Wastewater Treatment and Recycling
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Lecture – 30
Biological Treatment of Wastewater: Microbial Growth Kinetics

So, in previous class, we have been discussing about the microbial growth and we did discuss some of the basic aspects of microbial growth and what are the basic requirements for the microbes to grow. And, what we are going to discuss in this lecture is about the Kinetics of the Microbial Growth.

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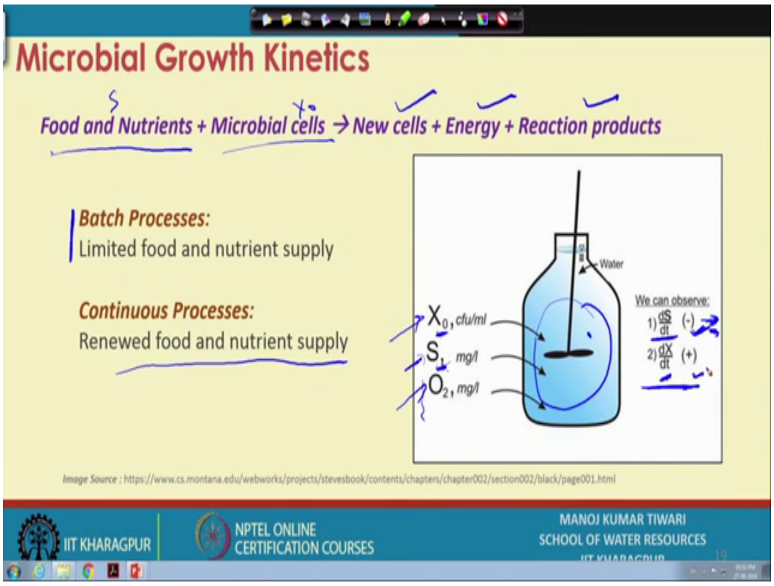

So, what we see that there are when there is food and nutrients available as we are discussing in previous class also. So, when all the requirements are fulfilled for the growth, there are food, there are nutrient, there are energy sources, there are favorable physiological conditions and then there are microbial cells present. So, they produce new cells, they produce energy and they produce reaction byproducts ok. This is typically such processes could be in the batch systems. So, we have already talked about what is the batch and what is continuous processes.

So, under batch processes what happens that because we are feeding inputs in a batch and then closing it so, no continuous supply of the nutrients or source. So, there is limitation of food, there is limited food present and limited nutrient present. Whereas, in continuous processes because we are continuously feeding in the system. So, there is a renewed food and nutrient supply. So, that is the basic difference between the batch and continuous processes in such system. Now, what we see here that if you let us say have a water or containing organic matter or substrate ok. So, that S is your substrate or organic matter or contaminant there is adequate amount of oxygen if it is aerobic process, there is certain amount of biomass present in the system. So, if you are having microbial cell that is your X 0, if you are having food and nutrient supply let us say S and the other physiological conditions or things are better.

So, what it happens? This will create more sales energy and that with now if you see what happens that substrate here or the carbon from the substrate is converted some of the carbon is converted into the biomass and some of the carbon is converted into the other byproducts ok. So, what happens that this substrate gets decreased because this is utilized by the micro organism. So, if we track the rate of the change of substrate d S by d t, it is often negative. While if we change the if we try to track the biomass concentration or d X by d t, it is often positive. So, that is what happens that the d X by d t which is X is your microbial cell.

So, rate of change of the cell being positive means there is an increasing concentration of cell in the system and rate of change of substrate being negative; that means, there is a decreasing concentration of substrate in the system. Now, being of if it is a batch process for say so, then since there is no renewed substrate sources. So, this will keep on decreasing until unless there is substrate is almost finished or exhausted and once the substrate is exhausted, the late of the biomass growth will also be not there. Because, the biomass present in the system will not have any food available ok. So, those kind of things will happen in that case.

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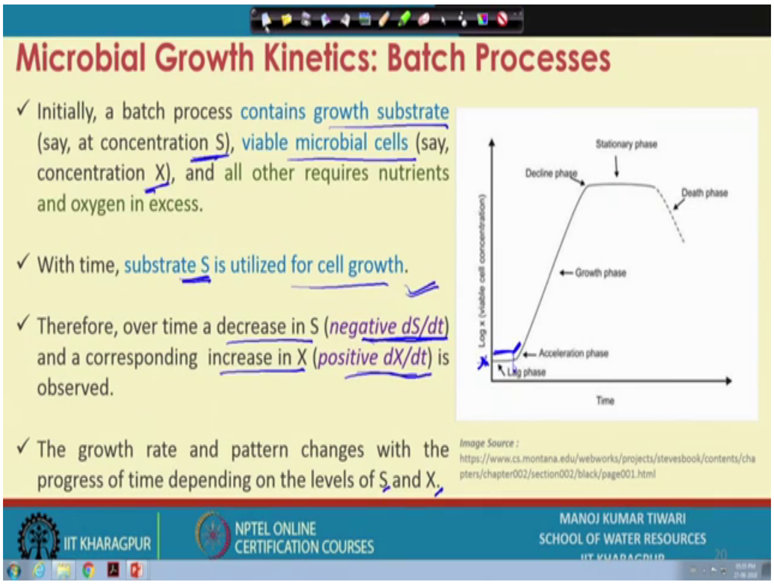

Now, so, if we see this batch process of the growth. So, initially what happens that there is there is a growth substrate present say the any concentration S, there are viable microbial cells present you say that concentration may be X and all other required nutrients and oxygen is for say in excess or in the sufficient quantity. So, growth is primarily dependent on the substrate. So, with time what happens that substrate S is utilized for cell growth and as we are discussing that we will see over a time decrease in the S.

So, d S by d t is negative corresponding to increase in the X. So, d X by d t becomes a positive this growth rate and pattern changes with the process of the with as the time progresses that depends on the level of the substrate and biomass present in the system. So, what happens in a batch process initially let us say we have we put in some cells here ok. X amount of cells, let us say we put in here what happens that if we inoculate cells from outside and they bought to a new environment. So, they try to first acclimatize in the system like for say we go to a new place ok, we go to a new place.

So, what is our first reaction? It is very difficult for us to like just went there and start working immediately ok. What we do? We first observe we first oversee if you are let us say moving to a new town. So, you will first see ok, your accommodation, your these things, you will try to settle in down your office productivity during that time may be very low ok. Because, you are more time more energy more effort is being spent towards getting acclimatized to the system. So, same thing happens with the bacteria they moved from a new environment to a batch culture with a specific type of substrate. So, they take some time to realize that in what conditions they are.

So, that is called acclimatization phase or lag phase and then, there is not much of growth in that period. Then, once their acclimatization phase is over, they start they realize that this is the food source available, there are the conditions favorable and those kind of things are there. So, then they multiply they grow and since initially, if say their concentration is very low and there is ample amount of substrate available. So, they grow pretty rapidly. So, they will from this almost negligible growth rate, they will accelerate ok. They will accelerate quickly and then that is becomes your acceleration phase.

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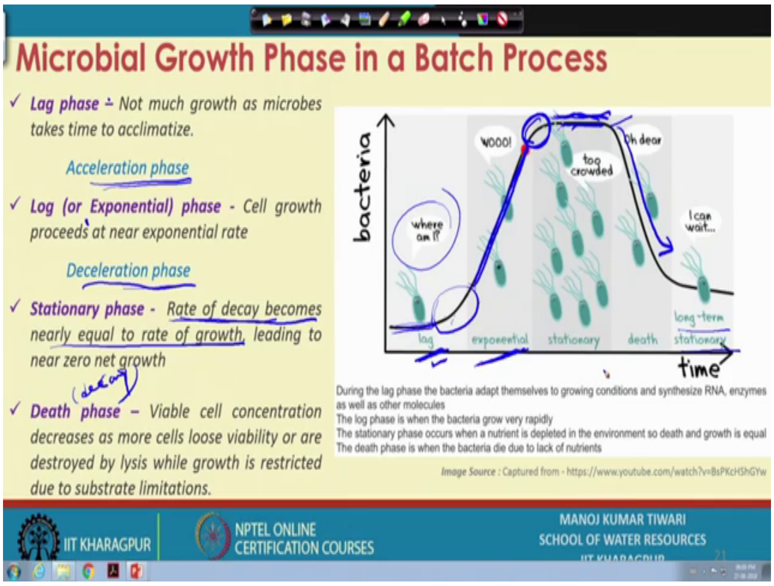

So, what happens? It is something like that in the initially there is when bacteria is introduced it says where I am ok. What has happened to me in which medium I am? So, it tries to get acclimatize and you will not see much of growth taking during that period. This is called lag phase. Then, once it realizes that ok, there are there are favorable conditions, there are all the nutrients available, food available, everything is fine. So, then it kind of grows very rapidly and that growth is near exponential.

So, we call that exponential growth phase or log phase. So, this is called lag phase or this is also called as acclimatization phase because here the bacteria is essentially trying to acclimatize and then in the next one, it actually growing exponentially. So, that is called the exponential phase or log phase because exponential is the inverse of log. So, that way, it is growing on a log scale.

In between, there is a transition from this not growing phase to a rapidly growing phase which is typically called as acceleration phase because it is accelerating it is growth rate ok. So, since it is accelerating it is growth rate, we call that as an acceleration phase and then once it has accelerated. So, it grows pretty rapidly. It grows exponentially and then once it grows exponentially during this growth process, what happens that it utilizes substrate. So, the substrate limitations started coming in and the concentration or the number of cells of the microorganisms start increasing. So, there is 2 conditions. The population of the microbes is increasing whereas; the food supply is decreasing, right.

So, there is since the population is increasing there is in fact, more demand of food. That way, but the substrate is decreasing. So, the amount of substrate is decreasing amount of microorganisms is increasing and that results again because, when the food falls below a certain category, we will talk about that when we discuss food to microorganism ratios. So, when this food falls below that food to microgram ratio category appropriate level category, the growth rate slows down and then we call that as a de acceleration phase or deceleration phase where the growth rate. Now, because it was growing rapidly so now, it slows down.

And then, there will be a phase coming when we do not see any net growth, why because the rate at which the bacteria is growing given the available substrate because substrate is very low in the system. So, the rate at which the bat biomass or bacteria grows becomes nearly equal to the indigenous rate of decay. So, there is shortage of food. So, bacteria goes on to decay as well. So, rate of decay becomes nearly equal to the rate of growth and that leads to the net rate of growth almost 0.

So, there is too crowded, there are lot of microorganisms, there is not much of food. So, there is a fight for food. Those who can get can survive; those who cannot get will undergo indigenous decay, those kind of thing. So, since the rate of growth and rate of decay more or less becomes equal. We not we do not see much of growth in this phase and that is why, it is called stationary phase. So, that will again last for some time and after that because it is a bad system.

So, all they substrate if is utilized, there is no more substrate present. So, there is no more growth because for bacteria in order to bacteria grow. In order to multiply, they need a food source, they need a carbon source, they need an energy source.

Now, if their carbon source is exhausted, they do not have food source present in the system. So, they cannot grow, but their decay will be taking place, ok. So, their indigenious decay takes place, but they are not growing. So, what happens? Their concentration starts falling and that is what is called death phase or decay phase, ok. So, this is death or decay phase ok. And this is lack phase or acclimatization phase.

So, we have lag phase or acclimatization phase log phase or exponential phase stationary phase and decay phase. So, these are the 4 more like 4 kind of important phases of the lifecycle of a bacteria in a bad system ok. Of course, there are acceleration de acceleration and at the end, when almost major thing as there might be few species which can survive for over a large period. So, there is a long term stationary phase can also come there very few population can still survive ok.

So, those kind of things are possible. So, that way we have these different growth phases of the back this thing. But they are the 4 major ones are lag phase or acclimatization phase log phase or exponential growth phase, stationary phase and death phase which is the typically when the endogenous decay becomes more prominent ok.

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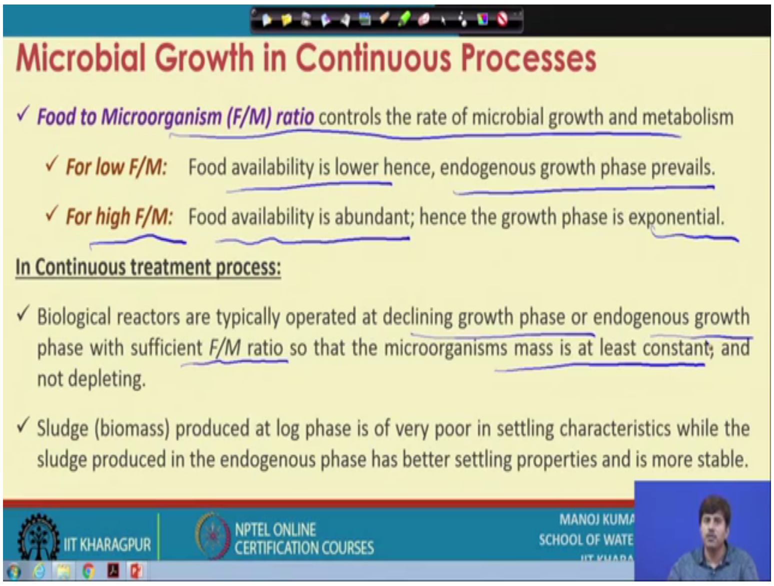

So, that is about a bad system. Now, if we see in the continuous processes. So, continuous processes there is continuous supply of the food, ok. Now, the continuous processes again will work based on the available food to microorganism ratio. And that is what controls food to microorganism ratio is what controls the sort of rate of microbial growth and metabolism. So, food to microorganism ratio essentially which is F by M ratio is essentially the amount of substrate present in the system and amount of the biomass present in the system. Because substrate is the food and M is microorganism is the biomass or the amount of bacteria number of cells.

So, when the food to microorganism ratio is low; that means, the food availability is lower and endogenous growth phase prevails. So, bacteria will grow in an endogenous or growth phase. There is not too much of substrate available, there is decay also taking place. So, all those things are there when there are high food to microorganism ratio. So, that means, food availability is in abundance and the growth phase is nearly exponential.

Now, in continuous treatment processes, actually the biological reactors are typically operated at this declining growth phase or endogenous growth phase, ok. So, it is not it generally does not work at a exponential growth. We do not operate reactor in that sense that is primarily because in exponential growth phase the mass of the biomass grows very rapidly and then it becomes very difficult to maintain the biomass growth at a constant level and that will lead to like your reactor will not come under a steady state.

So, in order to steady state operation, you want your biomass to be fairly constant that way. So, this that is why, these are typically operated at declining or growth rate phase. Declining growth rate means de acceleration phase post which almost the net growth is stationary as we see which is also called endogenous growth phase. So, there is sufficient food to microorganism ratio to maintain this thing. So, it is not that deep it is not that decay is prevailing and the system is losing biomass. But, there is not too much of growth of biomass also in the system. So, there is just adequate growth in order to maintain the biomass levels in the system, ok.

So, that the microorganism mass is at least constant and not depleting the biomass produced at log phase is of very poor in settling characteristic. So, when this like the cells which are often, it has been observed experimentally also that the cells which are produced in the log phase are not are not that sustainable. They do not get retained very well in the system and are like pronto wash out whereas, the cells produce in the endogenous phase. I have better settling properties and are more stable. So, they can retain in the system for larger time or for better time.

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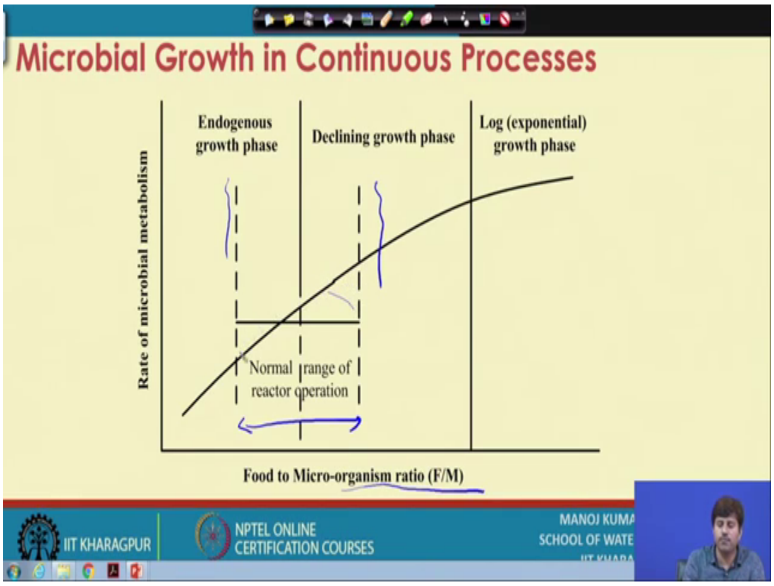

So, it is something like that you have a food to microorganism ratio that depends on the, this is your endogenous growth phase, this is your declining growth phase and this is the normal range of the reactor operation. So, during this like more or less the study growth phase, one actually operates the such systems.

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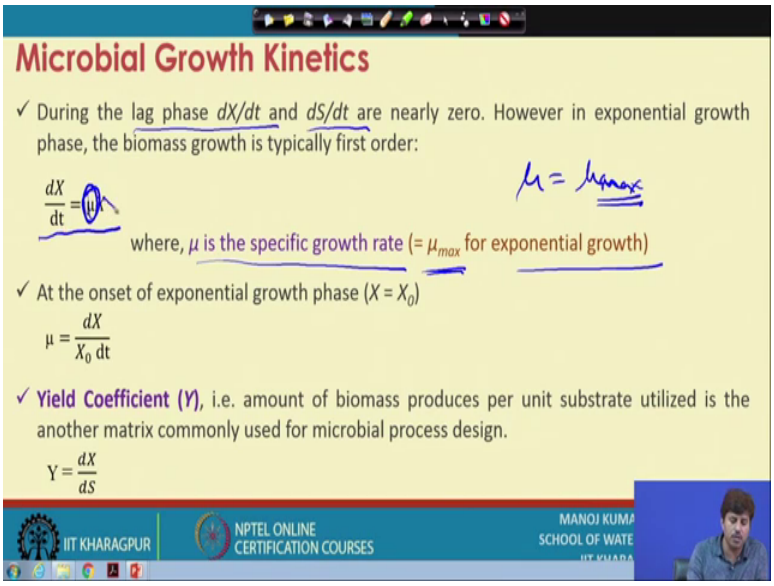

Now, if you see the kinetics of biomass growth, so, during the lag phase, the rate of change of the biomass and rate of change of the substrate are nearly 0 because, in lag phase, it is just acclimatizing. So, d X by d t and d X by d t are not that prevalent. They are nearly 0. However, in exponential growth phase, the biomass growth is typically of the first order because that is what the exponential system is. So, we will see that d X by d t is actually mu X and mu is the specific growth rate which is nearly equal to the mu max for exponential growth.

So, during the exponential growth rate, mu is equal to mu max. That means, the growth rate at which it grows it the maximum or the exponential system and that is how basically the growth takes place here. So, at the onset of exponential growth phase because when we are the exponential growth phase is just starting.

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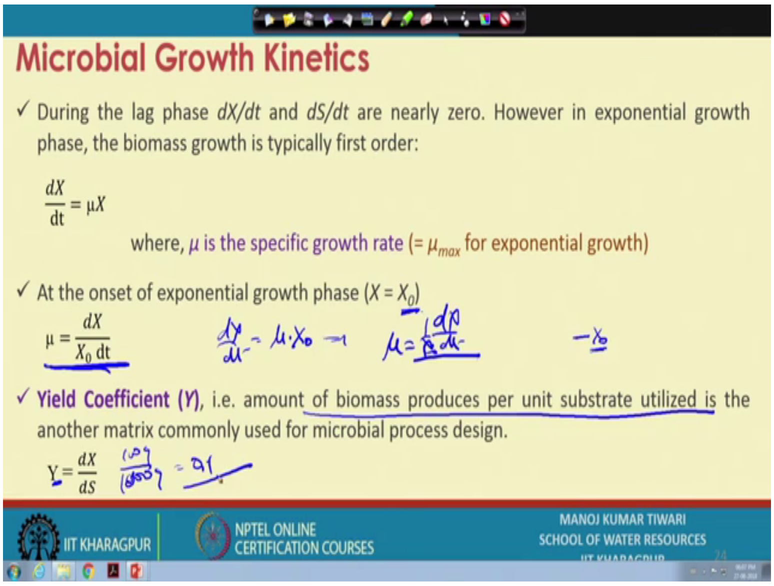

So, what happens at the starting point? If you let us say have added X 0 or biomass inoculated with X X 0 amount of biomass. So, biomass at the time t is equal to 0 is your X 0. So, that will like if you see your d X by d t rate of change will be actually mu times X 0 or from here we can get mu is equal to d X by d t to 1 upon X. So, X 0.

In fact, so, this mu becomes equal to d X by X 0 d t that is what is the specific growth rate is and then there is another term which is typically used to define such processes or used to basically model such processes yield coefficient which is typically denoted by Y which is nothing but the amount of biomass produced per unit substrate utilized.

So, if let us say 1 K g of organic matter is decomposed or 1 K g of substrate is utilized. So, how much biomass is produced out of that 1 K g this is a dimensionless number ok. So, if out of 1 K g, let us say you say that for say 1 out of this 1 K g 100 grams of biomass was produced. So, that means, your d X is 100 gram and d S is 1 K g; that means, 1000 gram. So, this becomes yield coefficient becomes 0.1 that way.

So, the yield coefficient is just ratio of the d X which is the change in the biomass concentration or how much biomass is produced with risk to the d S which is change in the substrate how much substrate is consumed and if you see.

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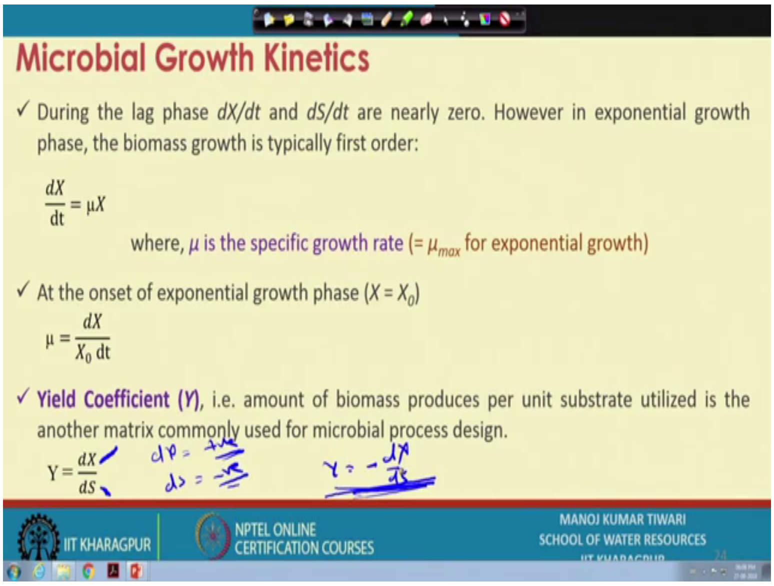

So, what happens that your d X is positive because biomass is increasing and d S is negative because substrate is decreasing. So, Y that way at few places you will see it is written as minus d X by d S ok. In order to see the sign control, but the point here is one should whether you are using this way or that way well you should realize that this is increasing while this is decreasing. So, if you take that way. So, Y is either you report Y as a negative or you use this formula and then report Y as a positive value.

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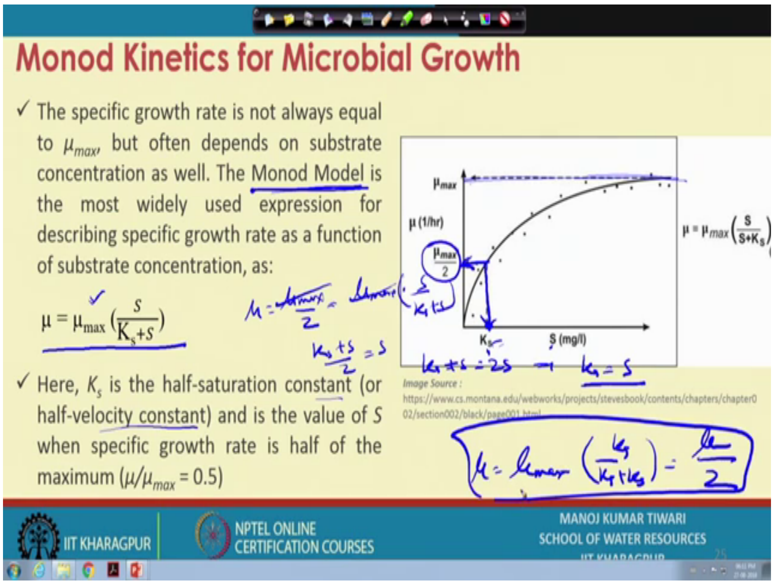

Now, that is just simple first order kinetics which first order kinetics assumes that the specific growth rate is close to mu max and that is why, the growth is exponential, but often it is not seen in the practice. So, it is actually not equal to mu max; it is lesser than mu max. So, that means, that the growth is not taking place exponentially and there might be a role of whatever is the substrate available or substrate concentration available as well. So, the Monod model was the one first one which actually kind of considered this and came up with a substrate dependent specific growth rate ok.

So, they had a specific growth rate which is a function of the substrate. So, the specific growth rate here mu is equal to mu max into S upon K S plus S, where mu max is the maximum specific growth rate which is close to exponential growth rate. In fact, ok, but in Monod it is they are different in Monod model. It is the different it is basically a empirical parameter that way and K S here is called half saturation constant or half velocity constant which means that is the value of substrate. When the specific growth rate is half of the maximum ok; so, half of the maximum means what happens if you have mu is equal to mu max by 2? Say, half of the maximum ok.

So, that means, you will have a equation as mu max by 2 is equal to mu max into S upon K S plus S. This cuts down here ok. So, you have K S plus S by 2 is equal to S or K S is plus S is equal to 2 S and then you will have K S is equal to S. So, it is actually a substrate concentration a value of substrate concentration at which the growth rate is half of the maximum growth rate. So, if this is my maximum growth rate, this is my half of the maximum growth rate. So, this value means at whatsoever substrate value, we achieve this mu max by 2 is known as K S value ok.

So, if you keep K S as like S ok. So, at S is equal to means, when you have S is equal to K S or K S is equal to S that way. So, when S when your substrate concentration is at K S. So, you have here mu is equal to mu max K S upon K S plus K S. So, that is actually mu max by 2. So, this way we can actually see that how we can get the specific growth rate as a function of K S and mu max some of the empirical parameter and dependent of course, dependent on the substrate.

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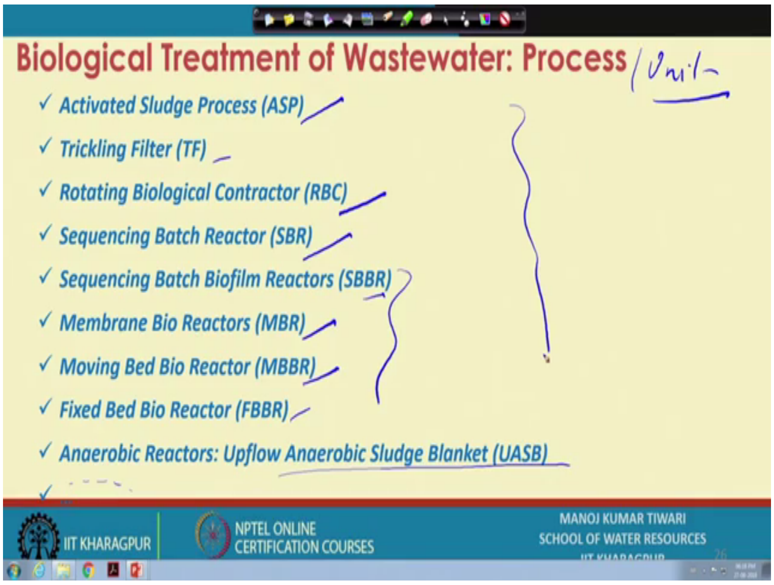

So, that is kind of the kinetics which are often used in designing the various reactors biological growth reactor. So, one can go for first order or one can go for Monod kinetics. Of course, there are various these things available in terms of various specific cases available.

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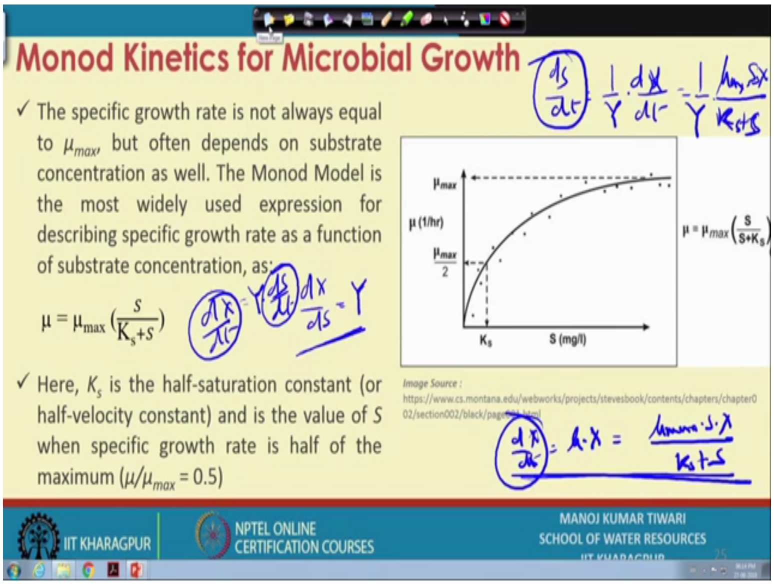

And, based on these mu value, we can actually have the like you see what d X by d t is equal to mu into X. So, that way if you substrate this mu, so, we will get d X by d t is equal to mu max into S into X upon K S plus S. So, this becomes d X by d t rate of change of the biomass. Similarly, we can have d S by d t ok. So, d S by d t how we can have we know that d X by d S is Y ok. This we know d X by d S is Y. So, here again from here we can see that d X is equal to Y into d S or we can divide both sides by d t here. So, d X by d t is Y times d S by d t or we can have d S by d t is equal to 1 upon Y times d X by d t. So, that will that way d S by d t will become 1 upon Y times mu max into S into X upon K S plus S.

So, this way we can actually get the rate of change of the substrate rate of production of the biomass ok. Using these things and these are the one which are used in the designing of the activated sludge process, we will which we are going to discuss in the next class anyway, ok. So, these are the things. Now, again we can have special cases, we can have simplification of this simplification of these things. So, remember like if we say in terms of biomass growth only ok.

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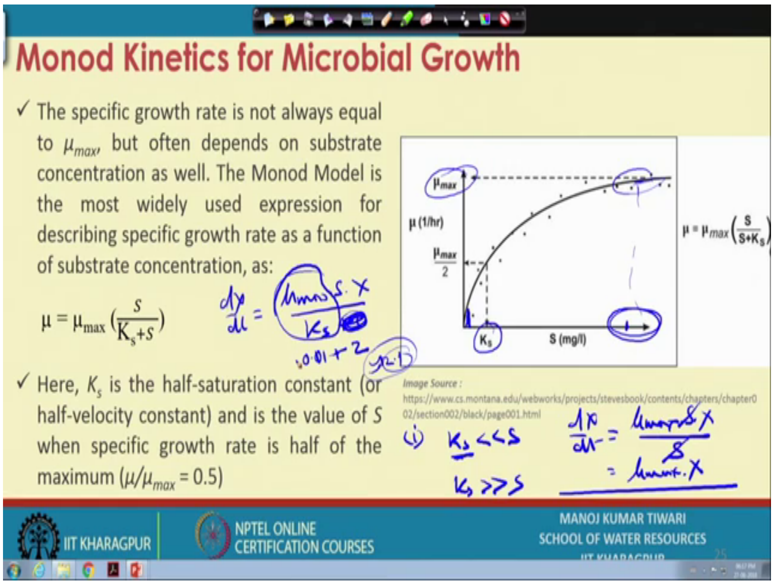

So, what we get? D X by d t here is equal to mu max into S into X upon K S plus S right. Now, let us see couple of special cases. As a special case 1, for say when you have your K S value very, very less than S, so, if your K S value is very, very less than S, what happens means you are actually; that means, you are working somewhere in this range where your S value is much larger than K S ok. So, if you are working in this range, you can see from this graph itself that your growth is close to mu max over here which numerically if you want to see that. So, you have d X by d t is equal to mu max into S into X upon if K S is very, very low than X.

So, let us say K S value is 0.1 and S value is 2 for say. So, if you add them, so, 2 becomes 2.1 or if it is 0.1, so, 2.01; so, almost is actually equal to 2 only. So, nothing much happens. So, we can ignore K S in that case and we can just keep S which gets canceled and what we get will be equal to mu max into X; the first order system ok. So, our growth rate becomes first order and it grows to at the mu max. We can have another special case when we see that your K S is way too large than S. So, we are somewhere here. In fact, and then what we can see we can actually omit S from here and then, we will have this way where this again becomes a constant ok. So, that way we can have certain special cases of this as well.

Now, these are the basics of the kinetics of biomass growth. So, these concepts are eventually applied in biological treatment systems and we can that we have a list of various processes or various units rather than which are typically used in the in the wastewater treatment systems. The microbial units which are used in the wastewater treatment systems the most common the most conventional is activated sludge process, then we have trickling filters rotating biological contractor, there are certain hybrid reactor systems also coming in ok. There are various configurations some other things are being tried out. So, there are sequential batch reactor S B R, there is a sequencing batch bio-film reactor S B B R.

Similarly, moving bed bioreactor M B B R or moving odd membrane bioreactors M B R fixed bed bio reactors. These are a series of different processes. Then, we have anaerobic process also up flow anaerobic sludge blanket U A S B is the most common one and the under the anaerobic category, there are various anaerobic fluidized bed reactor or those kind of things are also there.

So, there are many other process. It is not just limited to these, but these are the major ones ok. So, we will eventually take up few of these may not be all, but and try to see how they are deployed in the field, what are their working principle, what is their philosophy ok, what kind of performances they yield once they are used. So, we will conclude this session here and then, in next class we will have a detailed discussion on the activated sludge process.

Thank you.