Water Quality Management Practices

Prof. Gourav Dhar Bhowmick

Agricultural and Food Engineering Department

Indian Institute of Technology Kharagpur

Week-03

Lecture-12

Order of Reaction and Types of Reactors Used in Wastewater Treatment

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Bhowmick from the Department of Agriculture and Food Engineering of Indian Institute of Technology Kharagpur. So, with continuation of the lecture 11, we will be discussing in the module 3 about the fundamentals of reactor engineering and self purification of natural waters. In this particular lecture, I will be discussing about the order of reaction and the types of reactors used in wastewater treatment. The concept that will be covered are the order of reactions, the types of reactor, the reaction rate constant, the types of reactions, the homogeneous and the heterogeneous reactions and the catalyst in the reactions. To start with order of reaction are it is a very important, it is very important for us to understand the you know the I would say the quality of the reactions and the what are the nature of the reactions and how it will involve the substrates or the final byproducts of the products.

So, in general order of reaction by definition it is the relationship between the rate of change of concentration of the reacting substance and the concentration of that substance over time in that particular reactor or particular setup ok. So, say mathematically if I say ds by dt is equal to k into s to the power n.

$$\frac{dS}{dt} = K \times S^n$$

What is this $\frac{dS}{dt}$? This $\frac{dS}{dt}$ suppose is the rate of change of concentration of a substrate s and what is s is the concentration of the reacting substance ok. And k is the reaction rate constant and this n is a very it is very important, this n denotes the order of the reaction ok.

So, whereas, the t is the time taken during the reactions and also this k $\frac{dS}{dt}$ is equal to $K \times S^n$. This a number value in s n value of n is actually the one that will determine the order of the reaction ok. What are the importance of it? This determines the rate of reactions in order to successfully operate the treatment plant. It provides an indication of how changing the concentration of the reactant will affect the reaction speed and the other product by product recovery of the product recovery of the system. Suppose n is 1 this $\frac{dS}{dt}$ will become k into s isn't it.

And suppose it would be considered as a first order reaction then suppose that the n value of n is 2 that means, ds by dt will become k into s to the power 2 ok. It is a second order reaction and so on so forth. So, at which case it will be called 0th order reaction? What will be the value of n in case of 0th order reaction? Definitely 0 if the value of n is 0 S^0 means 1 if any unit to the power 0 is 1 anything about to the power 0. So, S^0 is 1. So, ds by dt will become constant that is why it is called the 0th order reaction.

But in case of 0th order reaction what will happen what does that mean? That means, the change of substrate has nothing to do with the inlet I mean like the nothing to do with the concentration of the reacting substance it is anyway constant ok. So, and what are the different factors at which this rate constant are affected on? First of all the temperature, temperature of the reaction, temperature of the nearby area when the reaction is taking place, the nutrient present in the waste water or the water or the reaction when it where it is taking place the toxicity. The presence of the toxicity will definitely change the characteristics of the microorganism the presence of microorganisms at a whole. So, which will also drastically change the reaction rate. And then there comes the catalyst sometimes we add catalyst.

What is the basic definition of catalyst? It somehow it will not act on it will not directly involve by itself in the as a substrate or as a product it will be only useful this catalyst to somehow accelerate or decelerate the reaction that is why it is called catalyst ok. That is why we call it catalytic reactions in the sometimes it can be accelerating the reaction it can be decelerating the reaction ok. So, based on this catalyst presence of catalyst also the rate constant will change isn't it? Then comes the zeroth order as I was discussing the N=0. Rate is constant it is independent of the substrate concentration what is the example? Certain catalytic reactions in certain catalytic reactions you add some catalyst it is you are you know that your the substrate I mean like the substrate concentration it does not have any effect on the change in substrate I mean change in substrate over time ok. So, the rate of change in substrate over time.

First order the rate is proportion directly proportional to the concentration of the reacting substance most of the most of the cases are decomposition of single substance as I was discussing in the earlier lecture also if you remember that suppose you have a sugar solution it has only the sugar ok. Suppose the only one particular chemical. So, the rate of change of this reaction will be obviously, directly proportional to the concentration of the reacting substrate. The more the reacting substance the more the sugar that you add it will take more amount of time which is quite directly proportional unless until some additional factors are also taking into like you know started playing a major role here ok. We will discuss about that also in this particular example please remember.

Next is second order in some cases the rate of change of this reactions is proportional to the square of the concentration of the reacting substance. For example, some attached growth biological processes like super rate trickling filter and all we will be discussing about it what is super rate trickling filter. This trickling filter we are hearing a lot. So, you will be understanding it in a very finer way in a coming modules that how this trickling filter comes into the picture what is this and how it actually works this is a very fascinating treatment unit ok. Anyway before that we have to understand what is attached growth also.

There are attached growth process and suspended growth process we will be discussing more in coming lecture, but to give you a glimpse suspended growth means suppose you have a column of water if a cylinder of waste water in the waste water there you are aerating and some amount of some kind of microorganisms will start grow into it. Those microorganisms will consume the substrate. So, once it will consume the substrate it will grow it will if it will not attach to the boundary wall or it will not attach to the peripheral wall or it will not attach to the on the bottom it will be floating freely floating on like floating on you know like in a moving or around the column of this water column what it will happen it will be called as a suspended it is not it is not in attached growth one it is a kind of like you know freely moving one ok. So, then there is come there is come there come some kind of microorganisms which needs some place to attach then only they will grow further we call it attached growth. So, there is one type of suspended growth another one is attached growth ok.

You understand this attached growth this trickling filter is a type of attached growth process that means, you need to provide some media some material on which over the surface or inside of some area is available for microorganism to grow. So, when the microorganisms will grow it will also reduce the substrate concentration it will reduce the pollutant concentration. So, that is how it works ok. In biological reactions definitely the order of reaction are in it is very crucial because you know it will give us an idea about that

how pollutants will be removed and the impact of different environmental conditions on the treatment process. It also helps us to optimize the treatment systems for more efficacy like biological stabilization of organic matter or etcetera.

So, when we talk about the biological stabilization of organic matter it is it is a very fascinating. So, in general when we were discussing about the simple sugar solution I told you it is a first order equation in general right. It feels like you know if you have the only you keep on adding the sugar it will take more amount of time for your organic for your biological treatment system to consume it I mean like the microorganisms to consume it. However, though it looks like a first order reactions it is actually pseudo first order reactions also we can mention. Because what happens sometimes it may have some say like some amount of additional foreign matter particles.

Normally on the most of the reaction in the organic matter when we add in the wastewater treatment unit it has a different kind of organic matter which does not follow the individually they follow the say like first order reactions, but when it comes they comes along with each other along with some environmental parameters also come into the picture. So, those environmental parameters also control the reaction. So, at that time it becomes the pseudo first order reaction. That means, the rate of reaction is proportional to the organic matter concentration at favorable parameter and which is controlling the reactions provided those parameters are favorable to them then only it will be considered as first order otherwise it is a pseudo first order and that is why it is it has certain you know like the controlling parameters. So, because of that it is called the pseudo first order reactions.

What is pseudo zero order reactions? The organic matter concentration is maintained constant within a narrow range and the rate of reaction is practically constant. That means, suppose your treatment unit is receiving same amount of waste for same amount of waste for a very small amount small range of time and all ok. But I mean a small amount of for a longer period of time in a very the I mean like the change of concentration is very narrow ok. So, it is almost receiving the same amount of waste over time. Once it will receive the same amount of waste over time all the reaction parameters will actually looks like it is constant because it is not changing the the the the it is.

So, it becomes the zeroth order reaction. So, it is called it looks like a zeroth order reaction, but it is actually a first order reaction. So, it makes it little bit ambiguous to each other. So, that is why we call it pseudo zero order reaction ok. In general the complex substrate present in the waste water or the sewage it may appear as first order reactions

with individual substrate exhibiting the zero order reaction kinetics and all ok.

What is the reason? Initially this reaction will be much higher because of the higher utilization of the easily biodegradable waste and then rate becomes slower with respect to time due to more complex substrate left in the reactor. The most more complex substrate will be there it will take more time for the microorganism to consume it with time. The reactions in the reactor. So, one of the major important thing is here the temperature either some reactions are heat liberating or the exothermic we call it some are heat absorbing or the endothermic in nature. So, operating temperature is thus the very important factor for designing a reactor.

The reaction in a reactor can be called homogeneous when it occurs only in single phase and when it heterogeneous that means, when it occurs in at least in the presence of two phases you can see the picture you can understand like you know in the homogeneous phase and you have a heterogeneous phase ok. So, then we have the catalytic reactions the reactions occurring in a reactor may be classified as catalytic or non catalytic based on what? Based on the presence of catalyst. If the catalyst are used is neither reactant nor product, but it can either accelerate or hinder a rate of reaction as I was discussing. So, this is called a catalytic reactions. In general wastewater treatment or treatment processes is generally achieved in the reactors through physical chemical and the biological process facilitating the treatment provided we sometimes add some catalytic reaction also in it and it can be homogeneous or heterogeneous in nature.

What are the types of reactor based on the you know the like the treatment process that will be following in order to achieve more better treated water with no minor or say almost no modification in the installed infrastructure we need to design a reactor in such a way that it will add the flexibility of retrofitting, it will add it will actually do the job that we are targeting in a minimum operational land requirement or the footprint we call it. The reactors of the wastewater treatment systems also have should have a different performance characteristics and also different direct impacts on the environment as I was discussing and the system modification is achievable only by the simple alteration of the process for a quality parameters. This is also very important for us to understand whenever we will be designing a reactor. So, you can see that in general how it looks like it is a very symbolic very nice picture if you see in the bottom the wastewater comes this rack or the screens then it goes to the grid chamber the grids were settled down in the bottom then it goes to the clarifier for primary sedimentation then it goes to the activated sludge tank is nothing, but the biological treatment unit from activated sludge tank the secondary treatment start the biological or biochemical treatment start. Then it goes to the immobilized lacquers chambers and then it goes to the flocculation on the filtration tank and then it goes to the

after the filtration everything is done then it goes to the water which is coming out of the treatment plant is almost clean water or you see we call it clarified water that clarified water it is almost clean almost adhering to the guidelines given by the regulatory bodies in general.

So, let us discuss about the types of reactor ok, why it is very important for you to understand when you will design a wastewater treatment unit or the plant ok. Based on the type what are the different types of reactors? Batch reactor, plug flow reactor, continuous flow state, tank reactor, arbitrary flow reactor, packed bed reactor and the fluidized bed reactor ok. What is batch reactor? It is very easy for you to understand suppose you have a container you have a container you fill it with the wastewater and leave it for say like one day. After one day say when it will you are sure that there are the substance I mean like the organic organic matter concentration goes down a bit then you take out the take out the supernatant and the sludge you put it in the different bucket then you clean it and then use the same tank same I mean like the container for new wastewater and use it for another one day. So, this is like the fill reaction settle decant and idle.

So, this is called the batch reactor means like you are using the same reactor and using you are waiting for the reaction to take place from the beginning to the end and you do this all the 5 operation at the same time then you start a new one in the same reactor it is called the batch process ok. They are normally operated as a fill and draw process fill and draw type fill and draw type you fill it and make the wait it for some reaction to take place then settle it when the settle solid is there and then you have you have you have the decant it and then you let it idle for some time or wash it and use the new batch again ok. So, this is called the batch reactor ok. You can easily understand BOD bottles we discussed about the how BOD we analyze the BOD reactors and all this BOD bottles are incubated in a incubator chamber for analysis of BOD is a type of batch reactor ok. Another important is a sequencing batch reactor or SBR remember this name SBR we will be discussing about it a lot and in future and it is a very advanced treatment unit that nowadays all over world people are working on SBR sequencing batch reactor SBR.

It drastically reduces the footprint required for a treatment plant instead of having a lot of treatment unit it can it can has it has the capacity to reduce the footprint like anything ok. Then there comes the continuous flow steer tank continuously mixed reactor we call it. Suppose you have a system where you are keep on mixing the water you know by some by using some mixer by using some say agitator or some aeration some by some means you are keep on mixing the water continuously. So, the what will happen when you add the influent you cannot distinguish you can take sample from any random point and the water constituents the homo like you know same characteristics the I mean like the whole reactor

will have a same homogeneous content. This is called the continuous flow steer tank reactor and all ok.

Then you when you keep on adding with proper calculation has to be done you add with a certain influent characteristics and the effluent has to be collected which will be having which will be having less than the parameter that is having that is there in the influent one another ok. So, this is this is quite interesting this continuous flow reactor and all. Then there comes the plug flow or the tubular flow reactor it is very easy to understand. It is more like you know you have a it is more like a you have a system where you put the water from one side and from the other side it will go out. So, the time taken inside this inside this say reactor is exactly the time for which the water will stay in the system you understand.

So, it is like you know the first water molecule when it enters to the systems it stay there for like say like 2 days and exactly after 2 days that water molecule will exit the system. So, whenever new water molecule come in the in the in the second one second one will come exactly in the second position second to the first one when it will leave. So, it will all the water molecules I mean like theoretically it should have exact amount of time to stay inside the reactor ok. So, it is like you know the I mean like the it has this proper system proper you know you know it is like you know we call it this is called this is why we call it plug flow or tubular flow reactors you understand. This is the all the particles remain in the tank has a for a time is equal to the theoretical detention time.

Then there comes the arbitrary flow or flow what is arbitrary flow? It is more like you know it has a it is a mixture of say the continuous mixed continuous type and continuously mixed time and also the plug flow time. So, it has a intermixing or dispersed flow, but it is somewhere lies between the ideal plug flow reactor and the ideal completely mixed reactor ok. So, it also we use arbitrary flow quite a quite a good amount of time in actual real field where the treatment plants are actually designed before the equillation tank was installed. If equillation tank is not installed because they have a arbitrary flow in the system. Then there comes the packed bed reactor packed bed reactor is nothing you have a media and waste water is in like you know come kind how to say introduced to the system from the bottom and then say like we have a media or it can be done from the upper side also ok.

It is not necessary that it should be bottom in this picture it is shown the off flow one there can be down flow one also ok. So, I mean like in general the off flow one if you see the picture how it looks like the waste water has to flow through a media then the effluent will come out from the top and it will be discharged. How it is important because this media

this is packed bed that means, this packed bed in this bed bed means this is a region where the microorganisms can develop easily ok. So, when the aeration is also supply in this particular case if you see the aerobic bacteria will grow. So, air along with the waste water enters to the media enters to the media bed and it will cross the media bed and it will go out.

That means, the aerobic bacteria will grow there in a very nicest fashion and it will actually consume the huge amount of pollutant from the waste water and then waste water once it will be consumed this waste water will go out of the system ok. This is called the packed bed reactor. Then there comes a fluidized bed reactor it is also type of packed bed only the only difference is the it is expanded to because of the upward movement of the fluid. In case of packed bed we are not letting in general the standard one the conventional one we do not let the bed to move much. However, in case of fluidized bed the it is looks like the bed is in boiling it is like you know it is keep on boiling it is like you know I mean like it is goes up down like you know there is a certain movement this is called the fluidized bed as if like the bed is in fluidized condition ok.

And because of the it can be done because of the flow rate also higher amount of flow rate that you can maintain or there is a chance because of the aeration additional aeration also you can do that. So, this is called the fluidized bed reactor ok. In this fluidized bed because of the presence of fluid of the air we make the bed in a floating condition this kind of like system like or very advanced very advanced and nowadays people are using it like anything. In general the moving bed biofilm reactor or moving bed reactor this is also called the this fluidized bed is also type moving bed is also type of fluidized bed reactor. In this concept nowadays very much encouraged in the washable treatment by properly selecting the media material which has a specific gravity close to that washed water.

So, that it will make this flotation possible I mean like floating thingy like fluidized thingy possible. So, these are the different types of reactor that we discussed. It is very important for you to understand this different types of reactor ok. So, first one we you remember batch reactor it is like fill and draw type, second one we discuss the continuous flow type, third one we discuss about the plug one you enter the it will take exact amount of time to it will stay there and the next batch will go from the other side of it ok. This is called the plug flow reactor, fourth one is arbitrary flow reactor, fifth one is packed bed reactor and the sixth one is fluidized bed reactor.

Placked bed how it is very hard to treat it in a very hard to because it may get like you know how to say clogged very easily there is a chance. In order to reduce the clogging and all this phenomena fluidized beds are installed like introduced ok. So, good that you

understand the basics of different kind of reactors you understand the necessity of different type of order of reactions and what is the order of reaction in the biological stabilization processes and the value the order of reactions denoted at n can be varying from 0 order where the reaction rate is constant to first order where the rate is proportional to the substance concentration. Sometimes it can be also the value can be also to in some specific type of trickling filters and all ok that also we discussed. We also discussed the different environmental parameters how those can affect the reaction rate constant and also the reactors used in the wastewater treatment can be classified into various types including batch, plug flow, continuous mix, arbitrary, packed bed and fluidized bed ok very good.

So, we understand it is a it is a very crucial to understand this this informations this is the references that can be followed to understand it more in details. So, I hope you got to know some very interesting nomenclatures and also understand something very new in this lecture module. We will be discussing more in details about all this informations in the coming lecture, but before that I would like to request you to please go through this lecture once more to you know have a better understanding of the nomenclature of the discussions that we had and if you have any queries and all please raise it in the forum in our in the NPTEL module and all ok. Thank you so much see you in the next lecture video.