Basic Environmental Engineering and Pollution Abatement
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Lecture 31
Secondary treatment equipment 1

Hello everyone. Now, we will discuss on the topic secondary treatment equipment part 1, we have already discussed about the secondary treatment in our previous classes and we have seen the different units are used here like say activated sludge process unit and then trickling filter UASB and lagoon. So, these are some important unit or the steps or we can say the equipment which are used in the secondary treatment. And we will discuss about all these and in this class we will discuss about activated sludge process unit.

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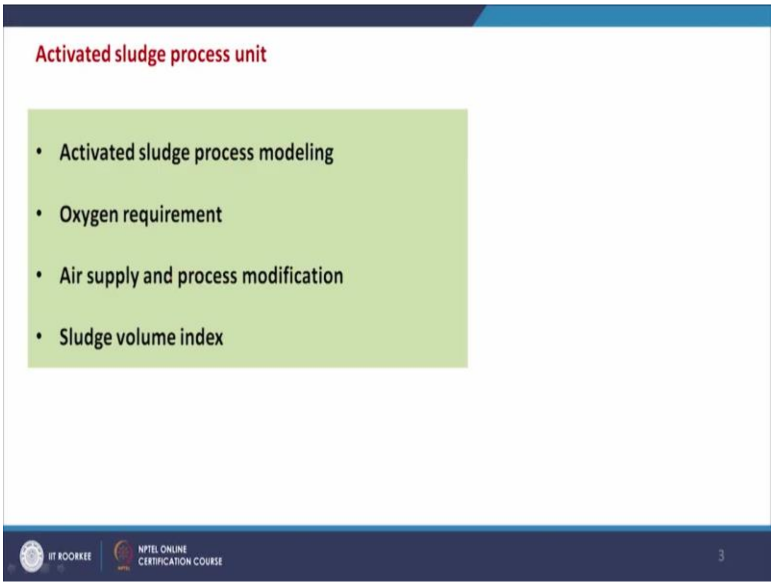

And we will be focusing on the activated sludge process modeling aspect, already we have made sufficient discussion on the fundamentals of activated sludge process and the growth kinetics of the microorganisms etc. in our previous class, now, we will be focusing on the design aspect that is activated sludge process modeling and oxygen requirement then air supply and process modification and sludge volume index.

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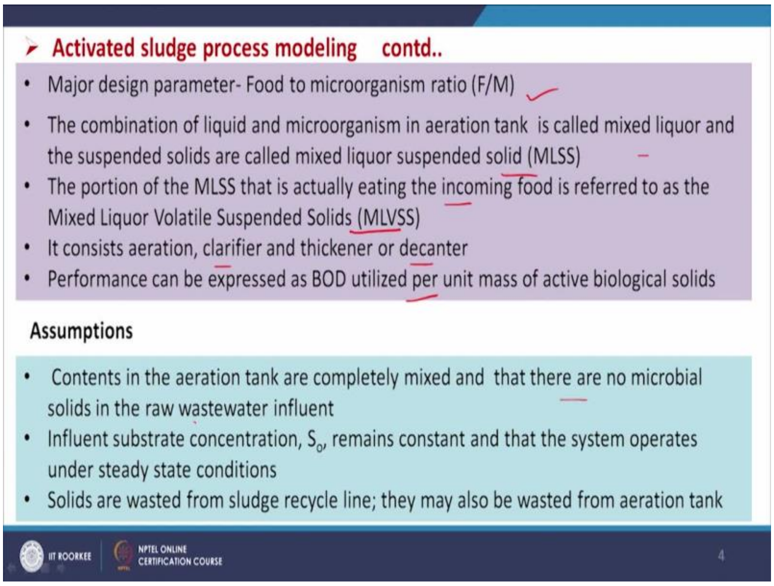

So, already we have discussed in our previous class, the activated sludge process uses microorganisms, which work on the organic substrate and of the organic pollutants and then deduce its concentration and after secondary clarifier that clear liquid goes out and sludge partially recycled and partially it is wasted and sent for further sludge management or sludge treatment.

So, the major design parameter for this system is food to microorganism ratio F/M. The combination of liquid and microorganism in aeration tank is called mixed liquor and the suspended solids are called mixed liquor suspended solid. we have already seen in our previous class also that in this process microbes are grown in the aeration tank and then microbial mass is developed. The total solid present in this aeration tank is called MLSS. The portion of the MLSS is actually eating the incoming food and that is referred as the MLVSS that is Mixed Liquor Volatiles Suspended Solids and these are the microbial biomass and how to measure these already we have discussed in our previous classes regarding characterization of the wastes.

So, we have seen their TSS Total Suspended Solids that may be volatile suspended solids and total suspended solids. So those can be referred and this activated sludge process consists aeration clarifier and thickener or decanter. And the performance can be expressed as BOD utilized per unit mass of active biological solids. So, this is the overall discussion on activated sludge process we have already made in our previous class also. Now, we will be focusing on the modeling aspect. So, for modeling, we need some assumptions. So, what are those assumptions, we are assuming that contents in the aeration tank are completely mixed, and that there are no microbial solids in the raw wastewater influent.

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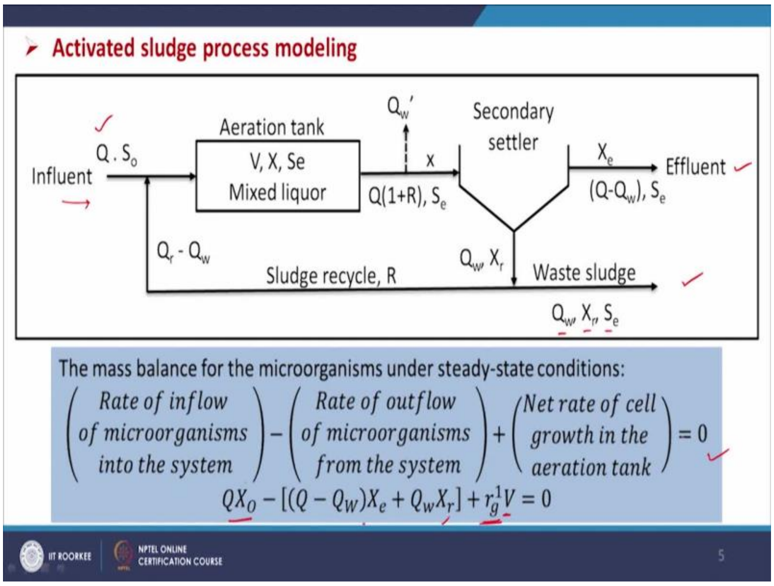

Like say example, if you see the flow sheet here, so, this is our aeration tank, so where influent is coming, and then that is having the concentration that is substrate concentration or organic load or pollutant concentration, you can say that is S_o and Q is the volumetric flow rate, then in this aeration tank, we will be providing air and microbial seeds will be provided here and microbial mass will grow and organic content will be degraded.

After that, it will be going out and then it will come into the secondary settler from the secondary settler will be getting the influent and from the bottom we will be getting the sludge part of the sludge is recycled and part of the sludge age sent as waste sludge for further management. So, if this is this flow sheet, then and if we want to develop a model on the basis of this flow sheet, then we need to consider some assumptions.

So those assumptions are here. One is that contents in the aeration tank are completely mixed, and that there are no microbial solids in the raw wastewater influent. So they are completely mixing. So uniform concentration we will be getting here and this there is no microbial mass present in the influent that is our assumptions. So, whatever microbes is coming that is from the sludge, the water is having no microbial mass. So, that is our first assumption. Other assumption is the influence of state concentration issue remains constant and that the system operates under steady state conditions.

That means this S_o is constant, this will not change with time. And another is solids are wasted from sludge recycle line, they may also be wasted from aeration tank. So, we are assuming that solid is wasted in sludge is wasted here. There is some option also that can be considered, but we are not considering this one we are considering that sludge is wasted from this line only. Now, if we want to develop a model on the system, then we can write the mass balance for the microorganisms under steady state conditions. Either we can develop the mass balance for microorganisms and also we need to develop the mass balance for the substrate. So, then we will proceed step by step.

So, The mass balance for the microorganisms under steady-state conditions:

$$\begin{pmatrix} Rate\ of\ inflow \\ of\ microorganisms \\ into\ the\ system \end{pmatrix} - \begin{pmatrix} Rate\ of\ outflow \\ of\ microorganisms \\ from\ the\ system \end{pmatrix} + \begin{pmatrix} Net\ rate\ of\ cell \\ growth\ in\ the \\ aeration\ tank \end{pmatrix} = 0$$

So, this is our equilibrium this condition will be maintained or other steady state this condition will be followed.

$$QX_O - [(Q - Q_W)X_e + Q_w X_r] + r_g^1 V = 0$$

where Q is the volumetric flow rate and X_o is the concentration of the microorganisms in the influent. And rate of outflow of microorganisms from the system, there are 2 outflow this one and this one.

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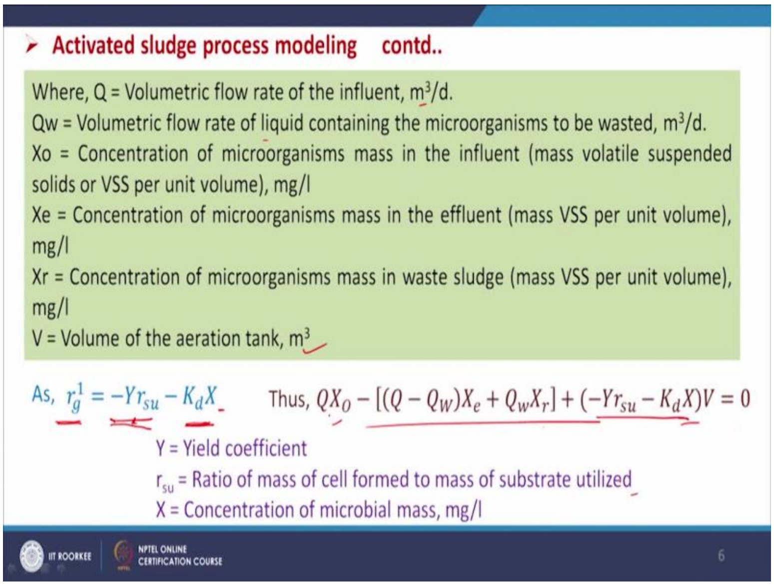

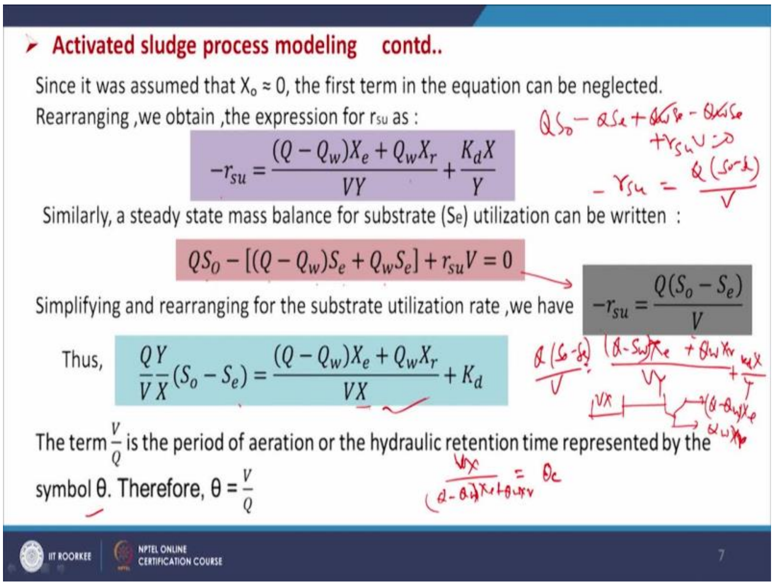

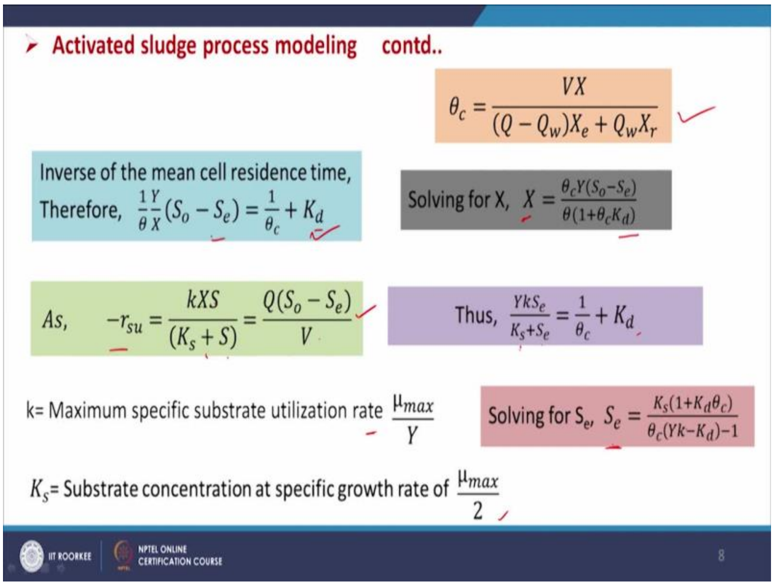

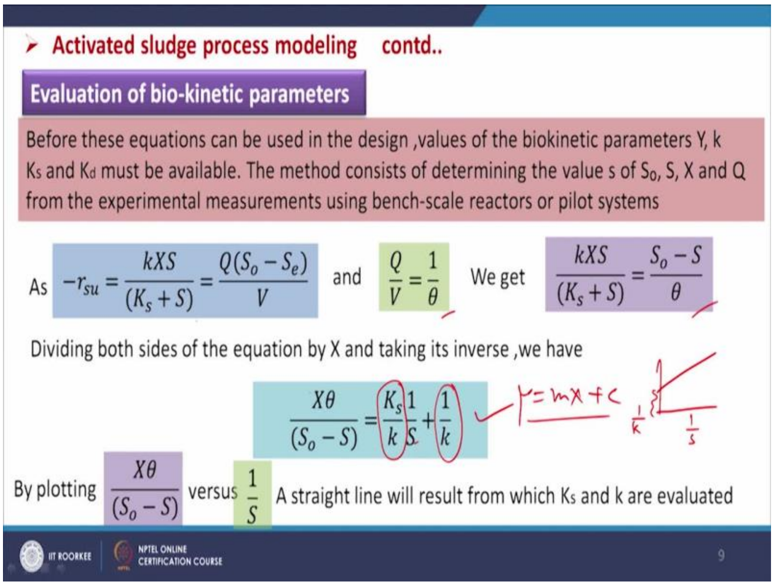

And in this case, that Q is the volumetric flow rate of the influent m^3/d and Q_w is the volumetric flow rate of liquid containing the microorganisms to be wasted m^3/d. An extra concentration of the microorganism mass in the influent and we have considered it as a 0 in this case and exceeds the concentration of microorganisms mass in the effluent that it mass VSS per unit volume mg/L and X_r is the concentration of microorganisms, mass in waste sludge mass VSS per unit volume mg/L and V is the volume of the aeration tank.

So, this is our expression we have gotten this previous slide this one, so now if we write this one in more detailed form,

$$QX_0 - [(Q - Q_W)X_e + Q_w X_r] + (-Yr_{su} - K_d X)V = 0,$$

r_g^1 that the growth rate of the microbial mass. So, in our previous class we have discussed

$$r_g^1 = -Yr_{su} - K_dX$$

So, $-Yr_{su}$ means, the rate of substrate utilization multiplied by yield coefficient Y= dx/dt. So, that we are getting here that is how the microbial mass is changing that is for growth and second part is for DK. So, that is DK constant K_d into x.

So, this total term is giving us overall growth rate. So, there is the net growth rate of the microbial biomass here Y is yield coefficient and r_{su} is ratio of mass of cell formed to mass of substrate utilized and then X is the concentration of microbial mass that is mg/L. So, this is the expression which we are getting here. So, now replacing this r_g^1 value in our previous expressions.

So, this is the expression now, and X = 0 as per our assumption. So, next expression we can get from this expression we can get by rearranging in terms of r_{su},

$$-r_{su} = \frac{(Q - Q_w)X_e + Q_wX_r}{VY} + \frac{K_dX}{Y}$$

Now, if we take the mask balance with respect to substrate, then also we can write

$$QS_O - [(Q - Q_w)S_e + Q_wS_e] + r_{su}V = 0$$

That means, what is the substrate getting entry and what is the substrate going out and what is the substrate converted.

So, that way that will be 0 at steady state condition. So, this will be the expression. So, by simplifying and rearranging for the substrate utilization rare we have now, if we rearrange this one you see here we are getting

$$QS_O - [QS_e - Q_wS_e + Q_wS_e] + r_{su}V = 0$$

$$-r_{su} = \frac{Q(S_o - S_e)}{V}$$

$-r_{su}$ we are getting from the substrate mass balance and from the biomass mass balance microbial mass balance we are getting

$$-r_{su} = \frac{(Q - Q_w)X_e + Q_w X_r}{VY} + \frac{K_d X}{Y}$$

So, both are same. So, then we can write this

$$\frac{Q}{V}\frac{Y}{X}(S_o - S_e) = \frac{(Q - Q_w)X_e + Q_w X_r}{VX} + K_d$$

$$\frac{Q}{V}(S_o - S_e) = \frac{(Q - Q_w)X_e + Q_w X_r}{YV} + \frac{K_d X}{Y}$$

Now, this Q/V we are getting and in our previous class, we have defined it that V/Q is nothing but the hydraulic returns and time. So V/Q is the period of aeration or the hydraulic retention time represented by the symbol ϴ. So, this one we can write in modified form,

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

You see VX is the volume of the biomass present in the reactor. So, if we have like this aeration then it is going to clarifier and then it is going to sludge.

$$\theta_c = \frac{VX}{(Q - Q_w)X_e + Q_w X_r}$$

So if this is the case, then by solving for X we will rearrange and we will solve for X.

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

So, we can determine the concentration of the microbial biomass in the aeration tank by knowing these values we can get the value of the X.

$$-r_{su} = \frac{Q(S_o - S_e)}{V}$$

And in the previous class, when you consider the relationship between substitute lesson date and growth of microbial biomass, so we have seen that

$$-r_{su} = \frac{kXS}{(K_s + S)}$$

$$-r_{su} = \frac{kXS}{(K_s + S)} = \frac{Q(S_o - S_e)}{V}$$

where k is the maximum specific substitute utilization rate that is μ_{max}/Y and K_s is the substrate concentration at specific growth rate of $\mu_{max}/2$ so, that we have defined in our previous class. So, if this expression we use and solve by that way we can get

$$\frac{YkS_e}{K_s + S_e} = \frac{1}{\theta_c} + K_d$$

For solving Se

$$S_e = \frac{K_s(1 + K_d\theta_c)}{\theta_c(Yk - K_d) - 1}$$

So, if I want to predict the concentration of substrate at equilibrium and concentration of microbial biomass in aeration tank, then these are the relationship which we can use to calculate these. So, without doing any experiment, we can calculate the value of S_e and we can calculate the value of X by knowing these parameters.

So, K_s, $K_{d,}$ Y and k are called bio kinetic parameter, we can determine it through some methods and then those values can be used to get the value of X and A_C without performing any experiment. So, that is the modeling aspect we wanted to discuss. And now, we will be discussing how these biokinetic parameters can be determined. So, you see we have one relationship

$$-r_{su} = \frac{kXS}{(K_s + S)} = \frac{Q(S_o - S_e)}{V}, \quad \frac{Q}{V} = \frac{1}{\theta}, \quad \frac{kXS}{(K_s + S)} = \frac{S_o - S}{\theta}$$

And just to rearranging

$$\frac{X\theta}{(S_o - S)} = \frac{K_s}{k}\frac{1}{S} + \frac{1}{k}.$$

Now, for determination of biokinetic parameter, if we perform some experiments, where we can measure the will of X, Ө and S_o and S the left hand side, this parameter we can determine for number of times, and for corresponding values of S, we can determine, and then we can plot in a graph. So, y = mx + c type of equation expression, we will get. So, in that case will be from this plot we will be having $X\Theta/(S_o\text{-}S)$ and this will be having 1/S. So the slope will be Ks/k and the intercept will be 1/k. So, you can get the value of small k and K_s by doing these experiments. So number of experiments you will have to do at the initial stage for the same system for the determination of biokinetic parameter Ks and K and that can be done.

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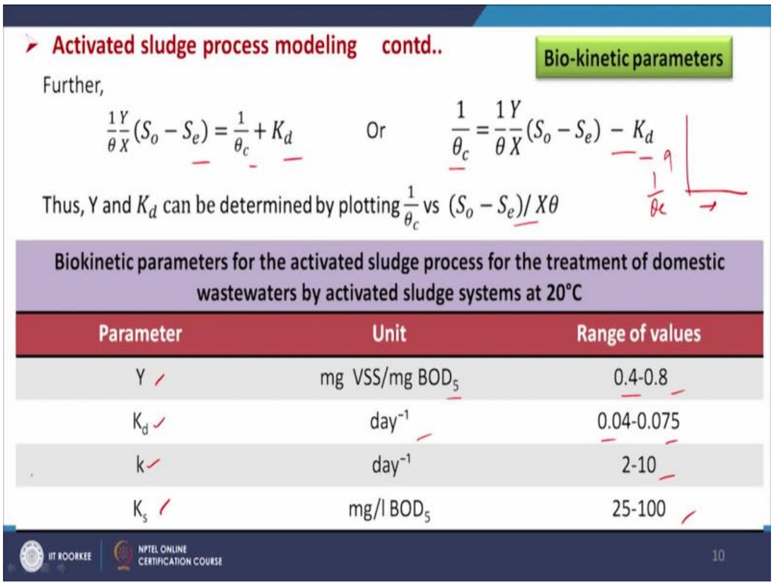

Now, we have another relationship

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

Or

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

So, $1/\Theta c$ and $(S_o - S_e)/X\Theta$. So, if we consider this, so, then we can have another plot, then we will be having this side $1/\Theta c$ other side is this $(S_o - S_e)/X\Theta$. So, we will be getting again a slope and intercept. So, that intercept will be this $-K_d$ value, and we will be getting and this from the slope will be getting the value of Y.

So, the 4 biokinetic parameters, we can get the K and K_s is from the previous expression, and from these expressions, we can get the value of K_d and Y in the similar way. So, these are the biokinetic parameters, which are basically determined through the number of experiments using the same system and then next, we do not need to perform an experiments we can predict by using these biokinetic parameters and applying this formula what will be the value of A_C and what will be the value of X.

So, now, let us see the range of these values at 20 ^{o}C. So biokinetic parameters for the activated sludge process for the treatment of domestic waste waters, where activities sludge systems are 20 ^{o}C. You see Y mg VSS for mg BOD_5 which 0.4 to 0.8, and then K_d per day

0.04 to 0.075 and then k per day 2 to 10 and Ks, mg/L BOD_5, verify that is 25 to 100. So, now, we have seen the biokinetic parameters.

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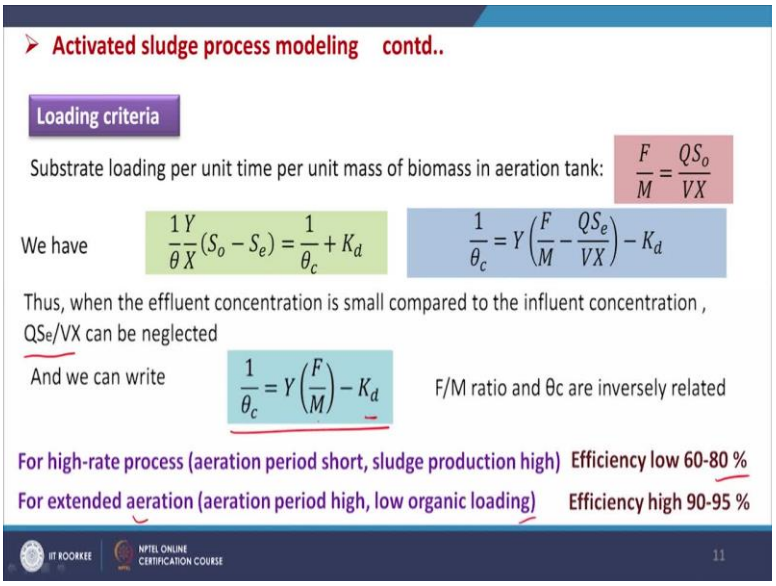

Now, we will see the loading criteria, loading criteria basically F/M ratio and Θ_C these two value influences the performance of the system. And in this slide we have seen that

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

And we also know that

$$\frac{F}{M} = \frac{QS_o}{VX}$$

Because F is equal to feed, So, Q volumetric flow rate into S_o, substrate concentration in the inlet and then mass of microbial biomass that is equal VX. So, if we use this relationship that is V/Q = Θ and again use this relationship here. So, we will be able to find out that

$$\frac{1}{\theta_c} = Y\left(\frac{F}{M}\right) - K_d$$

When Q S_e by VX is negligible that means influence substrate concentration is negligible. Then the Θc expression which you have used in the previous slide. So, that is F by M is substrate ratio. So F/M and Θc is inversely related. So depending on this Θc value and F/M, high rate process and extended aeration process are available for activities sludge process and for high rate process, aeration period short, sludge production high and efficiency low that is 60 to 80 % whereas, for extended aeration, aeration period high when low organic loading and efficiencies 90 to 95 %.

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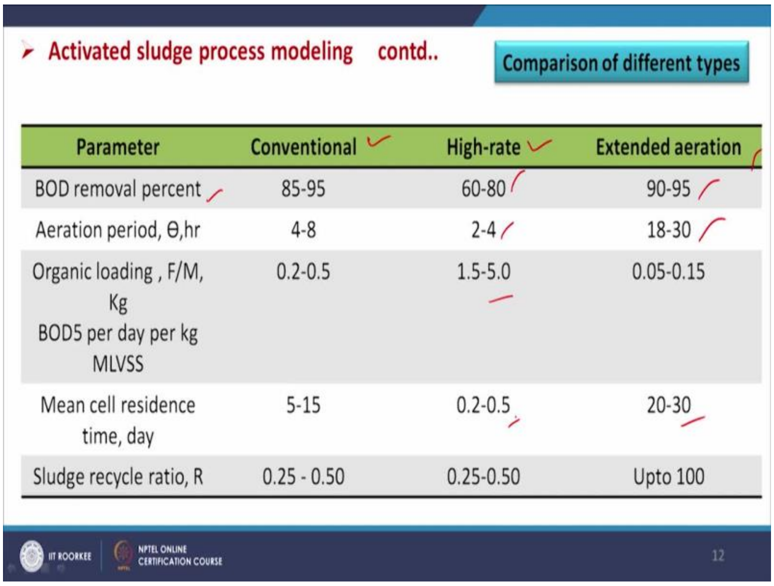

Parameter	Conventional	High-rate	Extended aeration
BOD removal percent	85-95	60-80	90-95
Aeration period, Θ,hr	4-8	2-4	18-30
Organic loading , F/M, Kg BOD5 per day per kg MLVSS	0.2-0.5	1.5-5.0	0.05-0.15
Mean cell residence time, day	5-15	0.2-0.5	20-30
Sludge recycle ratio, R	0.25 - 0.50	0.25-0.50	Upto 100

So now, we will see the comparison of different types one is conventional and is high-rate another is extended aeration. So here, BOD removal percentage we see the BOD removal in case of extended aeration mode because more air is provided and more residence time we will be giving you see here the aeration period is more but in case of high-rate aeration period is less and BOD removal is also less and organic loading that is kg BOD_5 per day per kg MLVSS, so, here also this is much and these values are less so, mean cell residence time here also we will be getting the maximum in case of extended aeration and minimum in case of high-rate. So, high-rate will be getting less removal efficiency, but its throughput will be much more with respect to other method and sludge recycled issue will also be different for different process.

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Activated sludge process modeling contd.. — **Comparison of different types**

Parameter	Conventional	High rate	Extended aeration
Excess sludge production, kg sludge solids/kg BOD_5 destroyed	0.5	0.5	< 0.5
Minimum allowable dissolved oxygen, mg/l	0.5-1.0	0.5-1.0	0.5-1.0
Air flow rate (m^3/day)/kg BOD_5/day	90-100	30-45	125
Sludge detention time, hr	1.5-2.0	2.0-2.5	2.5-4.0
Unit area for sludge thickening, m^2/(kg/day)	0.013	0.013	0.013
Overflow rate (m^3/day)/m^2	25-33	25	25

So, we will be requiring more treatment means more recycling ratio. So extended aeration so we will be having more sludge recycling ratio and excess sludge production kg sludge solids per kg BOD_5 destroyed those values are also different and it is much less in case of extended aeration. Minimum allowable dissolved oxygen in case of extended aeration this is equal to 0.5 to 1.0. So, minimal allowable dissolved oxygen.

This is same for all the cases and air flow rate requirement it is more in case of extended aeration because we are providing more air and sludge detention time again is more in case of extended aeration. In that case, we will discuss that sludge volume index will be more and sludge will get in this case. And unit area of sludge thickening it also provided here an overflow rate is also provided here that overflow rate is related to the clarifier design that how the upward velocity the water is experiencing when it is flowing in the clarifier so, that is almost similar in all the cases.

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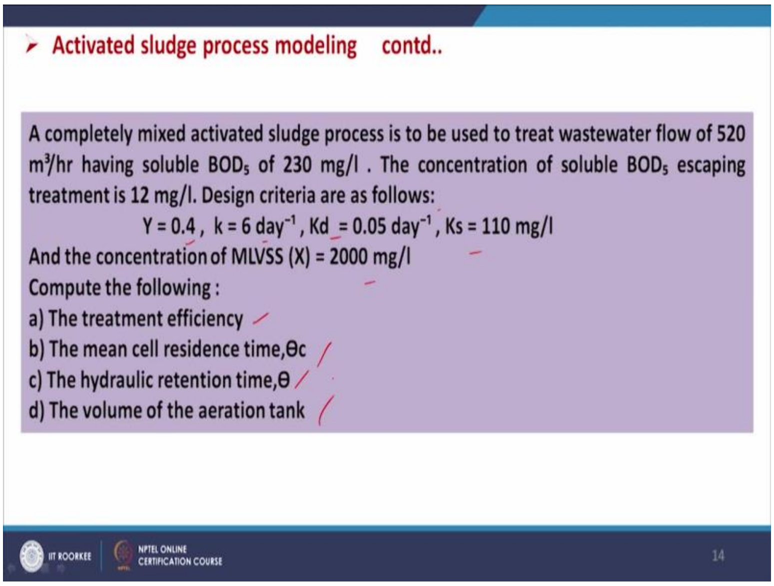

And now we will have one numerical problem a completely mixed activated sludge process is to be used to treat wastewater flow of 520 m^3/h having soluble BOD_5 up to 30 mg/L, the concentration of soluble BOD_5 escaping treatment is 12 mg/L design criteria are as follows. So Y equal to 0.4, k equal to 6 per day, Kd equal to 0.05 per day Ks equal to 110 mg/L values are given and the concentration of MLVSS is 2000 mg/L, then we have to compute the treatment efficiency, the mean cell residence time, the hydraulic retention time, the volume of the aeration tank. So biokinetic parameters are given. So we will be able to determine the performance.

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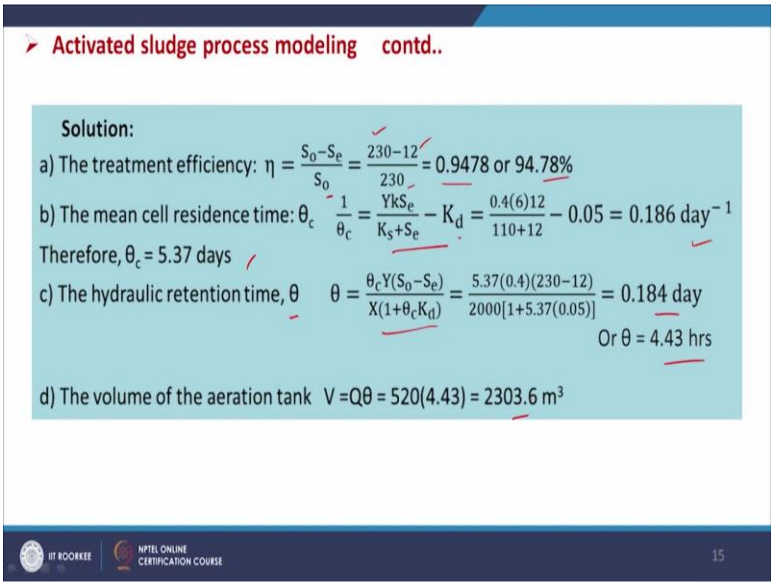

So

a) The treatment efficiency: $\eta = \frac{S_o - S_e}{S_o} = \frac{230-12}{230}$ = 0.9478 or 94.78%

b) The mean cell residence time: θ_c $\frac{1}{\theta_c} = \frac{YkS_e}{K_s + S_e} - K_d = \frac{0.4(6)12}{110+12} - 0.05 = 0.186\ day^{-1}$

Therefore, θ_c = 5.37 days

c) The hydraulic retention time, θ $\theta = \frac{\theta_c Y(S_o - S_e)}{X(1+\theta_c K_d)} = \frac{5.37(0.4)(230-12)}{2000[1+5.37(0.05)]} = 0.184\ day$

Or θ = 4.43 hrs

d) The volume of the aeration tank V =Qθ = 520(4.43) = 2303.6 m^3

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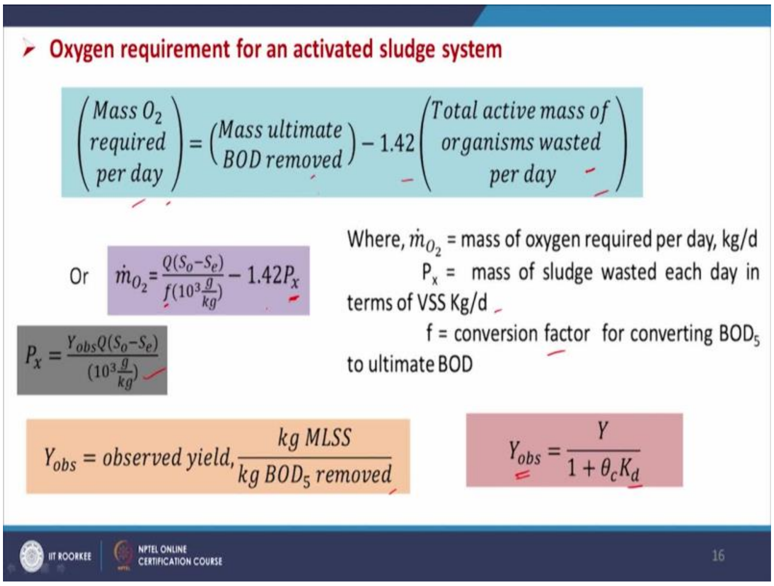

Now we will say what is the oxygen requirement For an activated sludge system.

$$\begin{pmatrix}\text{Mass } O_2 \\ \text{required} \\ \text{per day}\end{pmatrix} = \begin{pmatrix}\text{Mass ultimate} \\ \text{BOD removed}\end{pmatrix} - 1.42\begin{pmatrix}\text{Total active mass of} \\ \text{organisms wasted} \\ \text{per day}\end{pmatrix}$$

$$\dot{m}_{O_2} = \frac{Q(S_o - S_e)}{f(10^3 \frac{g}{kg})} - 1.42P_x$$

Where, $\dot{m}_{O_2}$ = mass of oxygen required per day, kg/d

P_x = mass of sludge wasted each day in terms of VSS Kg/d

f = conversion factor for converting BOD_5 to ultimate BOD

$$P_x = \frac{Y_{obs}Q(S_o - S_e)}{(10^3 \frac{g}{kg})}$$

$$Y_{obs} = \text{observed yield}, \frac{\text{kg MLSS}}{\text{kg BOD}_5 \text{ removed}}$$

$$Y_{obs} = \frac{Y}{1 + \theta_c K_d}$$

So, that way we can calculate the oxygen requirement for activated sludge process.

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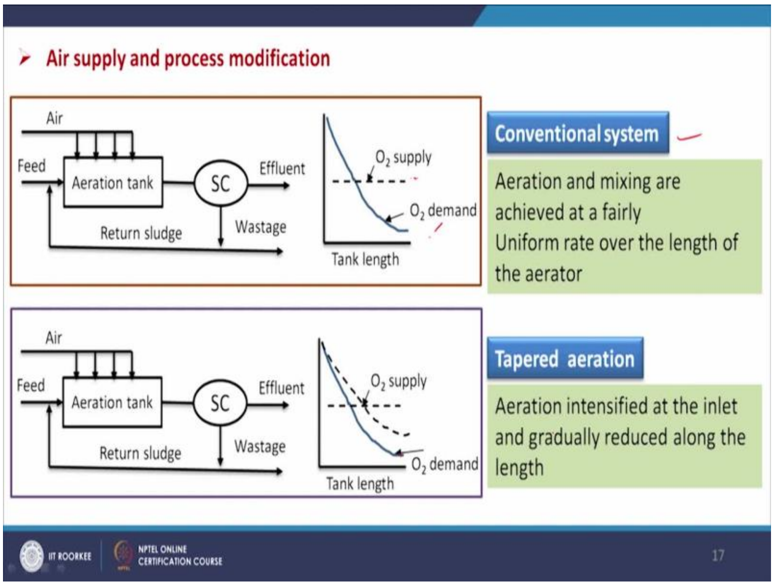

Now, how will provide air for the activated sludge process and we can get the optimum way for supplying air. So, here conventional system if we see in our aeration tank feed is coming air is sent at certain interval at the same rate so what oxygen we are supplying there is the same rate. But here the requirement is maximum here along the length organic concentration is decreasing. So, oxygen required for the degradation of those organic compounds will be reduced like this. Why like this, because the microbial growth follows the first order kinetics, so, this way it will be reduced.

So, this is supply, this is demand. So, this is my demand and we are providing more oxygen, so, we are losing oxygen. So, this is not a very effective process. So, people try to develop new approach and then in that case air is provided along the length but not in the same rate, the rate is reduced. So, like this oxygen demand is reduced and oxygen supply also reduced likewise. So, in that case, it was observed that the performance is literally more than the conventional system.

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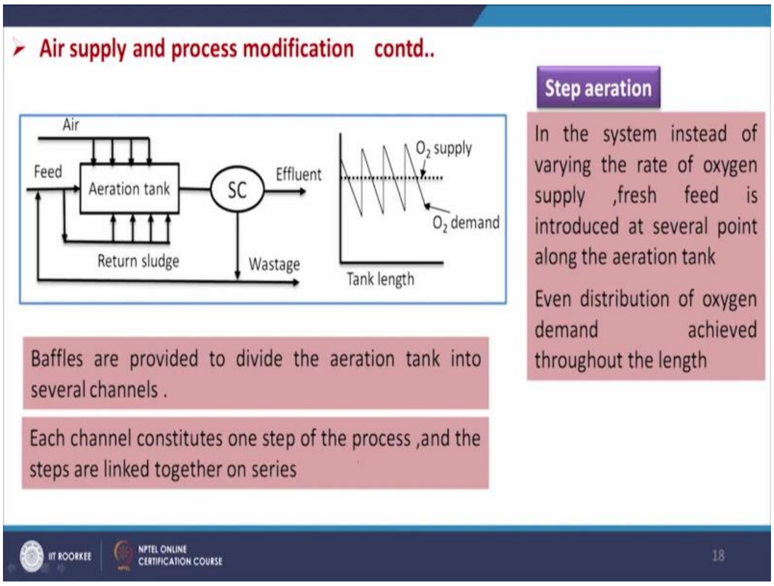

And then more investigation are carried out like say step aeration in this case, so feed is going there air is also sent. So air supply is constant, but feed is provided not only at the inlet along the length also at interval distance. So, oxygen requirement that oxygen demand gradually decreasing again new feed is added again it is increasing. So, again decreasing again increasing like this zig zag button, the oxygen demand is changing.

So, there are also some improvement was observed with respect to the conventional method. And in this system instead of varying the rate of oxygen supply phrase speed is introduced at several points along the aeration time even distributions of oxygen demand achieved through the length. And bubbles are provided to divide the aeration tank into several channels in this case, each channel constitutes one step of process and the steps are linked together on series.

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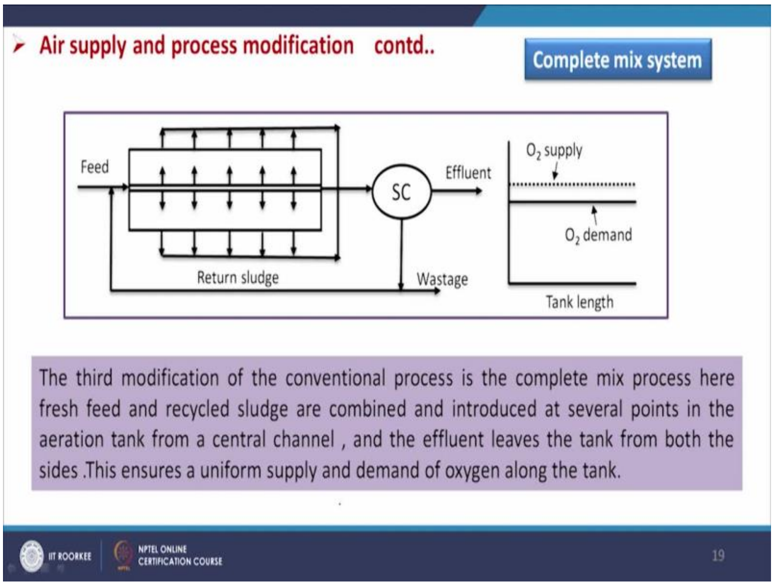

And then complex mix system have also been investigated. In this case feed and recycled sludge they are mixed and passed through this aeration tank it is diffused it at certain interval. Then from both side the detailed mass is going out and then it is secondary clarifier and then effluent and wastage we are getting. So, in that case oxygen supply we are providing an oxygen demand is also remaining.

So, that is also along the tank length oxygen demand and supply almost remains parallel. So the third modifications of the conventional processes is the complex mix process here fresh feed and recycled sludge are combined and introduced at several points in the aeration tank from a central channel and the effluent leaves the tank from both sides this ensures uniform supply and demand of oxygen along the tank.

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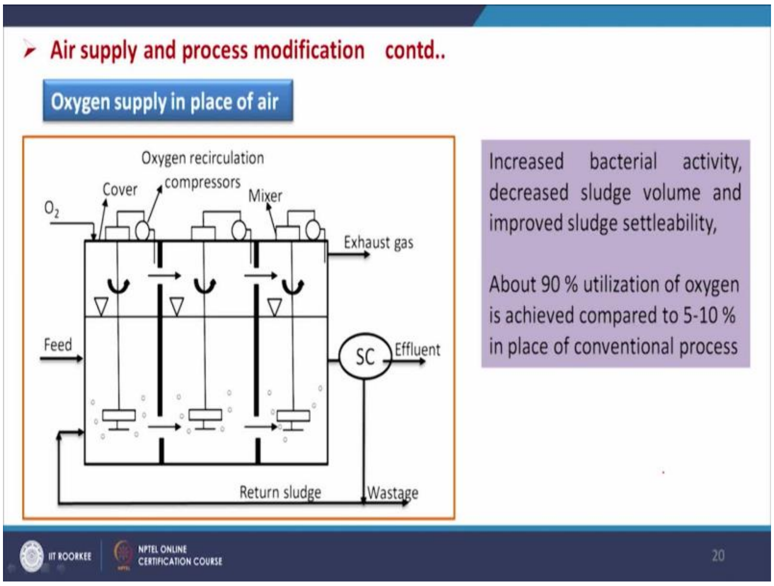

So, we can use pure oxygen also in place of air suddenly in that case, the handling of large amount of nitrogen is not necessary. And you see in this case, the increased bacterial activity decreased sludge volume and improved sludge settle ability we can achieve and about 90 % utilization of oxygen is achieved compared to 2 to 10 % in place of conventional process, but suddenly this is costly, because we have to produce the pure oxygen and that way this is not widely used in industry.

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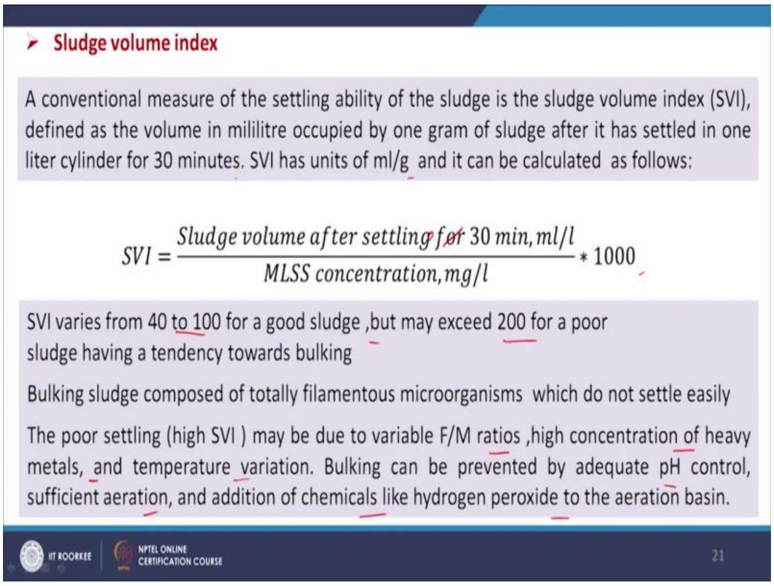

And next we will be discussing on sludge volume index. So, in the secondary treatment in the aeration tank, the organic compounds are degraded and cell biomass is developed show the solids residual and cell biomass that will be generated the mixed liquor suspended solids

MLSS and that needs to be separated from the water for further treatment or for tertiary treatment. And to understand that easiness of the separation of the solids from the solution the sludge volume index is developed and this is a conventional measure of the settling ability of sludge is the sludge volume index that is defined as the volume in milliliters occupied by one gram of sludge after it has settled in one liter cylinder for 30 minutes. Sludge volume index has unit ml/g and it can be calculated as follows

$$SVI = \frac{\text{Sludge volume after settling for 30 min, ml/l}}{\text{MLSS concentration, mg/l}} * 1000$$

SVI varies from 40 to 100 for a good sludge, but may exceed 200 for a poor sludge. So, if the value is more that means sludge volume is more. That means it is not very easily settleable. So, more desirable for separations of the sludge from the water is that SVI value will be lesser and that is 40 to 100.

This is considered as good sludge and bulking sludge composed of totally filamentous microorganisms which do not settle easily when this is more than 200 and the poor settling or high SVI may be due to the variable F/M ratio, high concentration of heavy metals and temperature variation. Bulking can be prevented by adequate pH control, sufficient aeration and addition of chemicals like hydrogen peroxide to the aeration basin. So up to this in this class. Thank you very much for your presence.