Institute of Technology- Roorkee

Lecture -21
Relevance of FM Ratio and Design Parameters of Activated Sludge Process

Hello everyone welcome back to the latest lecture session. In the last session we looked at understanding θ_c and relevant variables. And in this session we are going to pick up where we left in the last session. Namely we were discussing food to microorganism ratio and how is that relevant to our system that is something we will look at now.

(Refer Slide Time: 00:46)



what I have here so it is food to microorganism. Food can be based on S_0 what is coming in or what is coming in minus going out. Depends on who or which textbook or such people look at. So it can be something like these microorganisms in the system or as I mentioned you can just have QS_0/VX two so that is one aspect to keep in mind. So then what is this giving me an idea about in the first case.

It gives me an idea about the kind of bacteria that can thrive and does the kind of floc or settling characteristics. So here we have two figures a variation of this figure we looked at it earlier that figure was somewhere like you had this lag growth phase where you had acclimatization and then remarkable level of growth and relatively uniform growth and then stable and then decay.

So we had different stages there, so this is a variation of that figure. So what do we have here characteristic growth phase of a pure culture of bacteria and this is when we have substrate substrate is somewhere out here. And substrate or the food is being consumed. So that is what you have out here it is something like this. So if there is food available and that is how it is going to decrease.

On the y-axis we have concentration of biomass or the microbes on the x-axis we have time and also some information about the substrate available. So here I have a lot of substrate and this is in a pure culture there is no inflow no outflow. So, initially microbial concentrations is very less and it is X_0 and there is an acclimatization phase and then an exponential growth phase.

And then you are going to have what we say log growth or such where you have uniform growth characteristics and then you are going to have declining growth phase and then stationary and endogenous. Somewhere out here you see that almost all the substrate is zero and initially substrate is the maximum. But how is this still occurring here we have endogenous respiration, stationary phase.

And endogenous phase the cell mass of the relevant microbes are being consumed for the microbes to be able to survive endogenous respiration. So that is one aspect to keep in mind. Here though is that as bacteria die or I think reach this bacteria reach this endogenous phase they give out a slime layer I think we have the pictures from MIT open courseware. So these slime layers help in forming flocs and maybe the bacteria sticking together if I can use layman's terms.

So if you can see to it that your particular microbial population is in this phase you are going to have good sludge and sludge settling characteristics. So that is what we see here. So here we have on the x-axis food to microorganism ratio and here on the y-axis we have rate of metabolism. How fast are they or how well are they metabolizing. So what do we have out here, so in the exponential growth phase.

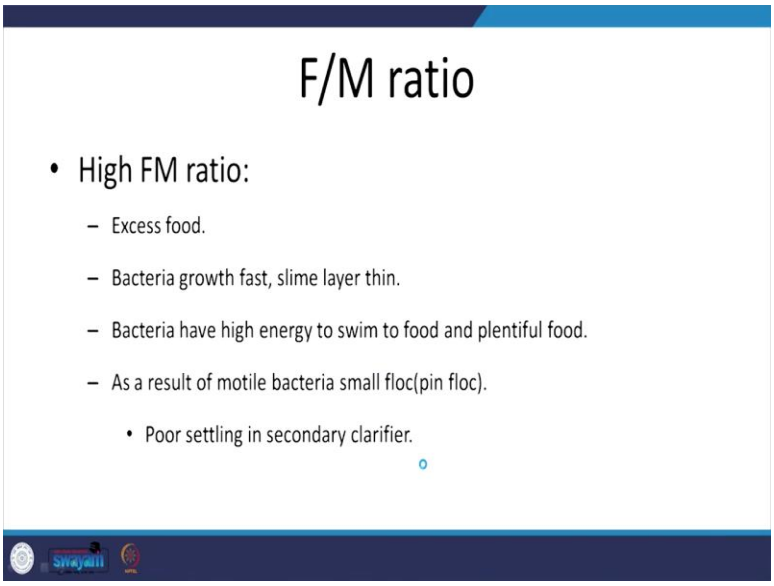
The firstly the settling characteristics are going to be poor here we have higher F/M and higher metabolic growth rate. What happens when you have higher food to microorganism's ratio. Let us just understand that before I think we are go before we look at that in detail. Alot of food and less microbes so there is a food everywhere. So the kind of microbes that are going to have or that are going to thrive or what are called as motile microbes.

These can move based on their or they have a free will if you can say so and they can move in search of food. And so these form flocs which are called pin flocs I think we looked at some such figure earlier when we were talking about settling or sedimentation. Pin flocs and they do not settle well. So, that is one aspect to keep in mind poor settling characteristics and also because the food or our waste is pretty high in this relevant system.

It is also going to leave the system through my effluent. So, some of the; or the concentration of the waste in the effluent is going to be relatively higher. So that is one aspect to keep in mind F/M here. So this is something that we do not want. So if the F/M is too low you are going to have different kinds of issues with respect to sludge bulking . as I mentioned we want that sweet spot where we have the slime being formed.

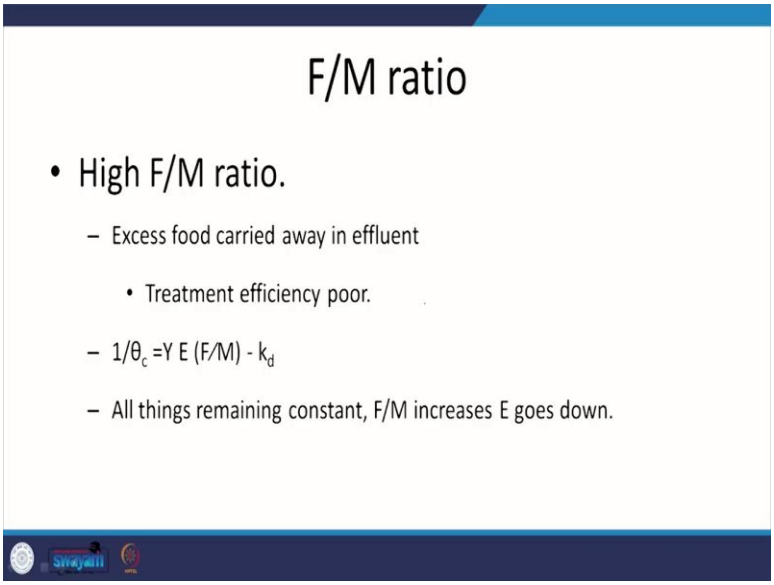
And it is between this declining growth phase and this endogenous growth phase. And this is the range of operation that is ideal so that is what we have out here. And you see that the F/M is not too low but it is certainly not too high. So that is one something that is something to keep in mind. Let us move on.

(Refer Slide Time: 05:50)



So high F/M ratio meaning high food so they grow fast and slime layer is thin here we are talking about I think the exponential growth phase that is something to keep in mind we have motile bacteria and they have high energy to swim to you food thus pin floc poor settling in secondary clarifier. First poor settling and also high food so both ways not a great aspect for us .

(Refer Slide Time: 06:19)



So excess food is carried away treatment efficiency is poor by playing around with the variables we can get this as we looked at this in terms of X and Y is that yield coefficient

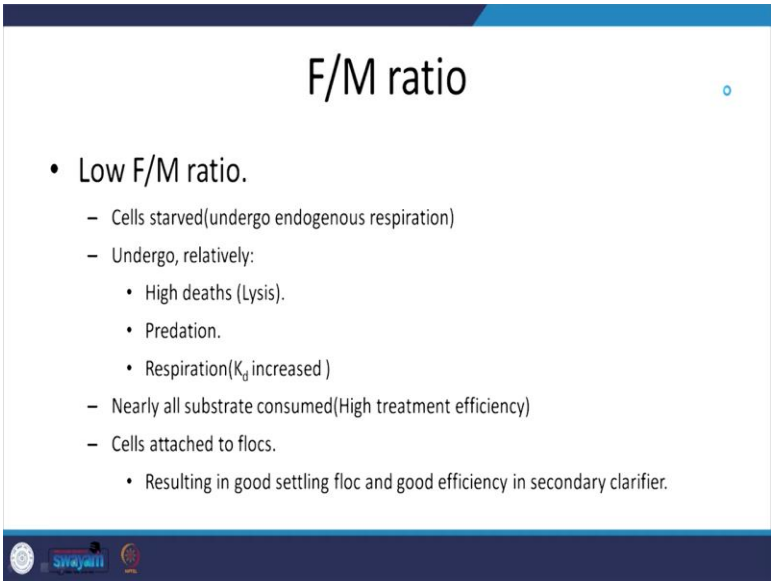
E is the efficiency of removal;

$$E = \frac{S_0 - S}{S_0}$$

So what do you see here when F/M is high θ_C will be less or the cell residence time will be less F/M if that is one aspect to keep in mind. If I keep the cell residence time the same and if I increase the F/M what will happen the efficiency of the process will have to come down.

So that is something to keep in mind if I increase the food to microorganism ratio the efficiency will come down. So efficiency is this so that is something to keep in mind.

(Refer Slide Time: 07:15)



And with low F/M, what is that we will see low F/ M meaning low food and more relatively more microorganisms everything is relative. So the microbes are starved now they are pretty hungry there might be some endogenous respiration but we are not at the phase where there is only endogenous respiration because you are still providing the our waste or the food or the substrate so that is one aspect.

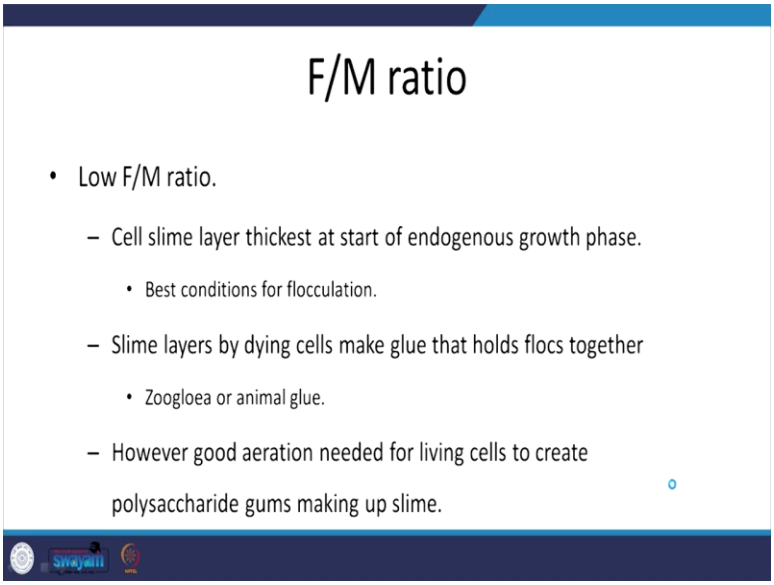
What is going to happen here undergoes or starts to undergo or experience endogenous respiration. So, a lot of relatively high deaths and more predatory or predation and so k_d is increased. Nearly all substrate is consumed so thus we have high treatment efficiency I think we also saw this

$$\frac{1}{\theta_c} = Y\,E\,\frac{F}{M} - k_d$$

So with the low F/M and for the same θ_C keeping θ_C the same you see that the efficiency will increase that is something to keep in mind.

And also if we maintain it at the same sweet spot we know that there is going to be a slime that is going to be formed and also you are going to have the combination of floc forming and filamentous microorganisms. So it results in good settling floc and thus good efficiency in the secondary clarifier.

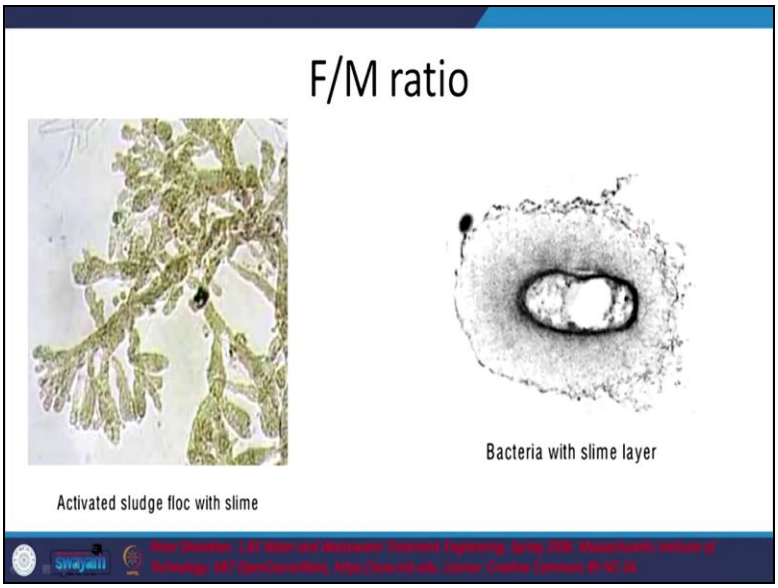
(Refer Slide Time: 08:40)



if we have some pictures we will come by that later. Cell slime layer is thickest at the start of endogenous growth phase, just at the start. And thus that leads to best conditions for flocculation. Slime layers by dying cells make glue it is gluey layer that holds the flocs together. Slime layers are formed when we have dyeing cells. And for getting this slime layer though we need to have good aeration for the living cells or when they were living to create the relevant polysaccharides that make up the slime.

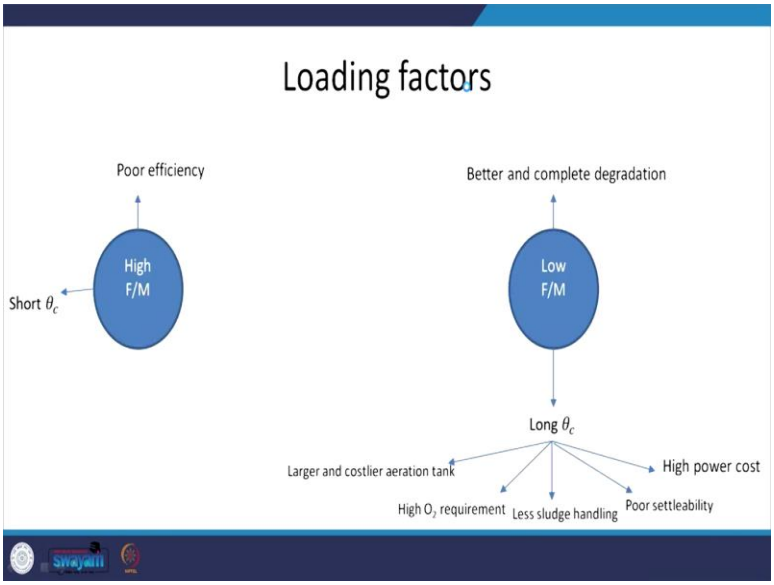
So to get to the conditions that can lead to formation of slime or this gluey layer or sticky layer you need to aerate it together. So that is something to keep in mind. if we have pictures.

(Refer Slide Time: 09:31)



So here we have the bacteria with the relevant slimy layer all around it. And then activated sludge flocs with slime. So this is the sticky layer that we want are trying to get that is when that is what we get when we maintain the F/M ratio at a sweet spot.

(Refer Slide Time: 09:45)

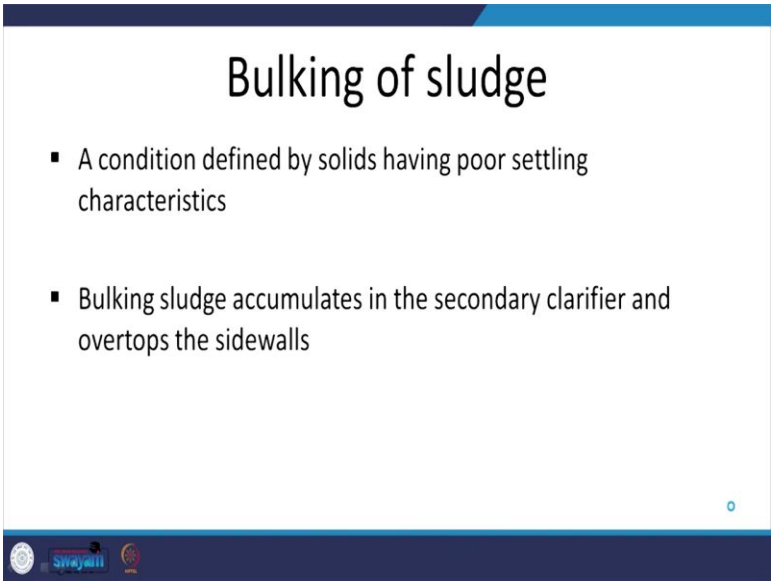


So let us look at some aspects so high F/M as θ_C is the same, poor efficiency and typically characteristic of low θ_C , if we look at it the other way. And low F/M better and more complete degradation and better settling characteristics. If we can maintain the F/M such that system is just at the endogenous growth phase. for that long relatively long θ_C but what are the issues?

For long θ_C that means more recycle more recycle meaning larger thus more costlier aeration tank. And if the microbes are spending a lot of time and also the substrate removal is more I need to provide a lot more oxygen. And well I should not say poor suitability this is the case when I have a very long θ_C but not in general. And high powers high power that is from the requirement of more recycle and more oxygen.

But if you maintain the θ_C and F/M at the sweet spot you will not experience poor settleability.

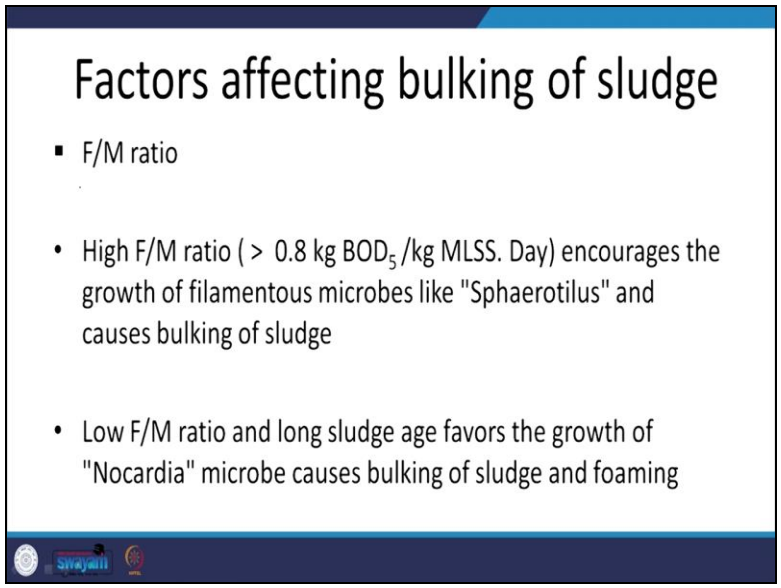
(Refer Slide Time: 11:03)



Let us move on, so bulking of sludge this is one common factor that ruins many Indian treatment plants or quite a lot of treatment plants around the world. So you have the aeration tank microbes are degrading it, it meaning our waste once they go to the secondary settling tank or secondary sedimentation tank or clarifier what needs to happen you are not going to provide air you are not going to provide turbulence.

You need to provide the kind of bacteria that form flocs and settle down. But depending on the F/M and θ_C you are going to have what do we see sludge that is not going to settle down but for have bulking of sludge. So what is this characterized by half the solids having poor settling characteristics. It accumulates in the secondary clarifier and even can overflow the side walls.

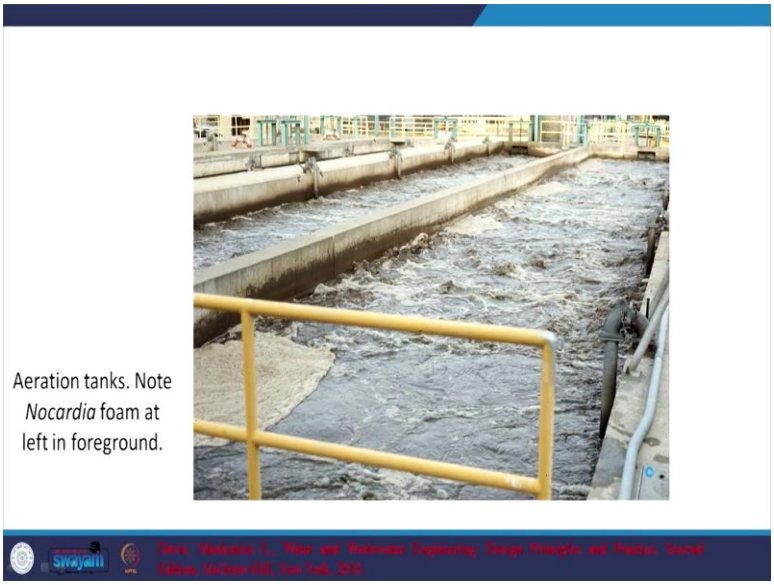
(Refer Slide Time: 11:53)



So with respect to F/M ratio and its effect on the bulking of sludge bulking of sludge unlike what you might have heard from what I have seen or read. There seem to be various factors that can lead to bulking of sludge. So one can be filamentous one can be non-filamentous let us look at some of the; factors or variables that can lead to bulking of sludge.

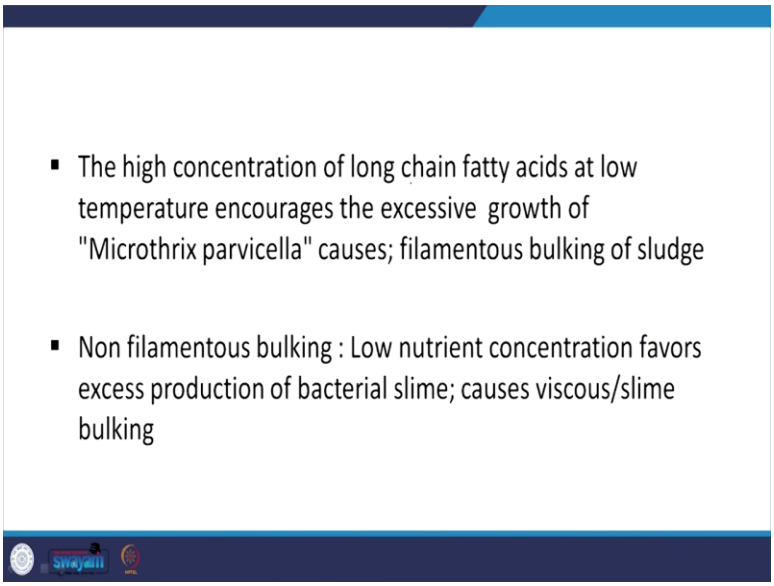
So here we have high F/M ratio encourages the growth of filamentous microbes like spherotylus and causes bulking of sludge. So that is one aspect and the relevant aspects are given. Low F/M ratio and long sludge, age favours the growth of nocardia microbes causing bulking of sludge and more importantly foaming.

(Refer Slide Time: 12:45)



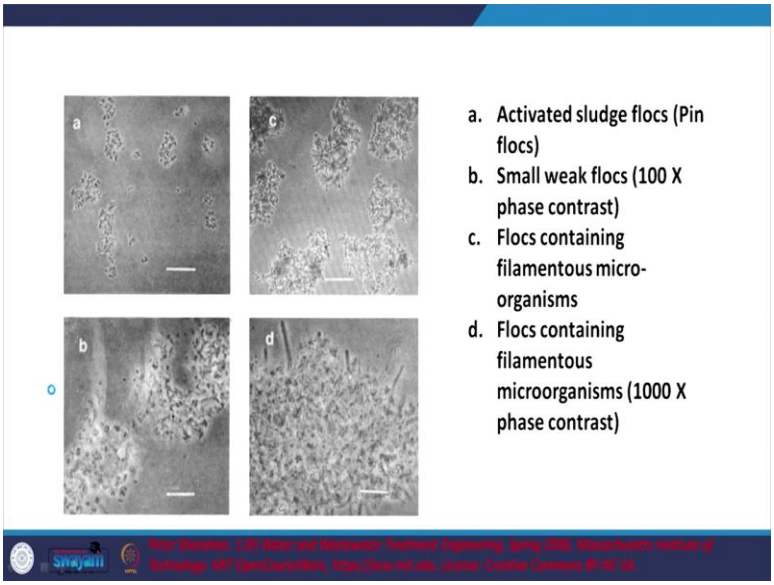
I think I have a picture here. So you can see the kind of foaming out here. Yes so that is something that you see fine or this is the relevant aspect high and low.

(Refer Slide Time: 13:02)



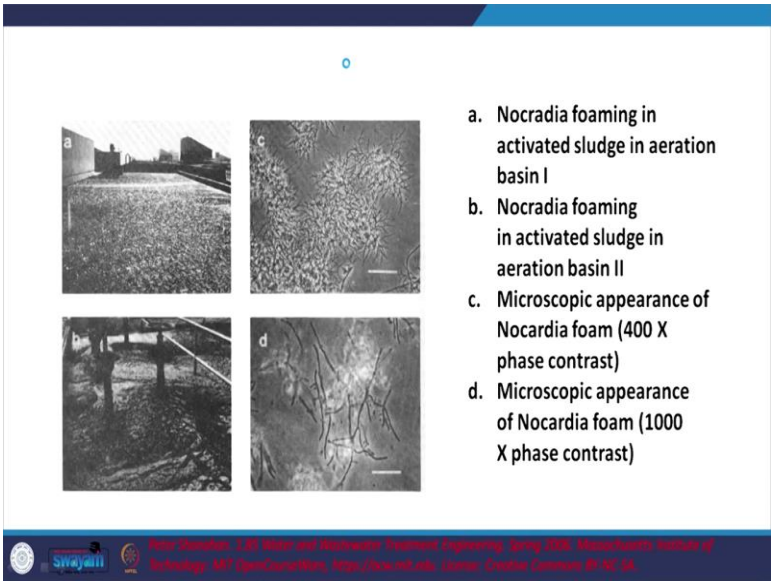
The high concentration of long chain fatty acids at low temperature encourages excessive growth of these kinds of bacteria which leads to filamentous bulking of sludge. And there is another kind of bulking called non-filamentous when we have low nutrient concentration which favors excess production of slime and thus you have viscous slime bulking. So, that is something to keep in mind.

(Refer Slide Time: 13:33)



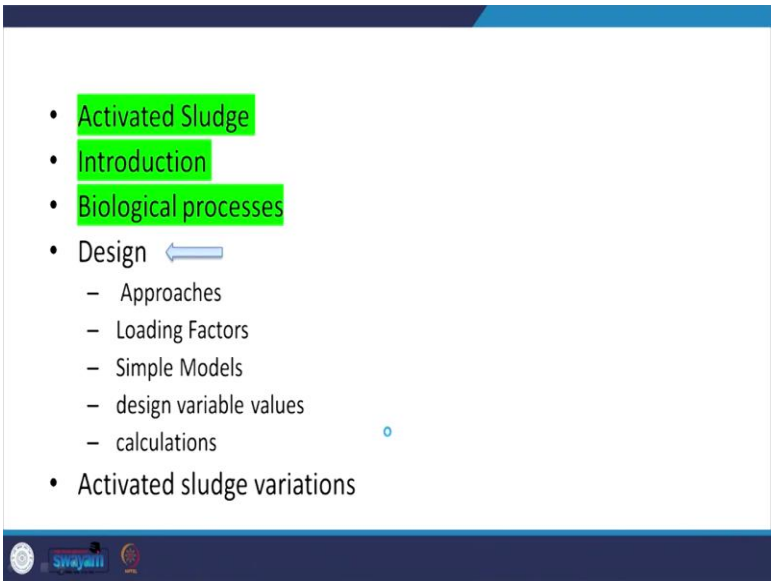
So we looked at a similar figure earlier and I think we will look at it. So pin flocs when we had high F/M and thus leading to small weak flocs with respect to magnification. I think I do not have that information. Flocs containing filamentous microorganisms probably at the; mix with their floc forming and filamentous microorganisms. So you see the relevant backbone and the relevant bigger flocs difference between this and this set of what do we see images.

(Refer Slide Time: 14:08)



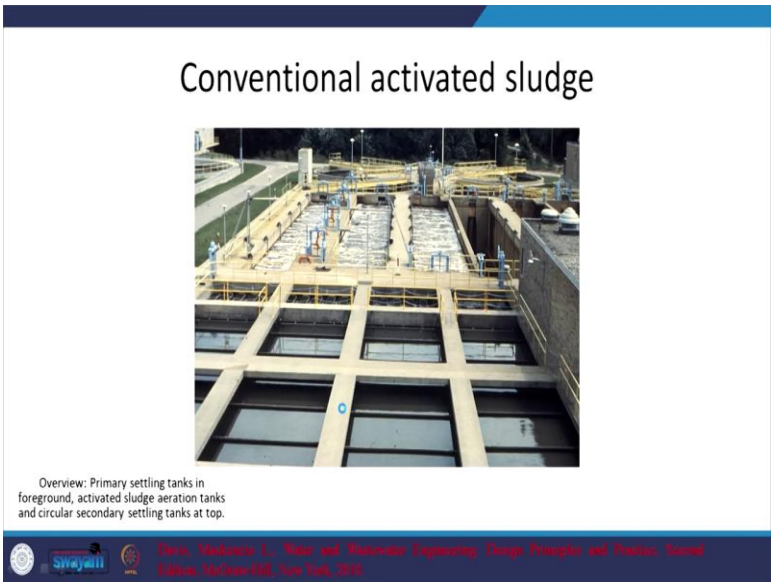
Let us move on and so nocardia forming in activated sludge basin that is in a and b you can see the kind of foaming these are black and white pictures maybe we can get better pictures later. And the microscopic what we see appearance of the nocardia forming which you can see the kind of foaming. And these do not settle down well so that is something to keep in mind and you can see the difference between the two kinds of bacteria or microbial populations.

(Refer Slide Time: 14:42)



So let us move on so we looked at activated sludge and the biological process. So major aspect is design how do I go about it? So here based on thumb rules or such depending upon how much mass load or how much waste is coming in you have some what we say factors based upon which you can choose the relevant volume. In India I do not think we choose that often simple models based on calculation. Simple and design variable values that is what we are going to look at.

(Refer Slide Time: 15:12)

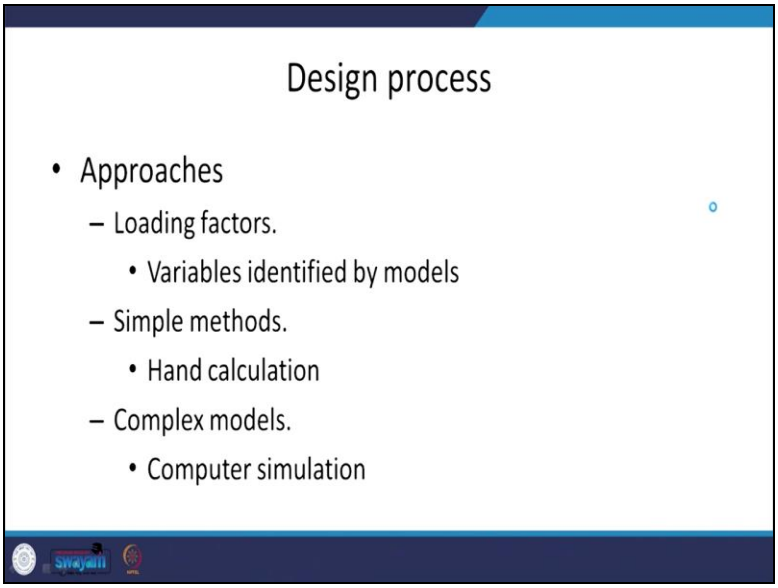


So what we have? So, conventional activated sludge, so primary sedimentation out here aeration out here. So I think water is flowing in this direction and then after aeration after the microbes have degraded the relevant substrate and the kind of microbes have been formed here you have

circular sedimentation tanks or secondary clarifiers. So that is the relevant process. So, here as can be seen they have what seems like a sinusoidal flow.

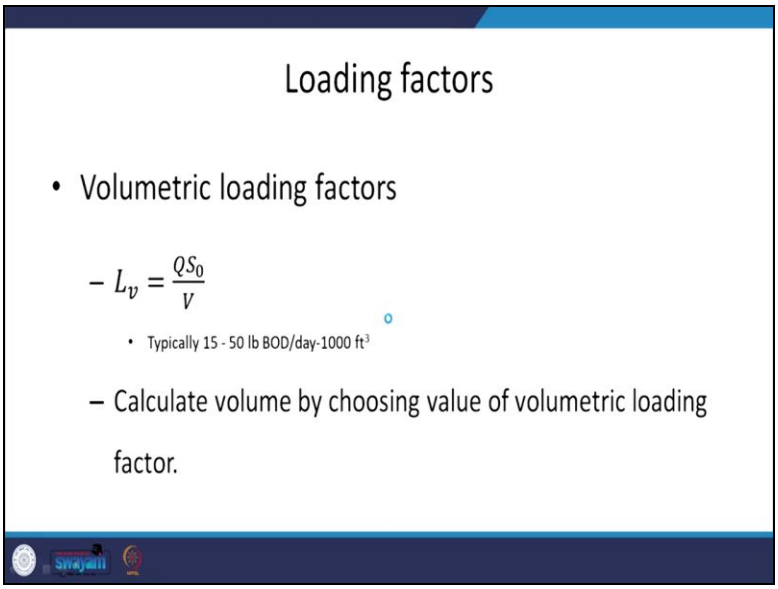
So that you have plug flow characteristics we looked at why plug flow our relatively ideal case plug flow is better than what we say the usual or ideal CSTR but we are not going into that now.

(Refer Slide Time: 15:56)



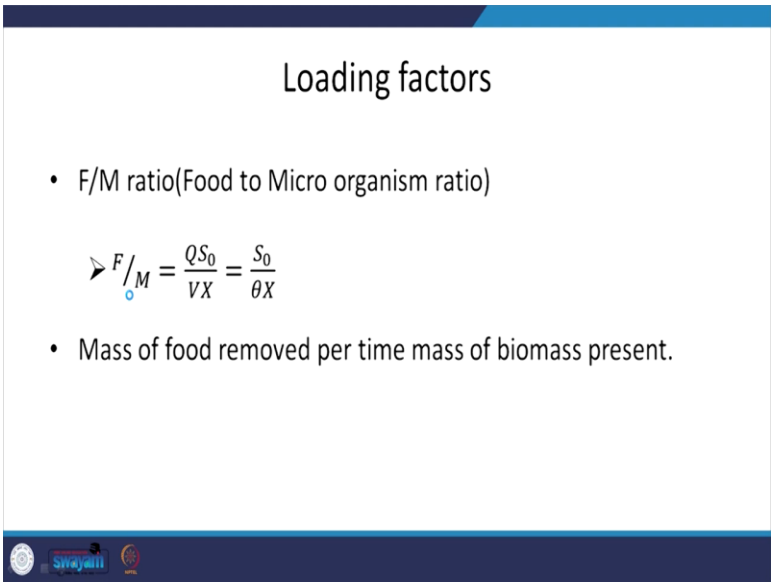
So design process one based on loading factors simple methods and complex methods are based on computer simulation we are not going to that in detail this too or not we are not going to discuss this. We will briefly look at it we will spend more time on this aspect let us move on.

(Refer Slide Time: 16:15)



So volumetric loading volumetric loading this is the mass of the waste or your waste or the substrate or the microbe's food that is coming in and volumetric loading. And you can calculate the volume by choosing the value of volumetric loading factor we will not look at this.

(Refer Slide Time: 16:38)

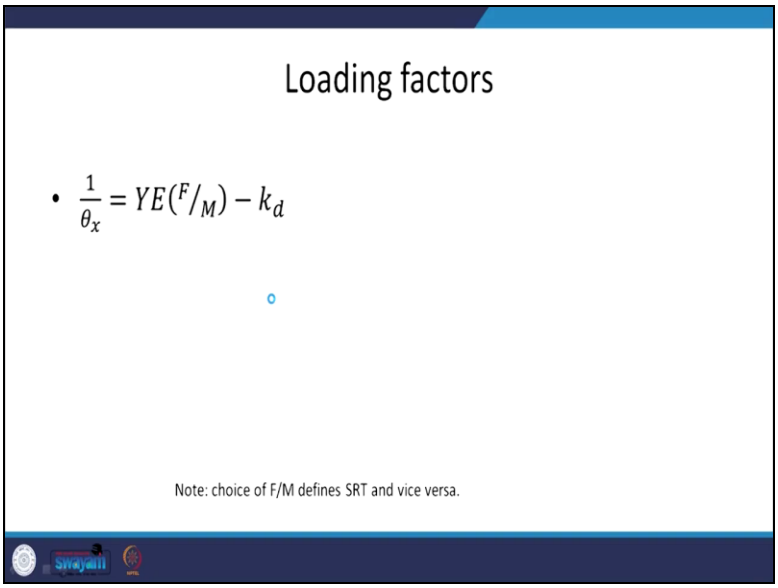


Another aspect is trying to maintain this F/M ratio as I mentioned

$$\frac{F}{M} = \frac{QS_0}{VX} = \frac{S_0}{\theta X}$$

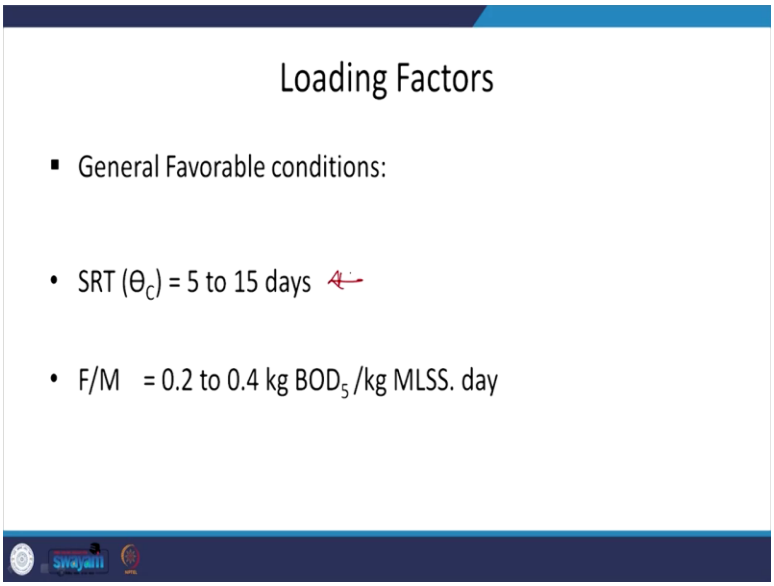
then you can calculate the relevant variables that you need.

(Refer Slide Time: 16:49)



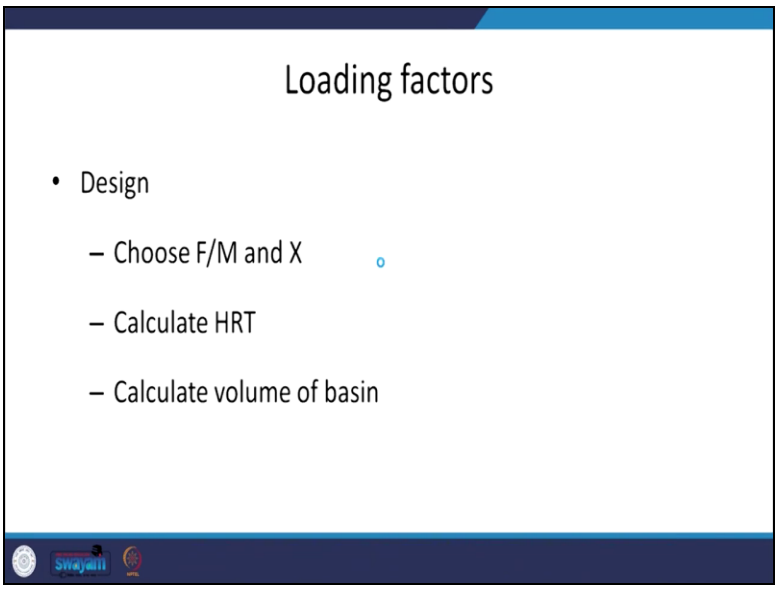
So this is something we already looked at earlier so I will not come back to look at this but based on what you want to maintain of these three variables you can get the other variables from here.

(Refer Slide Time: 17:01)



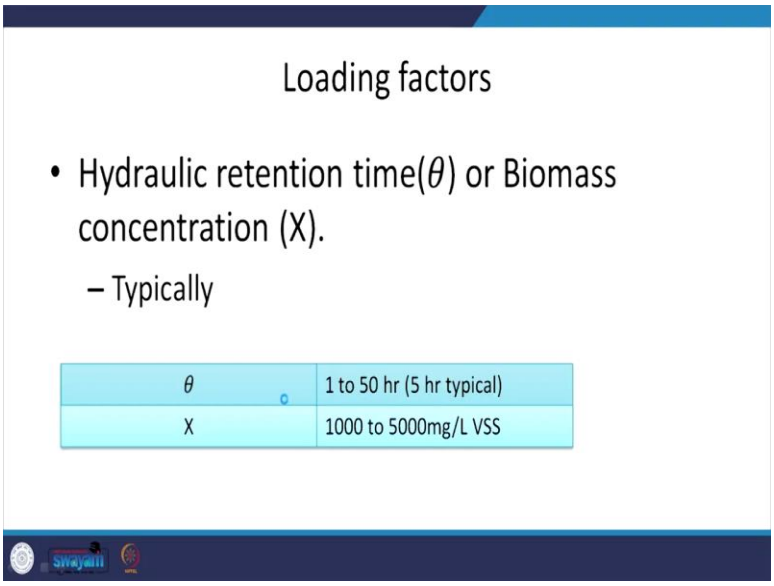
And so in general SRT 5 to 15 but it depends on the kind of plant the extent of removal F/M 0.2 to 0.4 kgs of body per kg of MLSS per day and I think we saw that the bulking was occurring when we were at around 0.8 or such if I am not wrong. As you see high of F/M 0.8 fine.

(Refer Slide Time: 17:23)



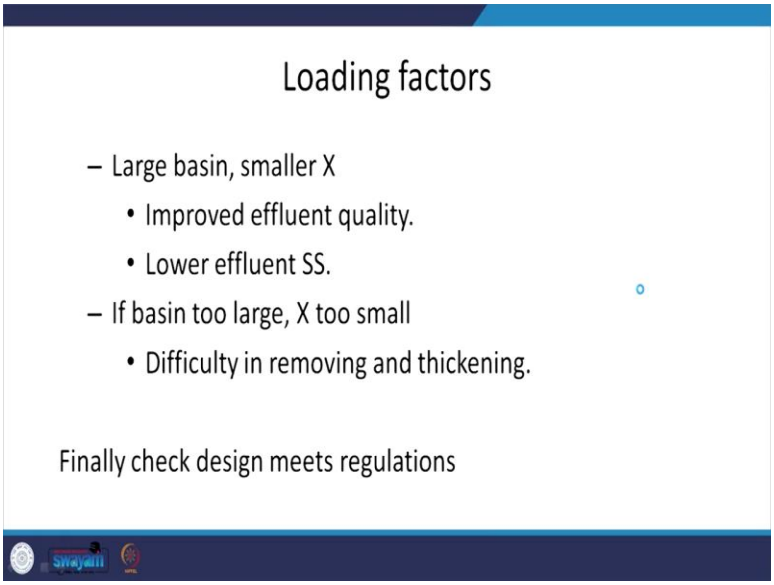
So that is one aspect so how do we go about it choose the F/M and X that you want from that calculate the HRT and then calculate the volume of basin but we are not going into that.

(Refer Slide Time: 17:34)



So loading factors and what are the typical values theta x ranges from 2000 to 5000 volatile suspended solids typically 2500 ml VSS is what you would have or else fine. So ɵ is the hydraulic retention time, keep that in mind it is not the cell residence time. So as you see the theta hydraulic retention time is much lesser theta C around the range of a few days. So that is something to keep in mind.

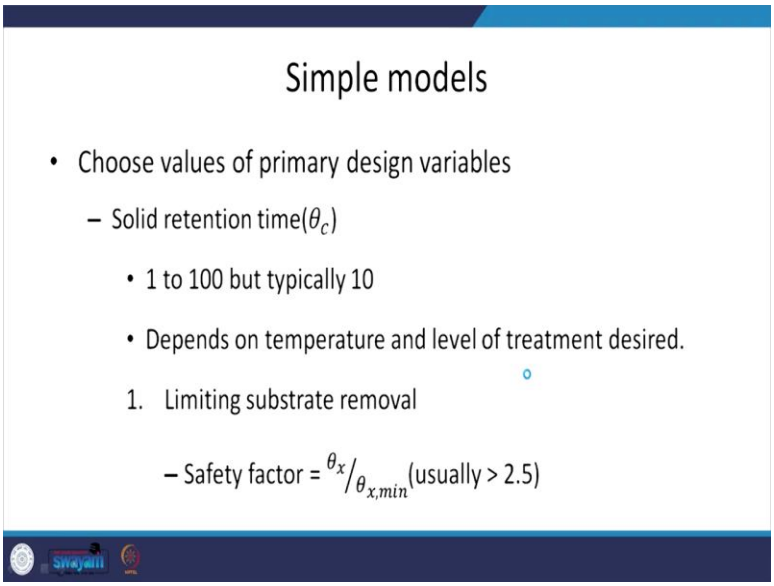
(Refer Slide Time: 18:09)



So with a large basin and smaller X what can you achieve? So improved effluent quality and lower effluent suspended solids in general for a well runs what we say treatment plant you will still have some BOD leaving the system but that is not due to BOD that is soluble it is BOD that is relatively suspended. So you would want to bring down that effluent suspended solids but if

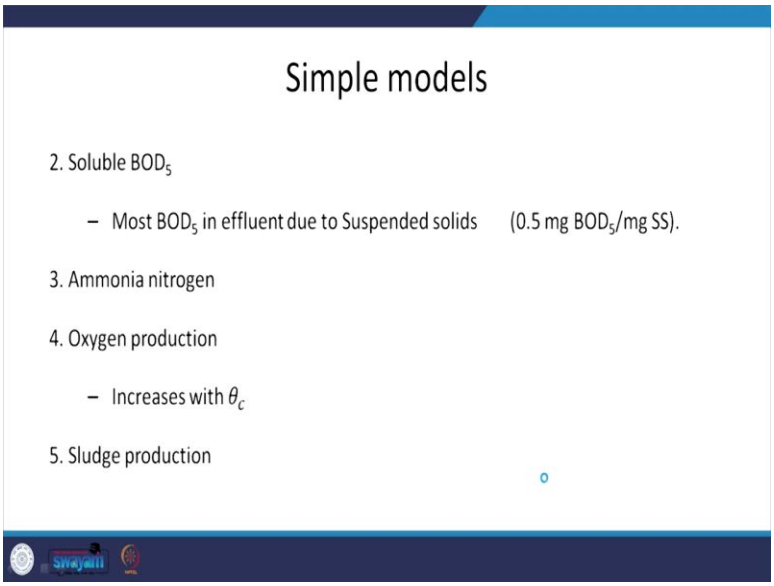
the basin is too large and leading to X being very small then difficulty in removing the relevant organics and also leading to poor thickening. we are not going to discuss this.

(Refer Slide Time: 18:48)



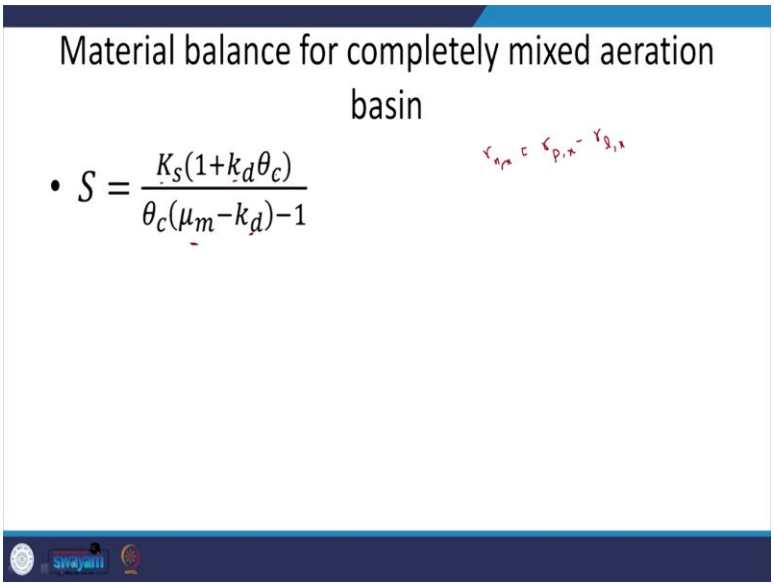
So simple models how are we going to go about it choose values for the primary design variables what are they θ_C and limiting substrate removal how much do you want to remove based on that you can choose a safety factor.

(Refer Slide Time: 19:04)



So soluble BOD_5 most BOD_5 in effluent is due to suspended solids as I mentioned earlier and you will look at the ammonia, nitrogen. The oxygen production that is required it increases with greater θ_C and then the amount of sludge that is being produced.

(Refer Slide Time: 19:22)

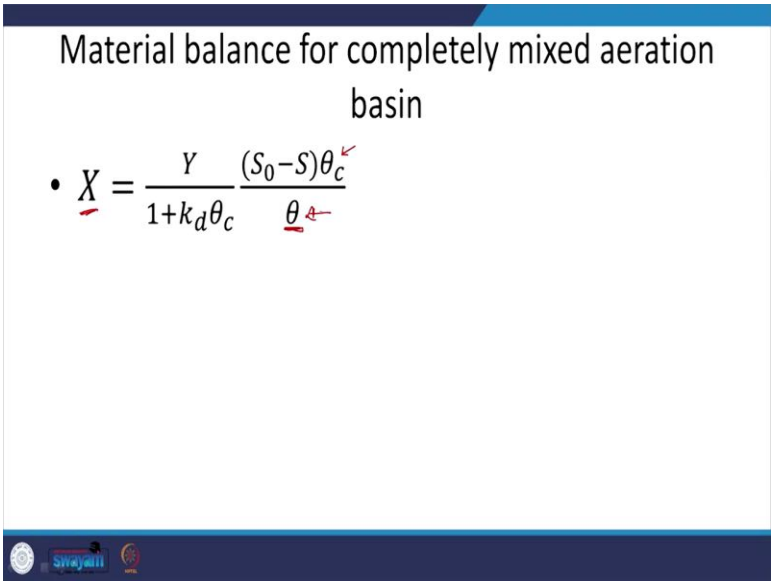


So effluent limiting substrate concentration this is something that we got based on the relevant mass balance. So we applied the mass balance and we also looked at the equation where we had rate of

$r_{net;x} = r_{p;x} - r_{l;x}$

substituted relevant aspects and we came up with this. So based on that you can calculate S or given S calculate the θ_C .

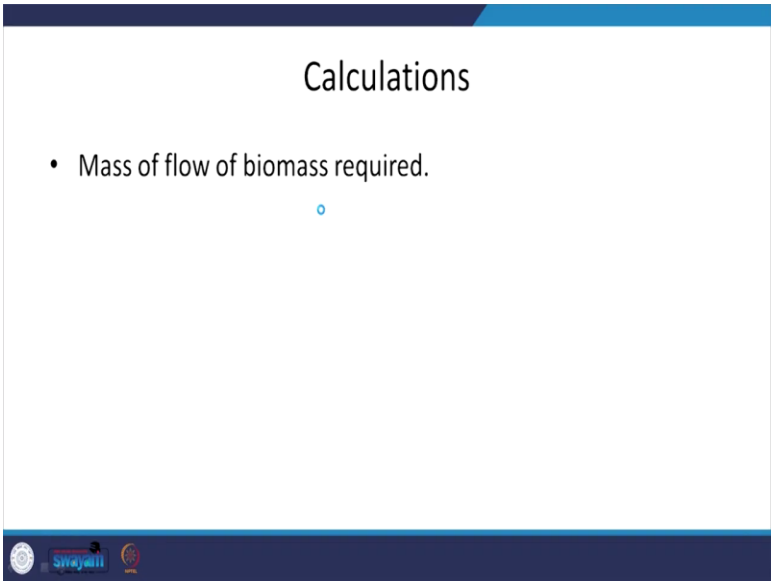
(Refer Slide Time: 20:00)



And then if HRT you can calculate that if X is assumed or if biomass concentration also can be calculated if HRT is assumed. So for that that is what you have here earlier based on S you can calculate θ_C and now if X is given you can calculate theta if theta is given you can calculate X one or the other. Typically you will choose the hydraulic retention time because that will give an idea about the volume of the relevant tank.

Well not only HRT that will give you an idea about what we say the flow characteristics too. So that is something you need to look at it.

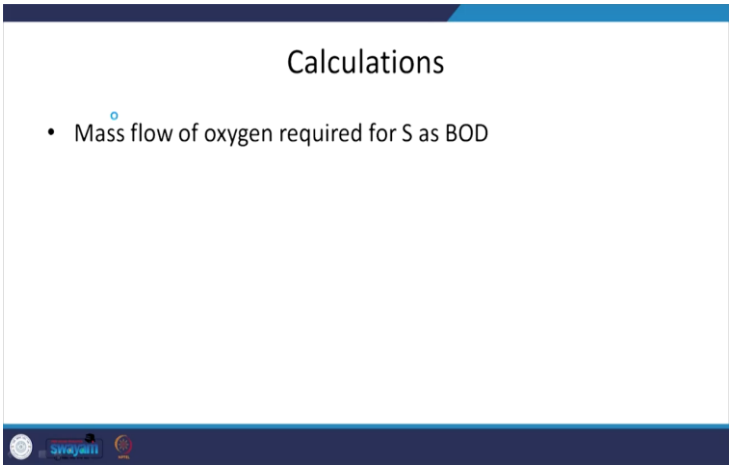
(Refer Slide Time: 20:41)



So mass flow of biomass required

$P_x = -Y_{obs} Q(S - S_0)$

(Refer Slide Time: 20:50)

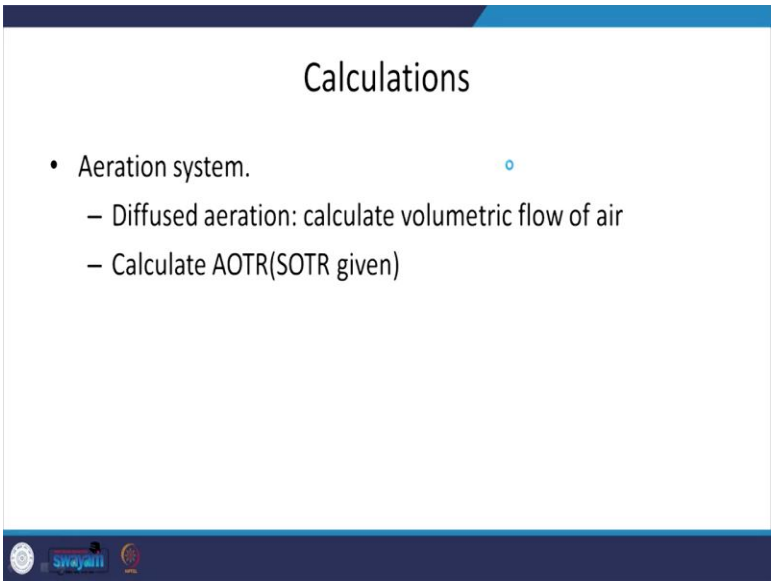


So this is also required Y from that you will have to calculate the mass flow of oxygen. So we looked at S equation we looked at X equation S is a function of ɵ and X is a function of theta and $ɵ_C$ and then we are calculating P_x and then we will calculate the mass of oxygen general steps out there. depending on what variables are given or not given you will have to play around and depending upon the assumptions that we made maybe we might change the assumptions or we might choose other assumptions.

So you might have to change the mass balance a bit. But please note that the mass balance there are only two aspects this is a CSTR and we either apply the mass balance around the entire system for the substrate and the microorganisms. If you want to look at the ratio of recycle how much I need to recycle what do I need to do I need to look at the relevant mass balance around the clarifier on the biomass.

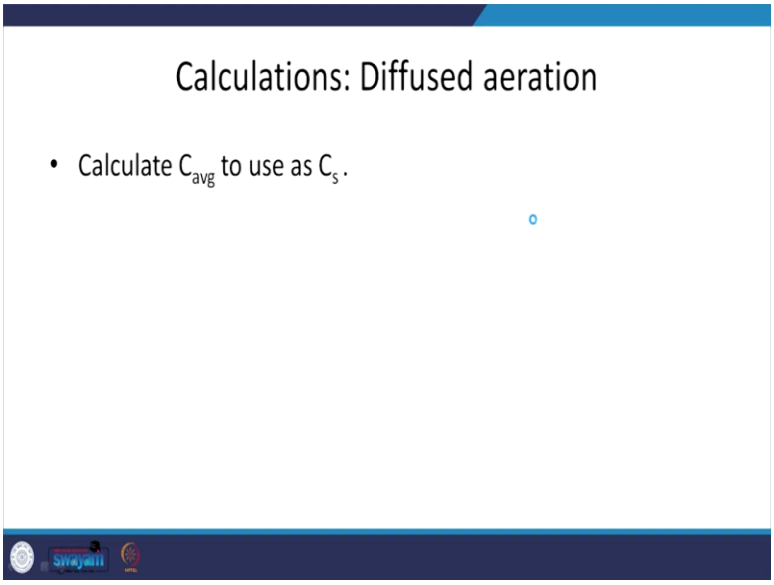
So from that and your relevant mono equation kinetics you can get whatever it is you want. So it is all about mass balance. So then you will be able to calculate the mass flow of oxygen required for S as BOD.

(Refer Slide Time: 22:07)



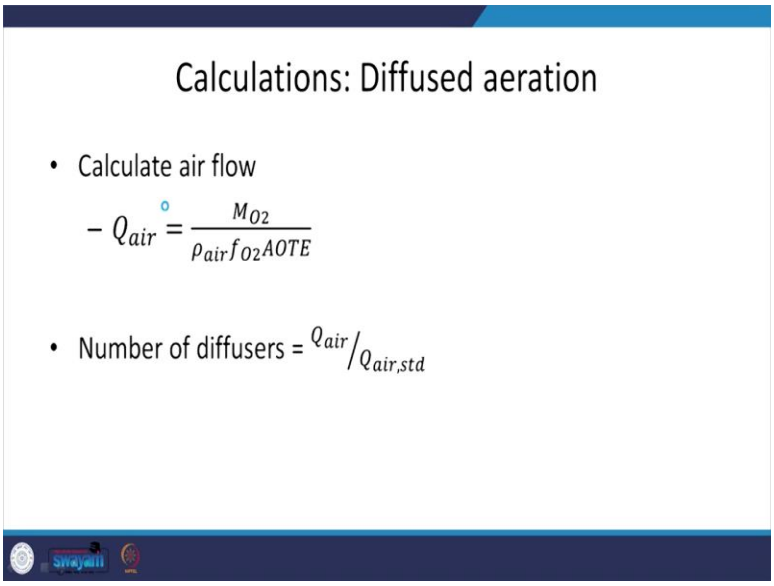
We look at the oxygen requirements. So actual oxygen transfer rate volumetric flow of air we already know how to do that.

(Refer Slide Time: 22:13)



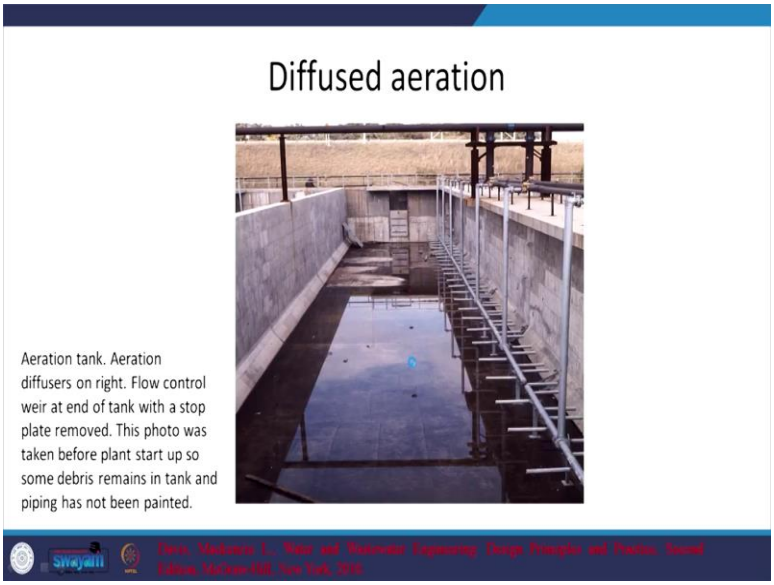
In that AOTE or AOTR that you need to calculate $C_{average}$ based on the pressure at that particular depth to the atmospheric pressure and the oxygen leaving the system. So this is what we have based on that you will calculate $C_{average}$.

(Refer Slide Time: 22:33)



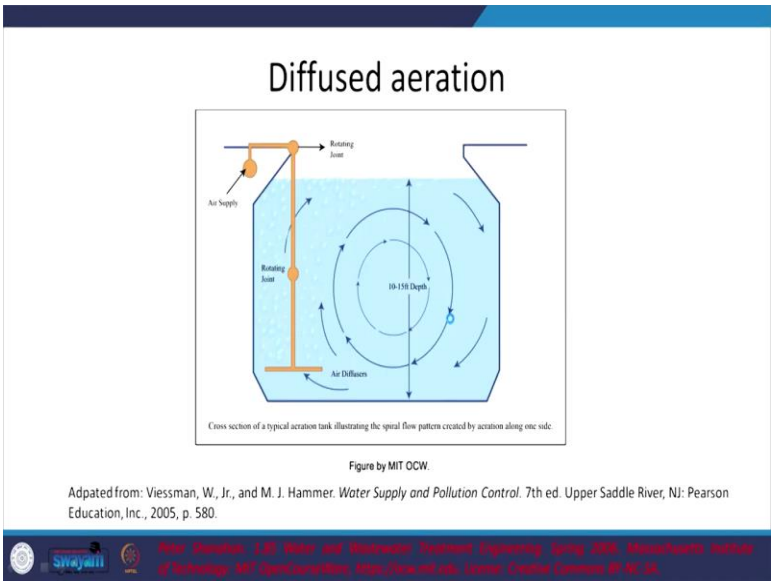
And then you can calculate AOTE and so forth and you will calculate the air flow total air flow that is required from this. You have the mass of oxygen required and these variables and thus you can calculate the required air flow. So the number of diffusers will depend upon this total airflow by the airflow at standard conditions or per diffuser.

(Refer Slide Time: 22:59)



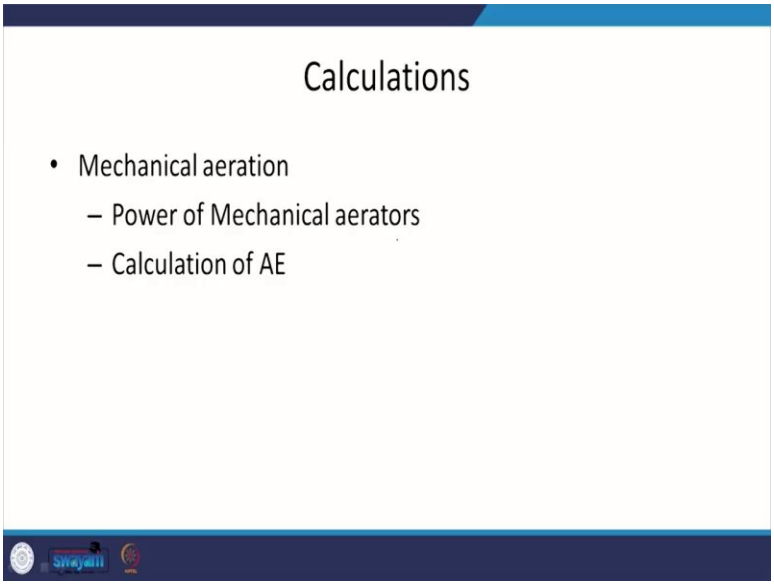
So, different kinds of diffusers, so, every aeration diffuse on the flow control where out here. So, that you have relevant outflow. So different kinds of diffusers let me see if I have a better diffuser. So here looks like they choose these kinds of aeration systems especially on one side so that there is a spiral role or good mixing as it goes along what we say as passes through the tank.

(Refer Slide Time: 23:28)



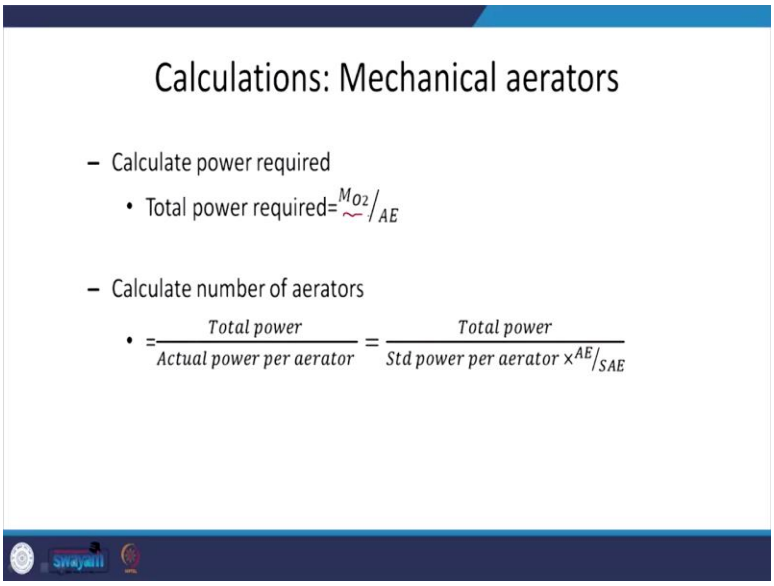
So diffuse aeration, so this is what we have cross section of a typical aeration tank illustrating the spiral flow pattern created by aeration on one side. So you have this spiral flow at least if not along the flow direction perpendicular to the flow direction you want to have good mixing. So that is what you are going to achieve and with that you are going to have what do you say forward movement.

(Refer Slide Time: 23:54)



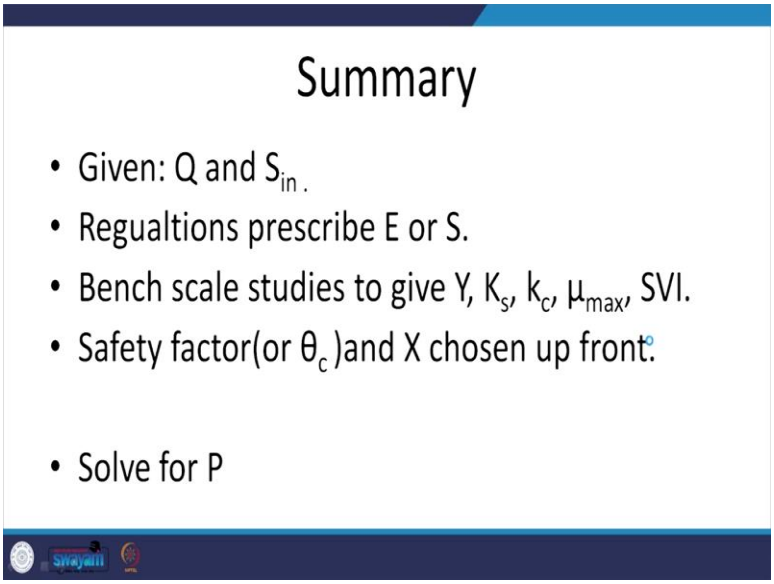
So calculations mechanical aeration power of mechanical aerators we know that actual efficiency with respect to standard efficiency where we look at the power or the energy requirements. We also looked at the relevant what we say formula.

(Refer Slide Time: 24:11)



And what do we have here total power required is the mass of oxygen by the efficiency or actual power per aerator. So these are all very general pieces of algebra just fractions and so forth.

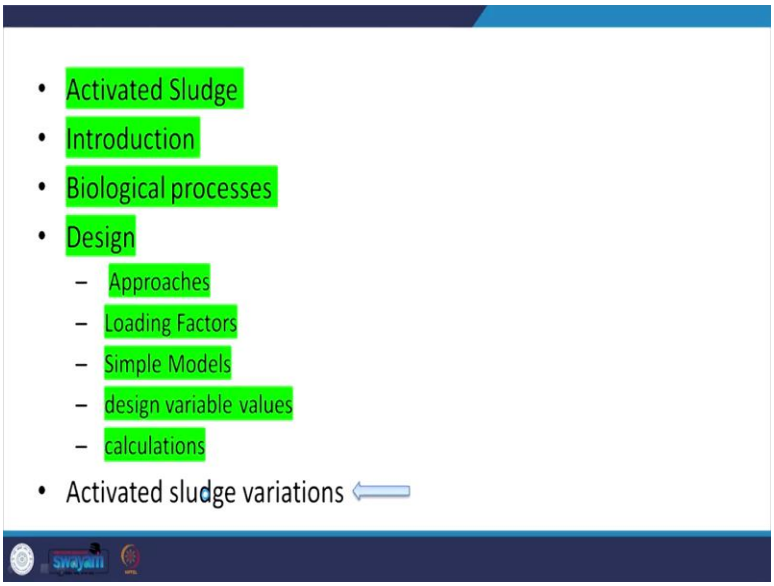
(Refer Slide Time: 24:29)



So in summary if Q is there the flow rate of the concentration of flow rate of the waste water and the concentration of the wastewater and regulations will typically give you if not efficiency what is the outlet for example in the plants discharging into Ganga. We know that the effluent body should be less than 10 milligram per litre. And from bench scale studies what are you going to have you are going to get the yield coefficient half maximum.

And mu max sludge volume index. Sludge volume index will give you an idea about how well the sludge is settling. And then safety factor or theta C and X can be chosen up front based on the kind of system that you want to have and then you will calculate for P mass off or biomass production.

(Refer Slide Time: 25:19)



So with that I am done with more or less done with design. So in the next session we will look at different kinds of activated sludge process and I think we will look at a video so that we understand the system in practical terms. And coincidentally I am also out of time. So thank you thanking you for your patience I will end today's session.