Water and Wastewater Engineering
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Treatment Reactor Analysis
Lecture-20

In last couple of lectures we were discussing about the physical chemical process for water and wastewater treatment. We have seen the plain sedimentation, coagulation, flocculation, softening, filtration and disinfection for the treatment of water and wastewater. And we have also seen that the physical chemical processes whatever we were discussing is mainly used for water treatment. Why we are using those processes for water treatment. It is all depending upon the nature of the pollutant present in the water.

The nature of pollutant whatever present in the raw water whatever we are collecting from surface sources or ground water sources is entirely different from water whatever is coming after the use by the people or whatever is coming through the sewers we call them as wastewater. In the wastewater the quality of solids or quality of waters or quality of pollutant present is entirely different. So depending upon the nature of pollution we have to select suitable processes.

Today we will be discussing about biological processes. These biological processes are mainly used for wastewater treatment. The reason is the solid present in the wastewater is mostly organic in nature so this organic matter can be removed easily by biological means or by the action of microorganisms because microorganisms can use them as their food and convert them into carbon dioxide and water if it is in aerobic condition or they can convert into carbon dioxide and methane if it is anaerobic condition or inorganic substances like nitrate or nitrogen gas depending upon the process we are designing. So the biological process the process is based upon the nature of the solids as most of the time these biological processes are being used for wastewater treatment. Now we will see what are the biological processes, what are the different processes or operations involved in biological treatment.

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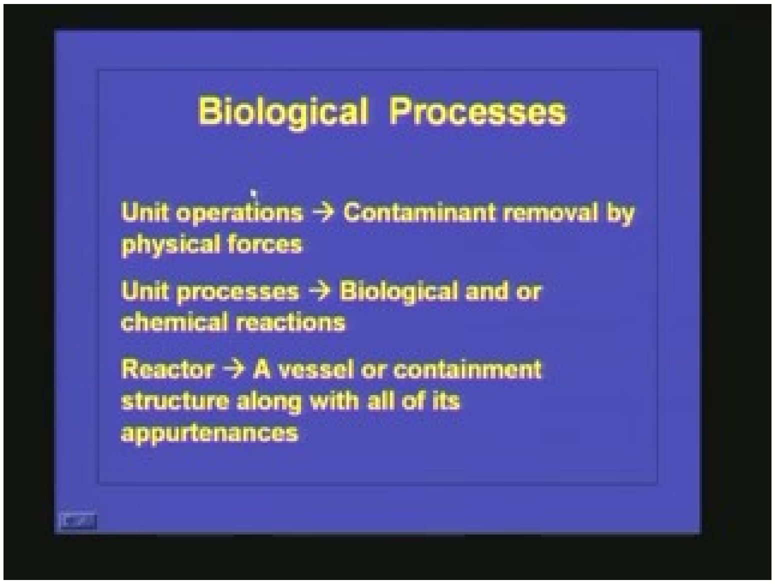

Biological treatment also has unit operations and unit processes because the wastewater will be containing a series or different types of solids present in that one so we can remove different solids by different method so unit operations are also essential for wastewater treatment. We have already discussed what unit operation is. Unit operation is the one in which the contaminant removal is by physical forces.

Most of the time it will be by gravity settling or by flotation because if the density is higher the gravity force will be predominant and it will be settling down and if the density is less compared to the liquid in which the solids are present then the pollutant or the solids will be floating. These are the two main mechanisms being used in unit operations. Then coming to unit processes we have seen that unit processes are the ones in which we use either biological or chemical reactions or both together. So biological processes also involves biological reactions because it is not merely because of the physical forces by which the removal of solids is taking place. Whenever we talk about biological processes we talk about the reactor. That means most of the processes are taking place in a closed container that is why we are referring it as a reactor.

A reactor is nothing but a vessel or containment structure along with all of its appurtenances. Therefore the vessel in which the reaction is taking place that is known as a reactor because any process especially the biological process whenever we term or call it we call it as a reactor. Hence, the wastewater treatment system is a combination of unit operations and unit processes and the selection of the treatment depends upon the quality of the pollutant present in that one. There is no difference between water treatment and wastewater treatment. If the nature of the pollutant is the same in water and wastewater then we can go for the same type of treatment or if the nature of the pollutant is different then we have to adopt different processes. All these are based upon the nature of the pollutant that is the most important point we have to be clear about. Now, coming to the wastewater treatment we will see how the treatment system is.

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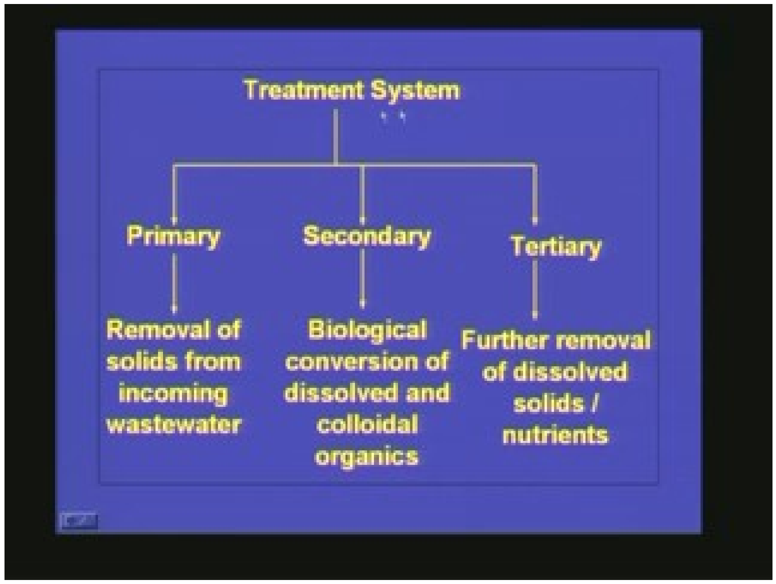

It can be divided into three different groups; one is primary treatment, second one is secondary treatment and the third one is tertiary treatment. Primary treatment basically consists of a series of unit operations. That means the treatment units are working based upon physical forces. So the major objective of this one or this primary treatment is to remove the suspended solids from the system because the wastewater also will be having lot of suspended solids.

So, if we can remove them by either gravity or by floatation then it will be very good because the load coming to the next treatment system will be very very less. If you see the solids in wastewater treatment we can see that there will be lot of suspended solids, floating material and colloidal solids and even dissolved solids. When we talk about the solids, the removal of dissolved and colloidal solids are much difficult because gravity force or floatation effective for the removal of that one. So in primary treatment basically what we are doing is removal of the solids which is easily separable.

Now, coming to the secondary treatment in wastewater mostly we go for biological treatment because the most of the solids present in the wastewater is organic in nature so we can easily use the microorganisms for the removal of them. So here in secondary treatment it is biological conversion of dissolved and colloidal organics. That is what is happening in secondary treatment.

Now, coming to the tertiary treatment what happens is most of the organic matter will be removed in the secondary treatment but there will be some other solids left over which cannot be removed biologically. So if you want to remove that one to meet the effluent discharge standard we have to go for some other treatment which is able to remove those solids.

For example, if you talk about wastewater it will be containing lot of ammonia, nitrogen, phosphorus etc or in other words lot of nutrients will be present in the system so nutrient removal can be achieved by biological processes and sometimes we can even go for physical chemical processes or adsorption, iron exchange etc for the removal of nutrients. If we talk about the wastewater coming from industries it will be having some other toxic compounds, most of them are [8:18 …….biotic] in nature. For example, if heavy metals are removed, heavy metals are present in the wastewater.

If we go for biological treatment most of the microorganisms will not able to survive under high concentration of heavy metals because heavy metal itself is very very toxic and it will be getting accumulated on the microbial cells and gradually the efficiency of the microbial system will be decreasing and it will be retarding the efficiency of your secondary treatment also. So usually what we do is, to remove such toxic component we go for tertiary treatment after the tertiary treatment you will be getting of water which can be reused for common purposes like gardening and if we can give the treatment up to the extend possible to meet drinking water standards then we can even use the water for drinking purpose. Since water resources are diminishing nowadays the reuse and recycle concept is coming up therefore tertiary treatment is also becoming very very important nowadays. Now we will see what a typical primary treatment system is.

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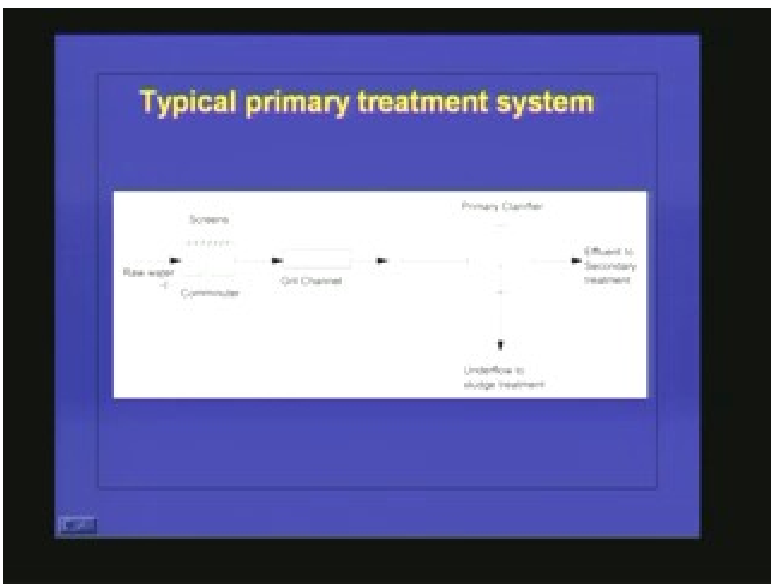

Here we can see, the raw water is coming and this is the screen, the major purpose of the screen is to remove the floating material. We have already seen in detail how to design a screen. From the screen we will be getting big solids or the floating solids so one communicator is here which will be setting the floating material into small small particles. Then after the screens next comes the grid channel or grid chamber. The major purpose of the grid chamber is to remove grids or sand whatever is present in the wastewater because if it goes to the secondary treatment system it will be reducing the effective volume of the treatment system because it will be getting accumulated there so before sending the wastewater to the secondary treatment we have to remove the standard silt particle or we have to remove the inorganic material or whichever material that is easily about to settle. That is the purpose of this grid channel.

Therefore, when we are designing the grit channel the most important point we have to consider is no organic material is getting settled here in the grit chamber because if organic material gets deposited there what will happen is anaerobic condition will prevail and microorganisms are already present there so anaerobic degradation starts so the efficiency of grit chamber will be reducing. Moreover there will be lot of gas production and it will be creating odor problems so the grit chamber should be designed only for the removal of sand, silt and other dense inorganic material.

After the grit chamber we may go for a equalization chamber because in the first lecture we were discussing about how the flow is fluctuating and we talked about wastewater because the water usage pattern in the domestic area or in industrial area or commercial area will be vary with respect to the time. During the morning time the water usage will be more then it will be peaking up towards the lunch time then it will be decreasing and when we come to the midnight time almost there will be any wastewater production. So if you want to have such a chamber what will happen is the flow to your treatment system will not be uniform so, that will be affecting your treatment efficiency so we may have to go for an equalization chamber.

Hence, when we design the equalization chamber we have to see that no other biological reactions are taking place here. What we usually do is the solids will be settling down so you have to provide a shaker or we have to mix the water properly so that the wastewater with uniform characteristics will be entering into the other treatment systems. This is known as the equalization chamber. The equalization chamber can be on line and off line.

Most of the time the flow is uniform and sometimes the peak factor is coming. So whatever is the excess than the designed flow can be collected in the off line equalization chamber and the remaining flow will be going to the treatment system and whenever the flow is lower than the design flow then we can permit from the equalization chamber. So depending upon the nature of the flow we have to design suitable equalization chamber. After the equalization chamber the next unit coming in primary treatment is primary clarifier or sedimentation tank.

When we talk about wastewater the solids present in the wastewater are not discrete in nature so we cannot use Stoke's law whatever we were discussing. These particles are flocculant in nature and the concentration of the particles are lower so this is coming under low concentration flocculant particle or type two settling. So the primary clarifier especially for domestic wastewater we have to design based upon type two settling.

Here again we have to be very very careful. If we give high detention time then the organic material will be settling down in the tank and the putrefaction will be taking place because anaerobic condition will be prevailing and the wastewater will be having lot of anaerobic microorganisms so they will start decaying the organic matter as a result the gas production especially carbon dioxide and methane. Moreover, if the wastewater is containing lot of sulphide what will happen under anaerobic condition is the sulphide will be getting converted into hydrogen sulphide so along with the gases hydrogen sulphide also will be coming up and that will be creating odour problem.

So the detention time in primary clarifier of wastewater treatment system should be in the range of 1.5 to 2 hours. Though other detention criteria is not detention time we have to design it for surface overflow rate. We have to check the detention time because if it is high your tank efficiency will be decreasing and if gas formation is there lot of turbulence will be there which will be lifting all the settled particle which will be acting as another biological reactor by which you will not be achieving the very purpose of your clarifier here that is very very important.

We have to design based upon surface overflow rate but we have to see that the detention time whatever is coming here is within the permissible limit. Once the primary treatment is over the wastewater treatment is going to the secondary treatment. Now we will see what are the secondary treatment systems usually we use in wastewater treatment. The most commonly used treatment system in domestic wastewater treatment is activated sludge process.

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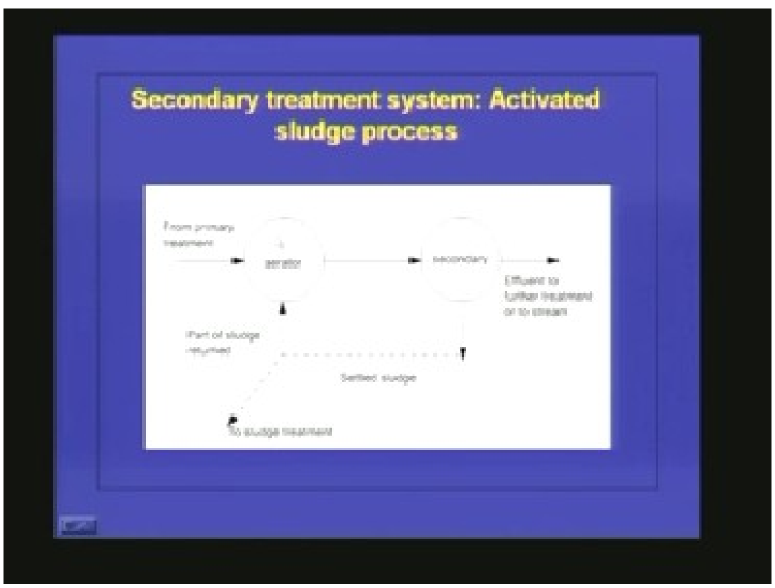

Nowadays anaerobic systems are becoming more and more popular. We will see in detail afterwards. The power consumption will be very very high so nowadays anaerobic processes are taking up more and more interest. Many treatment units are going for anaerobic units. If it is in activated sludge process what are the components present. There is an aerator then the aerator is there so the organic matter present in the wastewater will be utilized by the microorganisms and it will be converted into new cells and carbon dioxide and water. A portion will be going up carbon dioxide and water and remaining will be converted to biomass. So in the aeration tank you will be getting more and more biomass or in other words the solids whichever is present in the dissolved form will be getting converted to colloidal form.

Now we have to separate the solids otherwise practically speaking there will not be any treatment taking place because you are just converting the dissolved solids into colloidal form or colloidal form is nothing but the microbial cells, so how can we separate them? We have to have a clarifier. This is the secondary clarifier (Refer Slide Time: 17:32) so how the clarification is taking place? these microorganisms are able to exceed some extra cellular polymer and the extra cellular polymers will be acting as coagulants and they will be fluctuating the microbial cells so you will be getting bigger flocs so that can be easily settled in this secondary clarifier.

The secondary clarifier design we have to do based upon sand settling and sludge thickening principle because here they are flocculant in nature and the concentration is medium. The initial stage is when we go to the bottom of tank the concentration will be very very high so you will be having zone settling and compression settling. We will see about this design in detail afterwards. What will happen is here the sludge is settling so a portion of the sludge is going back to the aerator because we have to maintain a microbial concentration in the aeration tank and remaining sludge will be going to sludge treatment because we cannot just dispose this sludge because this sludge or the solids whatever we are getting in the secondary sedimentation tank is nothing but microorganisms. If you discharge them to the nature what will happen is the putrefaction will be starting so as a result what will happen is bad smell or odour will be generated. So we have to subject this sludge for further treatment then only we can dispose that one.

Here I was explaining about activated sludge process but in wastewater treatment we can use many different types of treatments. This is another one.

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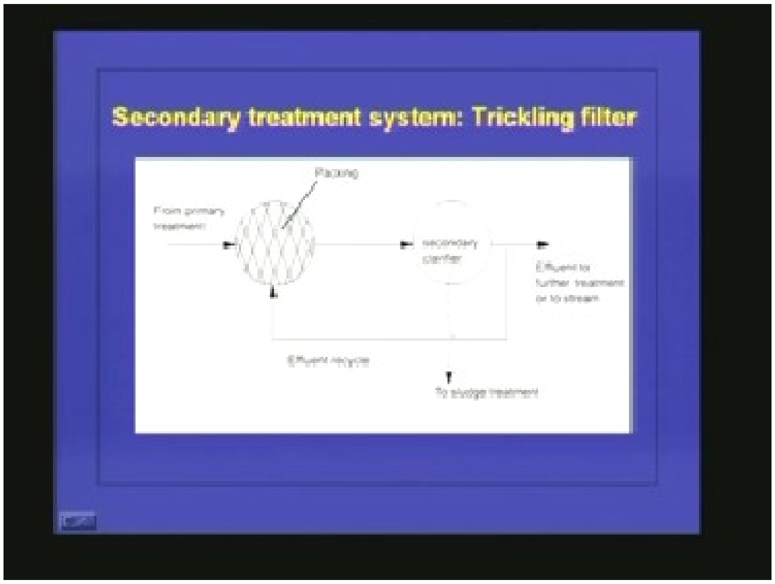

Here we are using an attach treatment system that is the trickling filter. So whatever water is coming after the primary treatment unit is entering into the attached growth filter so here the microorganisms are stationary so the wastewater is flowing or trickling to the filter so the microorganisms whatever is present there will be utilizing the organic matter so as a result more and more cells will be generated and the thickness of film in the filter will be going on increasing and a portion will be getting converted into carbon dioxide and water.

Since the microorganisms are attached you will be getting somewhat clarified effluent from the system. But one problem is there, as we have seen the thickness of the microbial film whatever is attached to the surface of the metrics will keep on increasing so after sometime what will happen is the food will not be penetrating through the microbial film. Thus, the microorganism which is attached to the solids which is sitting in the innermost portion of the film may not be getting the food so the microorganisms will be undergoing auto oxidation. As a result the microbial film may be scuffing off from the filter medium that is one reason.

Another reason is, the water is flowing through the filter media, so because of the shear stress created by the water and if the thickness of the film is very high it will be shearing off so some microorganism in the form of sludge will be coming. If you want to remove that one, here (Refer Slide Time: 21:06) we have to provide a clarifier and whatever clarifier is coming in the effluent is recycled here. Hence, with this we have to be careful. In attached growth system we are not recycling the sludge; we are recycling only the clarified water. But in activated sludge process we are recycling a portion of the sludge. We will see in detail in the coming lectures on why we are doing so. Whatever is the sludge here is going to sludge treatment because this sludge also consists of active biomass so we cannot dispose it off just like that so we have to go for further sludge treatment. Most of the time we go for sludge digestion anaerobic system and from here the effluent will be going for further treatment if you want to reuse our recycle the water or if it is not meeting the effluents standards. If it is meeting the effluent standard and we do not want to reuse the water then we can let it to the stream.

This flow diagram (Refer Slide Time: 22:11) shows how we can lead the sludge. so whatever the sludge generated either in attached growth system or in the suspended growth system what we have to do first is thicken the sludge because the sludge density will be in the order of 1.04 to 1.05 and it will be containing around 95 to 98% of water so the volume of the sludge will be very very high. If the volume of the sludge is very very high the handling problem will be too much so it is always advisable to have less volume of sludge. That is the purpose of this sludge thickener, get maximum concentration of the sludge in the thickener itself and afterwards from here it will be going to the first stage of digester and again second stage of digester and whatever water is coming from the sludge thickener or the digester it will be going to the secondary treatment or primary treatment so again it will be coming back to the system.

The sludge after the digester will be going to sludge disposal or sludge drying beds so afterwards we can use this sludge as manure. And when we use the sludge digester we will be getting gases like, carbon dioxide, ammonia etc. If lot of methane is there we can use it as a fuel otherwise we have to flare it up because we are not supposed to release this methane to the atmosphere because we all know that methane is a contributor of green house gas or methane is one of the green house gases. Therefore, if the concentration methane in the atmosphere increases the outgoing sun rise or radiation will be captured by or observed by these gases then the temperature of the earth will increase leading to global warming. Therefore, methane is not allowed to be sent to the atmosphere, we have to take care of that.

Now we will see there are certain biological treatment processes which do not require a primary treatment as such. Whatever we have discussed so far as activated sludge process or trickling filters need primary treatment because it will not be able to handle the suspended solids coming to the system. But certain treatment system like oxidation pond and aerated lagoons do not require a particular primary treatment system or equalization system because this itself will be acting as a primary treatment as well as a secondary treatment unit.

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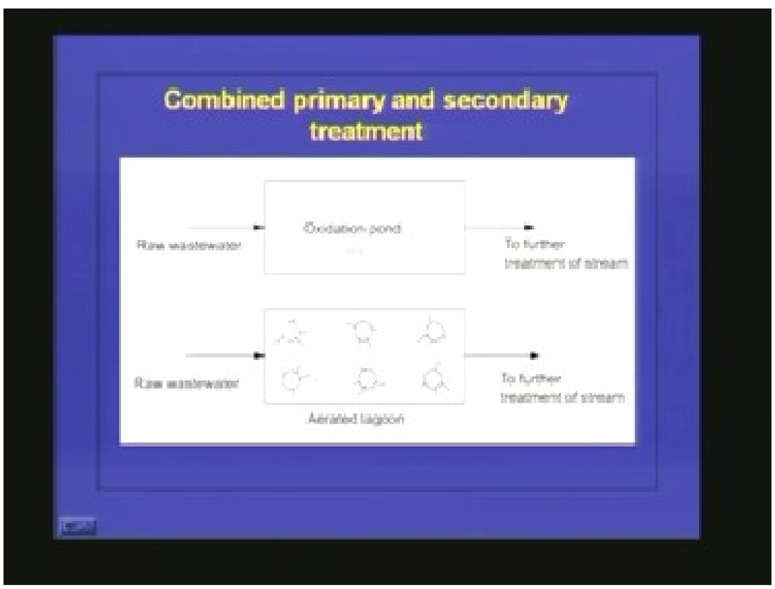

The raw water whatever is generated will be directly coming to the oxidation pond. This oxidation pond is very much similar to the natural processes. Here we are utilizing the symbiosis of algae and microorganism especially bacteria for the treatment of wastewater so here whatever inorganic substances present will be settling down and we can remove the floating material using a screen and afterwards whatever is coming here will be getting converted into carbon dioxide and water. The detention time is so high so the microbial population generated in the system will not be so high like activate sludge process and whatever is coming out can be sent for further treatment or to the stream.

But here if you see in oxidation pond lot of algae will be there so your total COD coming out of the system will be always higher. But if you remove the algae the soluble BOD will be within the permissible limit but the total will be always higher. Most of the time it may not be allowed to be discharged in the stream because of failing to meet the standards so we have to be careful about that. Another one is aerated lagoon. Here also it is just like an oxidation pond, the only difference is here we have some mechanical aerators but in oxidation pond we do not have any mechanical aeration system therefore the oxidation transfer is taking place naturally. But to increase the efficiency here in aerated lagoon what we do is we provide aerators but we do not have to go for any primary treatment and here after the treatment it goes to either for further treatment or to stream **sand line** for discharge.

The basic units of a wastewater treatment system are; the primary treatment should be there then secondary and tertiary based upon the quality of treated water or treated wastewater we need.

Now, before going into the process we will see the fundamentals of the process. Unless we know the fundamentals it will be very very difficult to design the reactor or the biological system. We have seen that the biological processes are taking place in reactors. Reactors are nothing but a close container with all the control devices. In biological process also it is a reaction; it is only a biological reaction or biochemical reaction.

Whatever we have discussed in physicochemical processes is we have seen various chemical reactions which is mediated by chemicals but in biological processes the biochemical reactions are mediated by microorganisms and the enzymes whatever is present in the microorganism. So whenever we talk about a reaction either it is a chemical reaction or a biochemical reaction we can classify the reaction based upon stochiometric basis and kinetic basis.

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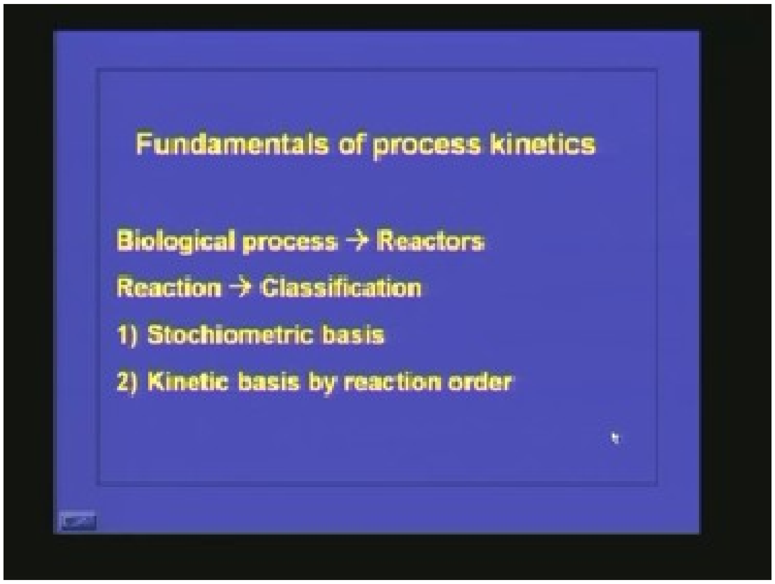

Whenever we talk about the biological process we usually classify the reaction based upon the kinetics because in stochiometric most of the organic matter present in the wastewater are so complex so we will not be able make the reaction comparison based upon stochiometric.

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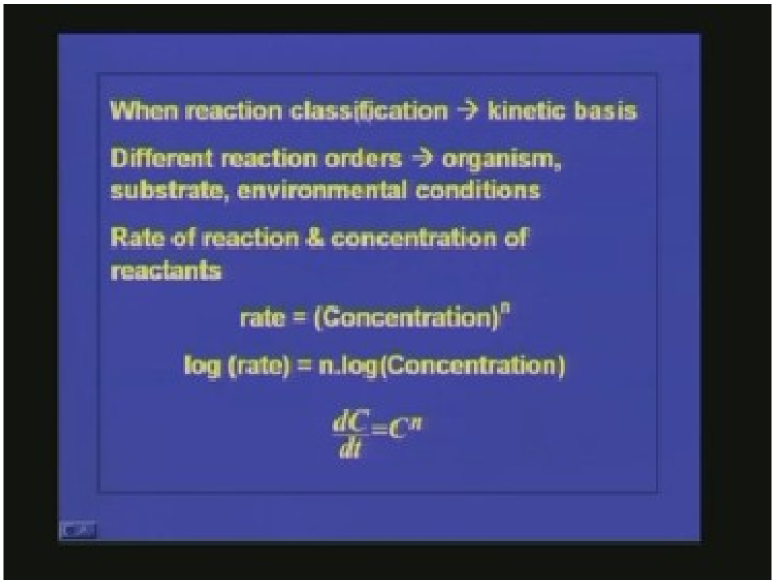

When we classify the reactions based upon the kinetic we can see different type of reactions, how the rate of reaction is depending upon or what is the matter which controls the reaction. Therefore, depending upon that we can classify the reactions into zero order, first order, second order or nth order or the classification of the reaction can be based upon the rate of reaction and concentration of the reactants. Or we can write like this; rate of any reaction is equal to concentration raised to n. so depending upon the value of n we can classify the reaction as zero order, first order, second order or nth order.

Or this equation (Refer Slide Time: 29:29) we can change it to log rate is equal to n into log concentration. So if you take logarithm on both sides we can write log rate equal to n into log concentration or rate of change of concentration dc by dt is equal c raised to n. This way we can write any reaction if we are classifying them based upon the kinetic basis. Now we will see how we can determine the rate of any reaction. If you want to determine the rate of any reaction we have to conduct laboratory experiments. Once you get the laboratory experiment results we have to plot logarithm of the rate with respect to logarithm of the concentration. So whatever slope we are getting based upon that one we can find out whether the reaction is zero order, first order or second order. This is the example of a zero order reaction.

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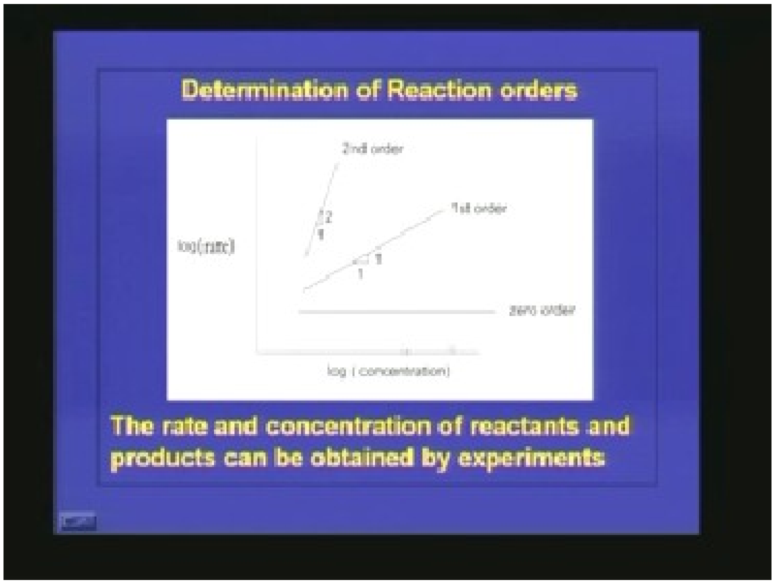

The rate and concentration are independent as we can see here and here the rate is linearly varying with the concentration. So this is first order, here the rate is varying and if you take the slope it is two is to one so the order of the reaction is second order. The rate and concentration of reactants and products can be obtained by experiments. Once we conduct the experiments whatever results we are getting we have to plot; log rate versus log concentration then we can find out what is the gravity of the equation. This is very very important when we talk about the reactors; the reactor volume and the time required achieving the desired treatment where we have to know what is the rate of the reaction. Now we will see zero order, first order and second order reactions in detail.

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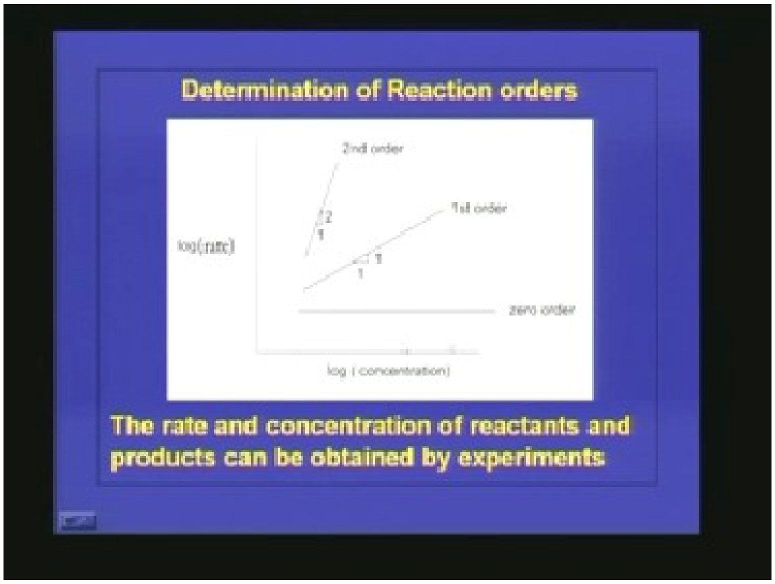

Zero order reactions: the reaction that proceeds at a rate independent of the concentration of reactants. Whatever be the concentration of the reactants the rate will be independent of the reaction or reactant concentration or the rate is independent of the reactant concentration that is known as zero order reaction. For example, we have a reactant A and it is producing product B so we can write like this; minus dA by dt is equal to K into A raised to zero. This minus sign is coming because we know that when a reactant is reacting and a product is formed the reacted concentration or the mass of the reaction will be getting reduced with respect to time. That is why whenever we write dA by dt we use a negative sign. If the reactant concentration is increasing in the reversible direction then we have to use the positive sign.

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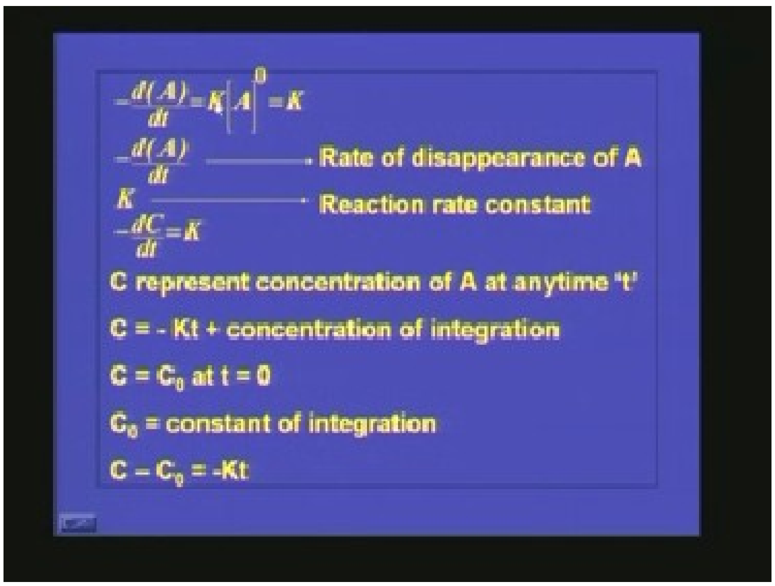

So the rate of reaction is equal to k into A raised to zero because it is independent of the mass of the reactant present here so this term will become one and you will be getting minus dA by dt equal to k or rate of disappearance of minus dA by dt is nothing but rate of disappearance of A and k is the reaction rate constant or the rate of disappearance of A is a constant that is what it means, this is the zero order reaction.

Now we will see each term in detail:

- C represents the concentration of A at any time t

So if you know the concentration of C at any time we can find out the rate of disappearance of A and if you want to find out what is C at any time we can integrate this expression then we will be getting minus Kt plus concentration of integration because minus dC by dt is equal to K so minus dC is equal to K into dt so if you integrate that one we will be getting C is equal to minus kt plus concentration of integration.

How can we find out the concentration of integration?

We can put this condition. What is the concentration when t = 0. For t = 0 the concentration will be nothing but the initial concentration C is equal to C_0 that is the concentration of pollutant or reactant whatever is coming to your system. So here C_0 is the constant of integration or we can write like this; C minus C_0 is equal to minus kt or if you plot the equation then it will be coming like this.

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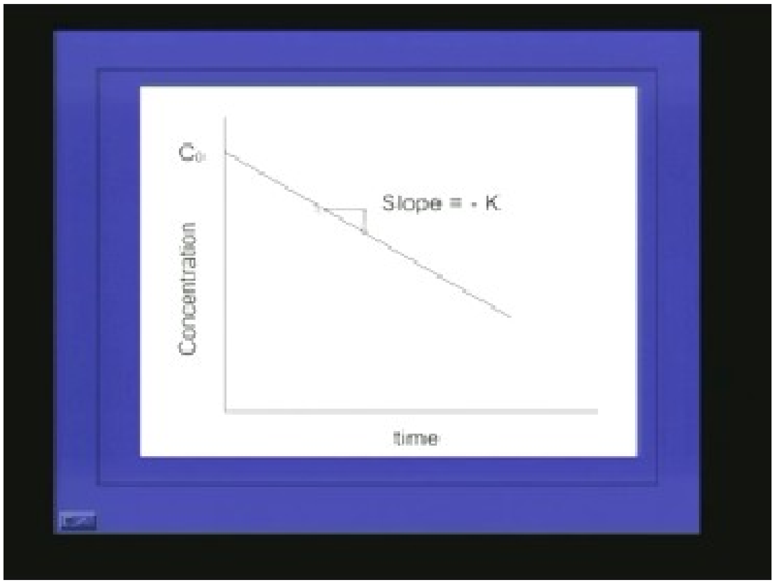

Initially it is starting from C_0 and the concentration will be decreasing like this and the slope is minus K. Now we will see what a first order reaction is. In a zero order reaction we have seen that the rate of change of concentration is independent of the concentration of the reactant present, it will be decreasing at a constant rate.

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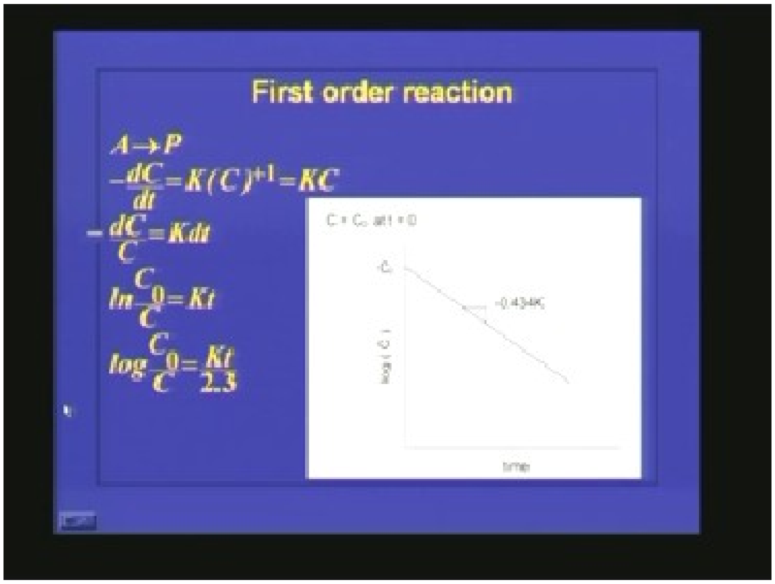

Now coming to first order reaction same example we will take. A reactant A is there and it is reacting and giving a product P. If you want to write the rate at which the concentration of A is changing we can write like this; minus dC by dt because A is disappearing or P is formed and it is equal to K into C raised to plus one that means the rate of disappearance is proportional to the concentration of the reactants present or we can write it as KC. Here also we can find out what is the concentration on any time minus dC by C and if you take this side we will be getting K into dt or $\ln C_0$ divided by C is equal to Kt because here also we will be getting constant of integration and that is nothing but $\ln C_0$ so we will be getting a $\ln C_0$ by c is equal to Kt. Or, if you take logarithm on both sides with ten base we will be getting C_0 by C is equal to Kt by 2.3.

So if you plot logC versus time then you will be getting the line like this with the slope of minus 434K. Or in other words the concentration or the rate of the reaction is directly proportional to the concentration of the reactant present in the system. And when we talk about the biological processes we assume that almost all the reactions are first order. But we can see later that up to certain level the reactions are first order but if the concentration is very very high then the reaction will be of zero order.

You have seen Monoid's equation there we have seen the concentration of the substrate increase, afterwards the substrate will be becoming independent of the microbial or microbial concentration will become independent of the substrate concentration. So that is the example of zero order reaction but if the substrate is limited and if you see the microbial concentration then it is a first order reaction. Another example of this first order reaction is whatever we have discussed last class we have talk about the six law of disinfection**. T**here also we have seen that the rate of yield of microorganism is directly proportional to the number of microorganisms present initially. so that is also an example of first order reaction.

Now we will see what is the second order reaction. Here also some reactant is there, the reactant is reacting and the product is formed. So if you want to find out the rate of change of concentration of A with respect to time that is nothing but minus dC by dt that is equal to K into C squared so dC by C square is equal to K into dt or we can see that 1 by C minus 1 by C_0 is equal to k into t of if you plot one C versus t you will be getting a line like this. So this is the example of second order reaction.

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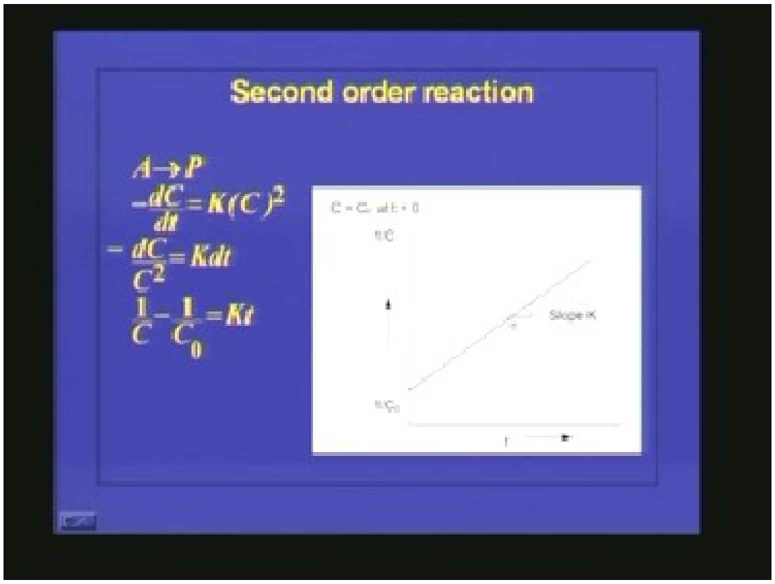

Now we have seen how to find out the order of the reaction whether it is zero order, first order, second order or nth order reaction. We can plot the log concentration and log rate to see whether we are getting a straight line and depending upon the slope we can find out what is the order of the reaction.

Now we are clear how the reaction rate is changing. Now we have to discuss about what are the different types of reactors are available. I have already mentioned that most of the biological processes are taking place in a reactor. We should know which type of a reactor is more effective or how can we control the volume of the reactor without affecting the removal efficiency. For that we should have a basic idea about what are the different types of reactors available. Basically we classify the reactors into three different categories. One is completely mixed batch reactor, another one is continuous flow tired tank reactor and the third one is plug flow reactor.

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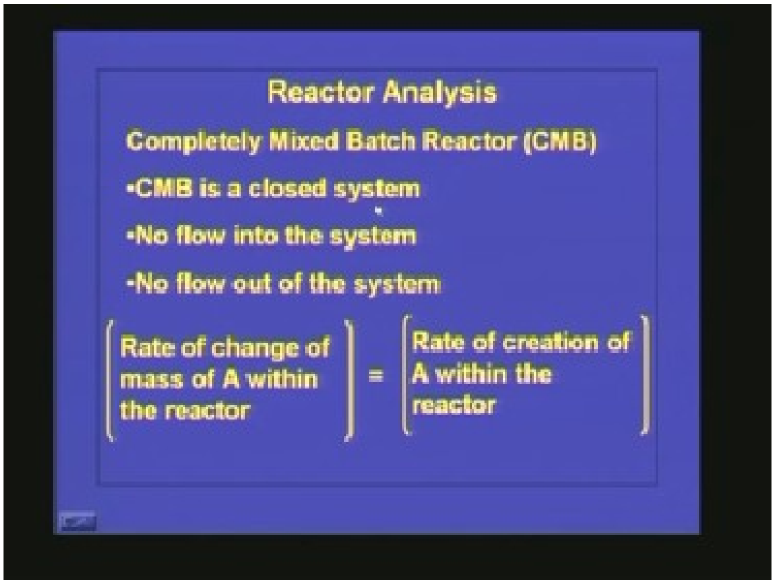

We will go see each one in detail because this is very very important. In whichever way we are designing our reactor system the efficiency will be changing accordingly. We will see how the time of reaction or time required for the wastewater to be there in the treatment system varies with respect to the configuration or the type of the reactor. First we will talk about completely mixed batch reactor CMBR.

This CMBR is a closed system that means we take the reactants whatever we have to reduce or treat in a closed container or in a reactor and there will not be any inflow or any out flow from the system. That is why we call it as a closed system. Nothing is coming into the system or nothing is going out of the system so whatever is there in the system it will be remaining there. CMB is a closed system, there is no flow into the system and no flow out of the system.

Thus, if you want to find out the rate of change of mass of A within the reactor A is nothing but the reactant. So how is the rate of mass of A changing within the reactor is nothing but the rate of creation of A within the reactor or rate of destruction of A within the Sometimes reactor. If we are interested in the product then naturally it is a creation, sometimes we are interested in destructing the pollutant then it will become destruction so how can we find out this one. we can write the equation like this:

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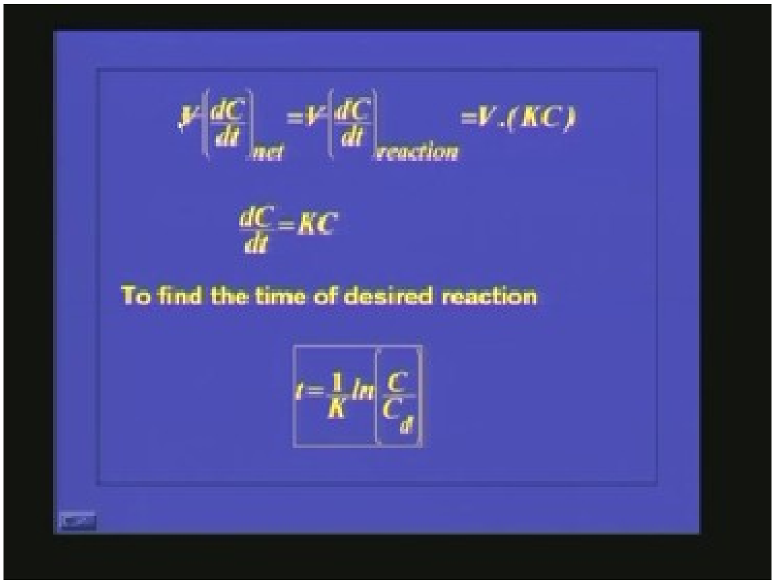

V is our reactor volume so V into dC by dt this is nothing but the rate of change of mass or concentration of A within the system that is the net change that is nothing but V into dC by dt reaction because we are not allowing anything to come into the system or go out of the system so because of that one no mass is changing so whatever mass is changing within the reactor is because of reaction that is why we can write it as the net change in the concentration of C within the system is equal to V into dC by dt reaction.

We have already told that in most of the cases we are assuming that the biological reactions are of first order. So if the reaction is first order then we can replace this dC by dt as K into C because for the first order the reaction rate is directly proportional to the concentration of the reactant so this will become dC by dt is equal to K into C.

So, to find out what is the time required in the reactor or what is the time required for the desired reaction we can find out like this; if we integrate this one we will be getting dC by C is equal to Kt or lnC_0 by C is equal to Kt. So we can find out what is the time required t is equal to nothing but 1 by K into lnC by Cd where this Cd is nothing but the concentration desired. After the treatment what is the concentration we want and C is the initial concentration. Thus, if you know these two concentrations we can find out what is the time required in the treatment unit. This time is the parameter which decides the volume of the reactor. This time is nothing but the hydraulic detention time. The hydraulic detention time we can find out by dividing the volume with Q where Q is the flow rate. So, if t is more definite our reactor volume will be very high.

Now we will talk about the continuous flow tired tank reactor. This is the second type of reactor. This is not a closed system because there is an inflow and there is an outflow. So whatever reactants are there in the reactor will be continuously getting mixed.

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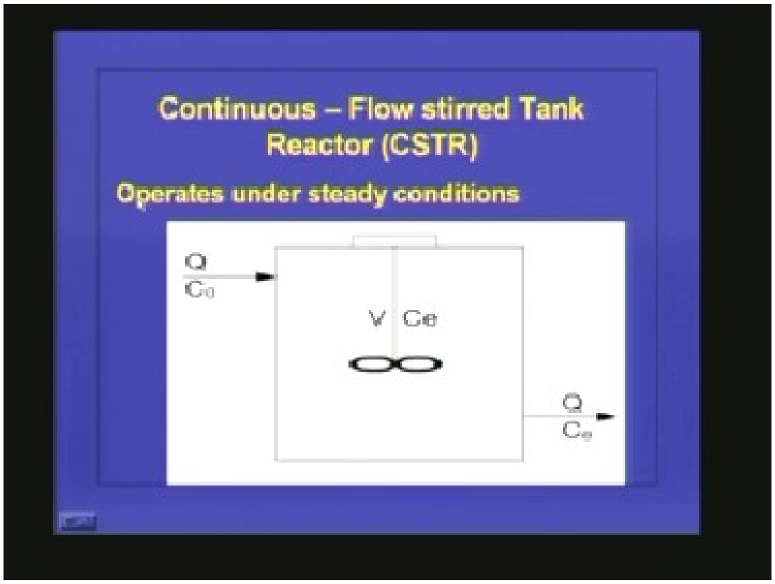

We assume that the reactor is working under steady state condition. Here Q is the flow rate at a rate of Q wastewater is coming to the system and the concentration of substance of interest or the concentration of the pollutant or the concentration of the reactant is C_0 and the volume of the reactor is V. So as soon as this flow enters into the reactor what is happening there is a continuous mixing taking place in the reactor and because of the mixing the concentration C_0 will be getting changed to Ce instantaneously this Ce is nothing but the concentration coming out. So in a continuous flow tired tank reactor the concentration gradient is very very less compared to a CMB or completely mixed batch reactor.

Since naturally for most of the reactions the concentration gradient is the driving force volume required in a continuously flow, tired tank reactor is more than a CMBR reactor this is an important point. CSTR reactor needs more volume compared to CMBR reactor or plug flow reactor. The reason is here the concentration gradient available for the reaction is much less compared to the other reactor. Now we will see how to find out the detention time or the HRT in a CSTR reactor if we are interested to get a desired amount to treatment efficiency.

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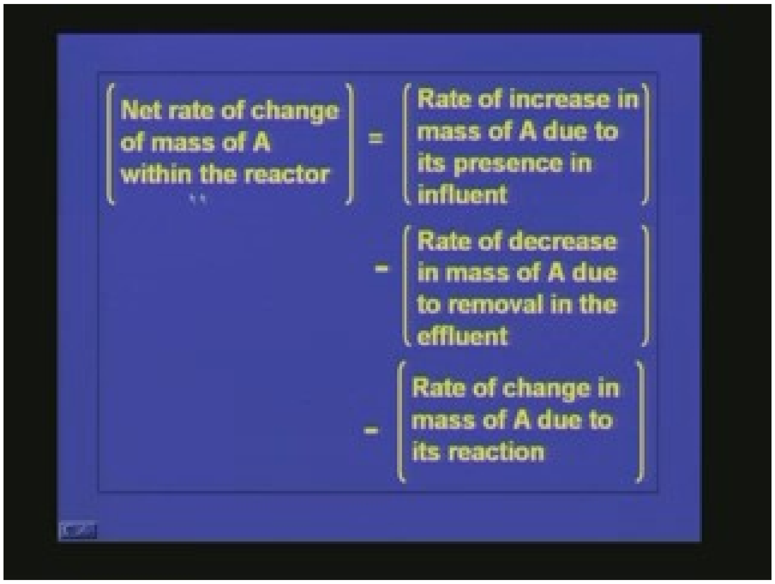

At steady state we will take the mass balance. Here we can see the net rate of change of mass of A within the reactor or net rate of change of concentration of A within the reactor which is equal to, since it is an open system there is some out flow and there is some reaction so the net rate of change of mass is equal to rate of increase in mass of A due to it presence in the influent because Q into C_0 is coming to the system always and rate of decreasing mass of A due to removal in the effluent and Q into C is going out of the system so that is this one, here (Refer Slide Time: 45:55) this is incoming flow and this is outgoing flow so because of that one some mass is going out of the system. Now the rate of increase or decrease of A is because of the reaction that is the third term. One is because of the reaction, another one is because of the incoming flow and another one is because of the outgoing flow. Hence, if you want to write a mathematical equation for that one we can write like this; v into dc by dt net that means net change of concentration of A or net change of mass of A within the reactor.

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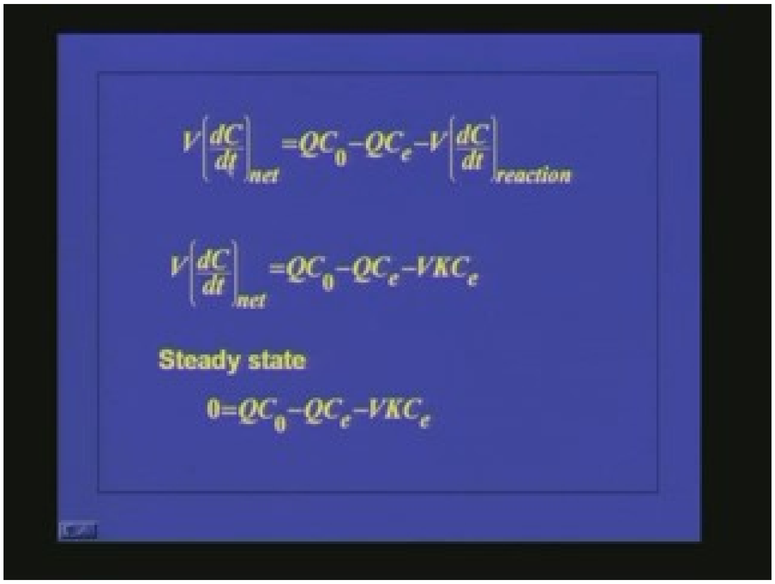

That is why we are taking V into dC by dt which is equal to Q into C_0. This is the incoming flow, Q is the flow rate and C_0 is the concentration so Q into C_0 is coming into the system minus Q into C this much is going out of the system and minus V into dc by dt reaction. So this is the change in mass of the reactant in the reactor because of reaction. Here we are using negative sign because the reactant concentration is decreasing with respect to time. But if the concentration of the reactant is increasing with respect to the time we have to use a positive sign here.

We have already seen that in biological systems we are assuming that it is first order and in CSTR it is completely a tired tank reactor. We have seen that as soon as the water or the liquid enters in the system continuous tiring will be there so the concentration will be reducing instantaneously from C_0 to C_e so the reaction will become like this; V into dC by dt net that means net change in concentration equal to Q into C_0 minus Q into C_e minus V into k into C_e because the concentration in the reactor is only C_e, this is very very important. We know that steady state the net change in mass of A in the system is zero. That means whatever is coming in and going out including the reaction that is taking place and the net if you take the net change in mass is zero that is the steady state condition. So the equation will be; zero equal to Q into C_0 minus Q into C_e minus V into k into C_e.

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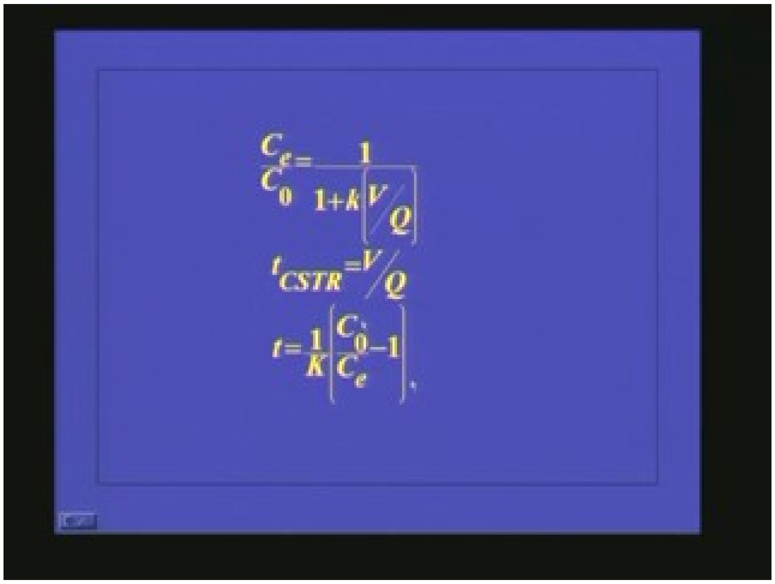

So we can find out what is C_e by C_0 which is 1 by 1 plus k into t where t is nothing but V by Q. This is the t, CSTR is V by Q or t we can find out t is equal to 1 by k into C_0 by C_e minus 1. Earlier we have seen what is C for CMBR reactor that is t = 1 by k into lnC by C_d, d is the desired concentration and when it comes to a CSTR reactor t is equal to 1 by k into C_0 by C_d or C_e effluent concentration minus one. And if this is the time required for a particular CSTR we can put n number of CSTR series to get a particular efficiency.

Thus, if you want to find out the time required in a series of CSTR we can easily find out using this formula C_2 by C_0 is equal to C_1 by C_0 into C_2 by C_1 this is happening in the first reactor and this (Refer Slide Time: 49:30) is happening in the second reactor. So if you want to have C_n by C_0 it is like this 1 by 1 plus Kt CSTR raised to n or n into t CSTR that means total time, this t represents time required in one reactor so if you want to find out what is total time required in n reactors n into t CFSTR is equal to n by K C_0 by C_n raised to 1 by n – 1 or in one unit this is the time required one by k into C_0 by C_n raised to 1 by n – 1.

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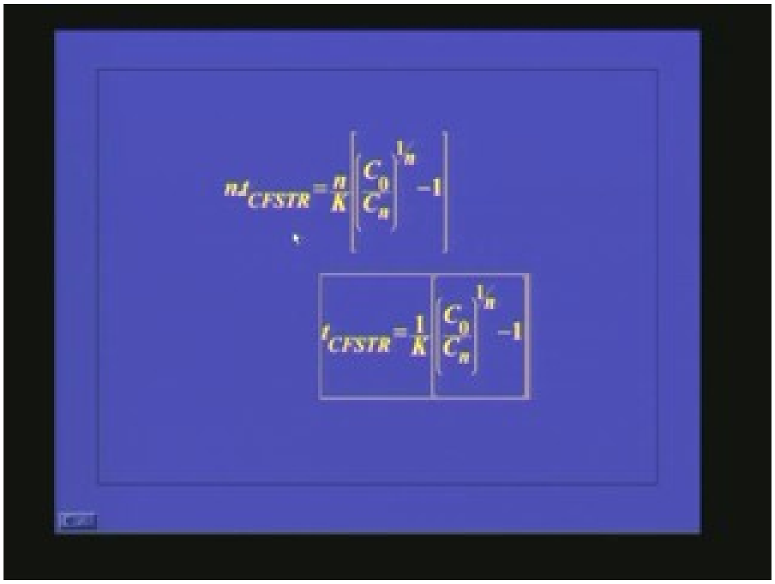

Why we are going for series of reactors. If you go for series of reactors we will be getting more efficiency than providing a single CSTR with large volume. The reason is if you are gradually decreasing the concentration, here if we provide serially then what will happen first it is changing from C_0 to C_1 then C_1 to C_2 then C_2 to C_3 like that. So the concentration gradient available will be higher compared to a single reactor.

In a single reactor it is changing from C_0 to C_e instantaneously but here it takes sometime to change to C_e so you will be getting a high concentration gradient. So it is always advisable to have a series of CSTR than having a single CSTR with large volume; that is an important point. This is important when we talk about oxidation pond design or pond system design in series. Now we will see the large type of reactor that is the plug flow reactor.

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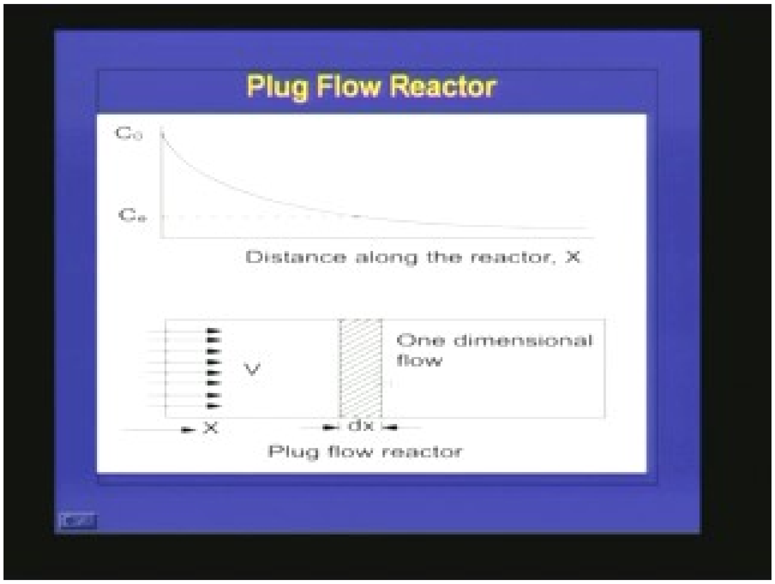

The plug flow reactor is something like this; long narrow reactor. Here, there is no mixing longitudinal mixing of the fluid element. So if you take along the distance of the reactor the concentration is varying or we can say like this; in the plug flow reactor whatever concentration change takes place along the distance is similar to the concentration change in CMBR. That means completely mixed batch reactor with respect to time or any small volume of this reactor can be considered as a CMBR reactor. in other words the plug flow is equivalent to a series of CMBR reactor. Therefore, here the distance as well as time is important to find out the concentration of the reactants or the concentration of the pollutant. The properties of a plug flow reactor are no longitudinal mixing between adjacent fluid elements, each fluid element is analogous to a CMBR and position variable in plug flow reactor corresponds to time variable in a CMBR.

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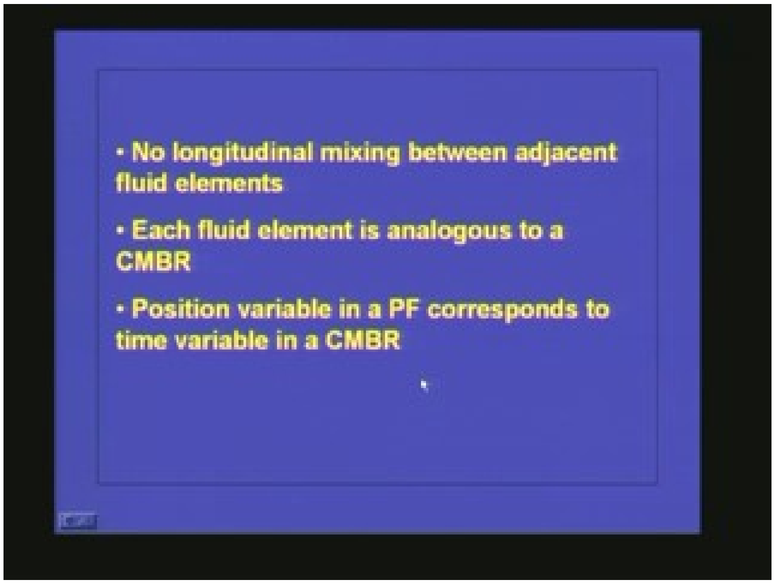

How to find out the time required in a CMBR or in a plug flow reactor?
That is change in the concentration of A due to the reaction of A in dt is equal to change in the concentration of A due to position change of fluid element in dt. We have seen that the time variable in CMBR reactor is equivalent to the position change in plug flow reactor that is why we are writing like this. So we can write the equation like this; minus dc by KC with respect to time how the concentration is changing; minus dc by KC that is equal to how the position is changing dx is the distance and V is the velocity. So how the position is changing with respect to the time is what we have to see. So we can integrate this one then we will be getting like this; 1 by k into ln C_0 by C_e is equal to l by V where V is the velocity here and l is because we are integrating it over 0 to l.

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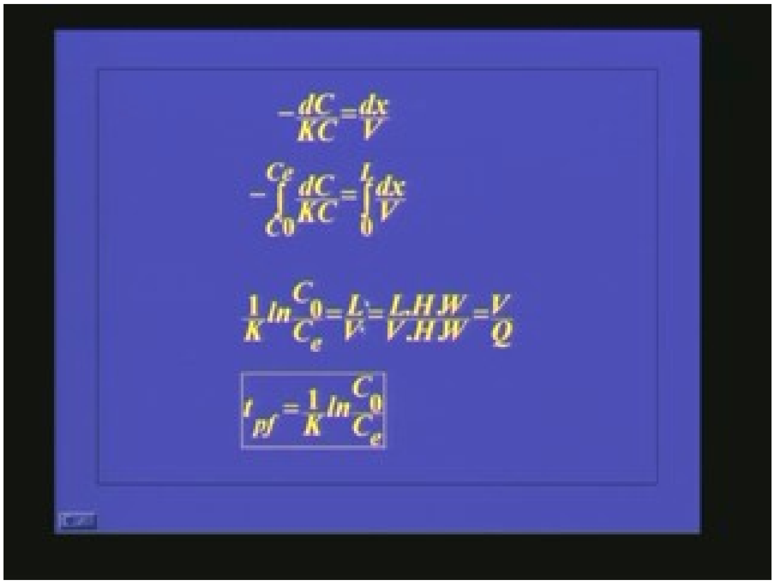

So this ds will become l and V will be a constant and this term will become 1 by K into ln C_0 by C_e so we will be getting 1 by K into ln C_0 by C_e is equal to length divided by velocity. So we can multiply both terms by H into W the cross sectional area of the reactors so we will be getting l into cross sectional area is nothing but volume of the reactor and velocity into cross sectional is nothing but Q so V by Q is nothing but the time. So time in plug flow reactor is equal to 1 by k into ln C_0 by Ce this is nothing but that time required in CMBR reactor so the plug flow reactor is nothing but CMBR reactors in series.

Therefore, if we talk about the concentration gradient in a plug flow reactor we will be getting maximum concentration gradient because there is no longitudinal mixing so in the inlet you will be having C_0 concentration and in the outlet you will be having Ce concentration and the concentration will be gradually changing.

Here (Refer Slide Time: 54:40) we can see the concentration is gradually changing with respect to time. So the concentration gradient available in the maximum here in the plug flow reactor so definitely the reaction rate will be more so the volume required to achieve a particular degree of treatment will be less in plug flow reactor compared to CSTR reactor. The CSTR reactor will require maximum volume and plug flow reactor will require least volume. Then why we are not going for plug flow reactors all the time is because there are many advantages with CSTR reactors.

Now we will see the entire things we discussed today. We have seen the treatment option; either we have to go for physicochemical treatment or biological process it is all depending upon the nature of the pollutant present in the system. But when we talk about wastewater treatment most of the time the solids present in the system is organic in nature so the best treatment option is biological because microorganisms can utilize that organic matter and convert them into carbon dioxide and water and more cells that is why most of the times biological treatment process is attached with wastewater.

Now, in wastewater treatment we will be having three different types of treatment; one is primary treatment, second one is secondary and tertiary. Primary treatment means the entire unit operation to remove settable and floating solids and the secondary treatment is biological system and tertiary is depending upon the nature of the pollutant and effluent quality required. Then we discussed about the different types of reactions depending upon the rate.

We have seen zero order, first order, second order and nth order but when we talk about biological systems usually we assume that it is first order and sometimes we assume that it is a zero order reactor. We also discussed about what are the different types of reactors. We have seen what CMBR reactor is, what is the CSTR reactor and what is the plug flow reactor. So, if you want to achieve the same degree of treatment CSTR reactors require maximum volume compared to plug flow reactor because the concentration gradient available in CSTR reactor is less compared to plug flow reactor. But when we talk about wastewater treatment it is because of many other advantages of CSTR we go for CSTR most of the times.