Wastewater Treatment and Recycling
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Lecture - 20
Engineered Treatment of Wastewater: Concept of Mass Balance

Hi everyone. So, we have been discussing natural purification processes this week, and because our natural treatment systems are often not sufficient to take care of the entire waste which we are releasing in the environment. We need the engineering interventions or engineering solution for waste water management. This briefly we discussed earlier as well. In this week and rest of the lectures, we will try observing how the concept of mass balance or material balance applies towards these engineered systems, which are intended for the transport or transformation of the various contaminants present in the waste water.

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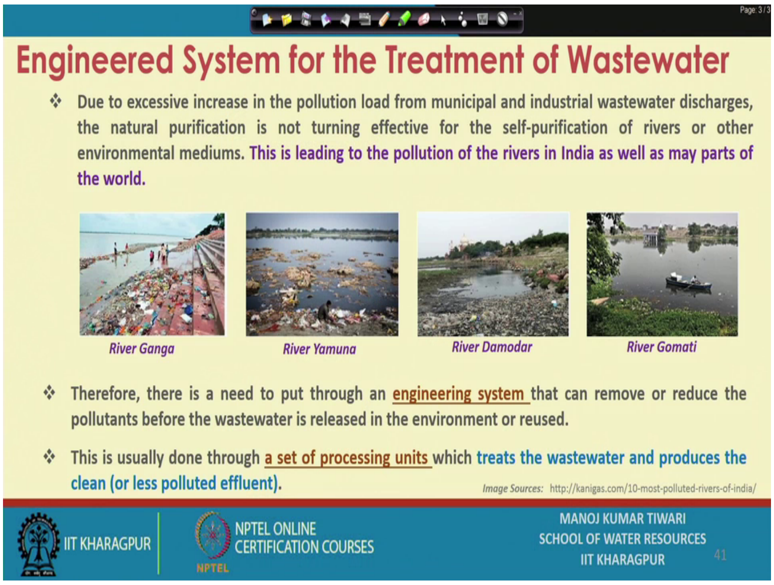

So we know that there is excessive increase in the pollution load which is coming from municipal as well as industrial discharge. And moreover the natural purification or self cleansing, ability of our, majority of the rivers has already almost exhausted ok. So, the, our natural systems or rivers are no more in a state to tackle more and more pollution load which is being discharge in them. And this is leading to the pollution of, where almost all the rivers, all the major rivers in India and as well as many other parts of the world as well. It is not the problem confined to just India only, but in many other countries, many other states problem are similar.

So you pick up all the major rivers; beat river Ganga, beat Yamuna, beat your Damodar, Gomthi and many other Sabarmati, all the rivers you can see that water is far from being of the very good quality. So that is why there is actually, as we have been discussing so far that once the waste is discharged in a natural system, they can tackle at least the organic waste or some of the sediments and these things by settlement by themselves, but in spite of that if the river water qualities are turning that bad. That means, the natural processes are not able to withstand or bear the load, which is being released in the rivers ok. And we must put some engineering system, we must put some engineering device that can remove or reduce these pollutants a in the waste water.

So, once it goes into the river, the volume becomes too high, means it is quite impractical to capture a river and treat it, the entire water in a river that is very unpractical solution. So, the waste or the pollutant in the rivers are primarily entering from the waste water discharge, either municipal or industrial waste water discharge, and if they are in the, like as we discussed in the very first week of this course that there are point load and non point load.

So, since these are point load, the discharges coming from industries or the municipals sewerage systems. So, they are point load so they can easily be captured. And if we put some engineering system on this discharge or on this waste water which is being generated which we intent to sort of either dispose in the river or do whatsoever.

So, if we put some engineering system that can remove or reduce the pollutant load in this waste water, before it is discharge in the environment or even if it is being, even if it is going for reuse purpose. Then also we need to reduce the contaminants load in this. So, this engineering system what we are talking about, is basically waste water treatment system and this is usually done through a set of processing units, so it is not just normally, there is no single unit which is used to remove all the impurities from the waste water, there is a set of units ok.

There is a set of units which treats the waste water and produces clean or at least less polluted if effluent. So, this effluent which is produced which is coming out of the waste water treatment system, is supposed to have much lesser pollutant load, much lesser pollution load in the water and therefore, depending on its quality and characteristics, it may be discharged or it may be reused.

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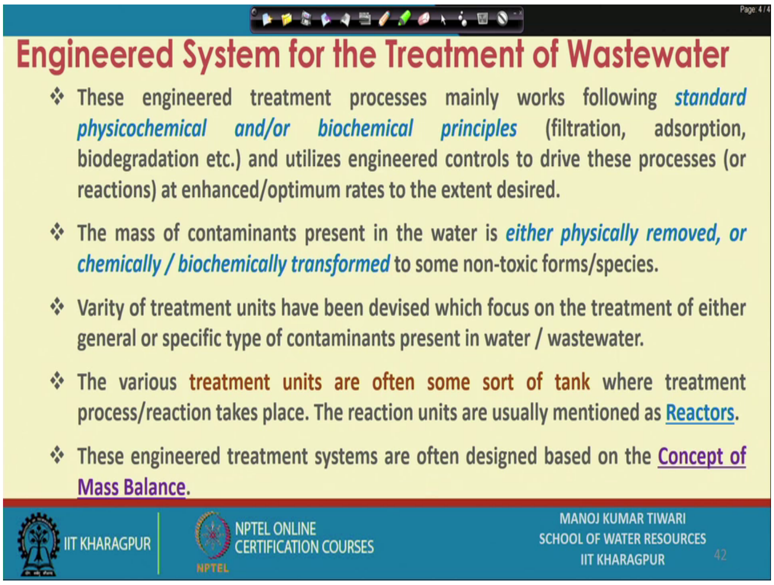

So, that kind of engineering systems are required. Now this engineering system for the treatment of waste water or typically the waste water treatment systems or waste water treatment plants are engineered treatment processes and they mainly work following the natural processes that we were discussing.

So, whether it is a engineered system or a natural system, the basic processes remains more or less same ok. So, in the engineering engineered system also, there will be standard physicochemical processes or biological principles, there would be filtration adsorption, biodegradation. And however, the differences in nature, it is controlled or governed by the nature, but in engineered system we have much larger control in these processes. So, we can utilize the engineered control to derive this processes or these reactions at enhance rate or optimum rate and we can derive this reactions to the desired level ok, to the possible level it can go of.

So, the processes or the basic principle basic concepts may remain same in a engineered system, engineering purification system or natural purification system. However, the control in the engineering purification system is much more as a post to the natural purification system, because in natural purification system we do not have a control on that ok. If, let say temperature is dipping in the night in a river, so it will dip, the biological processes if it is a, let say colder climates or in the winter season, if temperature is going as low as say 4 degree 5 degree, so your water temperature has dropped significantly and the biological processes or rate of biological processes is going to be reduced drastically.

You cannot do anything with that, it is not possible that you pull in all the; like blowers and this things to raise the temperature of the river water, again that is quite impossible and impractical, but in engineered system. Let say you are having a reactor set of a this things, so you can put all the control, you know that you can manage the temperature, you can manage the conditions, you can manage the kind of microbial species you want to represent in the reactor, you can trigger what kind of reaction you want it to take place. So, all those controls comes in the hand of engineers in such system.

So the mass of contaminants that are present in the water, is either physically removed, so through filtration or straining processes or even adsorption process, so it is goes to the to the phase transfer, so either it will be physically removed or it will be chemically or bio chemically degraded ok. And this degradation could be up to the scale of mineralization, where it is converting to the basic entities or could be some intermediate by products. So to what extent it is possible or how it can form non toxic form or non toxic species, because we are talking about engineered system, so we can control to that scale that ok. If this reaction is not complete let us supply more or let us make more favorable conditions, let us apply a catalysis or let us put certain reactants which can enhance the rate of reaction or can trigger this reaction to its completion.

So, all those possible, all those options remains available in a engineered system. There are variety of treatment units that has been devised and these different units focused on the treatment of, either general type of pollutants or at times very specific type of contaminants present in the water. So, we can have a nitrification de nitrification system specifically for the removal of nitrogen ok, or we can have just let say activated slug process for the removal of in general organic matter present, all the carbonaceous compounds which is leading to the CBOD.

So, that sort of you can have a system placed for removal of the suspended solid, so from whatever source is coming in ok. So, that way the treatment systems could be very specific or could be very general at times. So, these various treatment units are generally often some sort of a tank, most of these ok, where the treatment process or reactions takes place.

So, if it is a transformation thing, there will be a reaction. If you are talking about a biological treatment, so microbial species utilizes the organic matter and decompose and degrade them, so reduces BOD and COD from the water, so that is kind of a biochemical reaction. While there could be just specific treatment process, so you have filtration tank, where the suspended or this kind of impurities are getting retained.

We can have a sedimentation system, where this just a physical settlement. So, there is no reaction taking place as such, but there is a physical treatment process. So, either its a physical treatment process or there is a reaction taking place, most of time these are done in some sort of vessel or tank or system that we design. So, these reaction units are typically called as reactors ok. We often call then as a reactor and that is why we say that the waste water treatment plant or waste water system could have several units or several reactors integrated in it.

Now this engineered treatment systems are often designed based on the concept of mass balance, the basic concept of mass balance.

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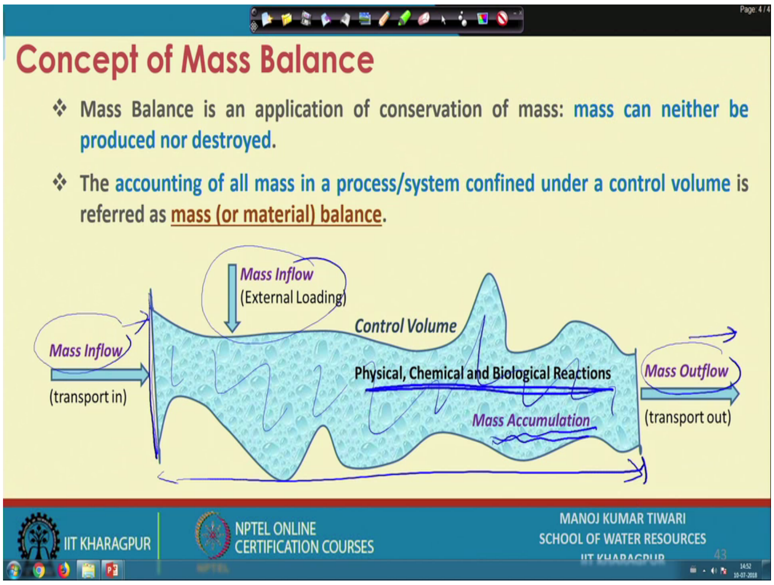

So, how the concept of mass balance helps or let see what is the basic concept of mass balance which we are discussing. So, mass balance is simply an application of conservation of mass. We have blogs conservation of mass which says that mass can neither be creative or produced and cannot be destroyed, so it can changes form from one form to another, from one phase to another phase ok, so that is a possibility.

So, the mass balance is essentially the accounting of all the mass in a process or in a system which are confined under a controlled volume. So, once it is, once we considered a boundary, a system boundary and we call that as a controlled volume, so like you see, you are seeing here as stretch of river for say. So, if this is stretch of a river is we want to apply a mass balance to this stretch of river. So this entire volume becomes our control volume and we need to apply a mass or material balance to this control volume. So, how do we do that? We apply the conservation of, principle of conservation of mass and try to see what, what is the mass getting entered in the system, what is the mass which is leaving the system ok.

So, is there any external loading or external entry of the mass which is coming in the system, and then what kind of various physical chemical and biological reactions taking place or if there is any mass accumulation happening in the system. So, we consider all these routes through which mass can enter the system, through which mass can leave the system, through which mass can transform within the system or mass accumulates in the system. So, a combination or a summary of these is typically referred as the mass balance.

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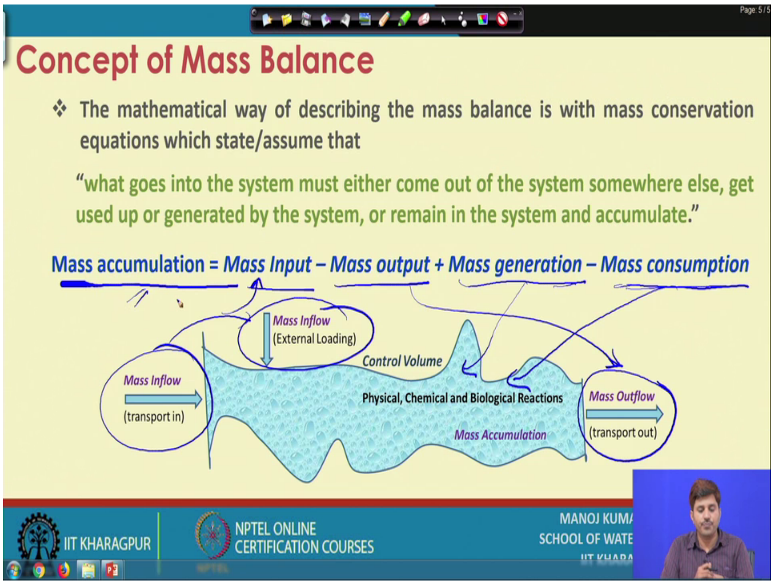

Now you see the mathematical we can describe this concept of mass balance as what goes into the system must either come out of the system somewhere else or get used up within the system or something which is generated by the system will also come out of simulates somewhere, or could remain in the system and accumulate. So, this concepts gives us the basic equation that mass accumulation will be equal to the mass input minus mass output.

So, this is your mass input, these two are your mass input over here minus mass output. So, the mass which is leaving the system is your mass output plus mass generated. So, any mass which is being generated within the system or mass consumed within the system.

So, let say if x amount is coming in and y amount is leaving out if the system, so x minus y amount is there within the system. Additionally, if let say there is some generation or consumption, so that will be trans, that will be considered from x minus y amount and whatsoever left is the amount of mass which has left in the system or which has accumulated in the system so that is; what is the CO basic concept of the mass balance.

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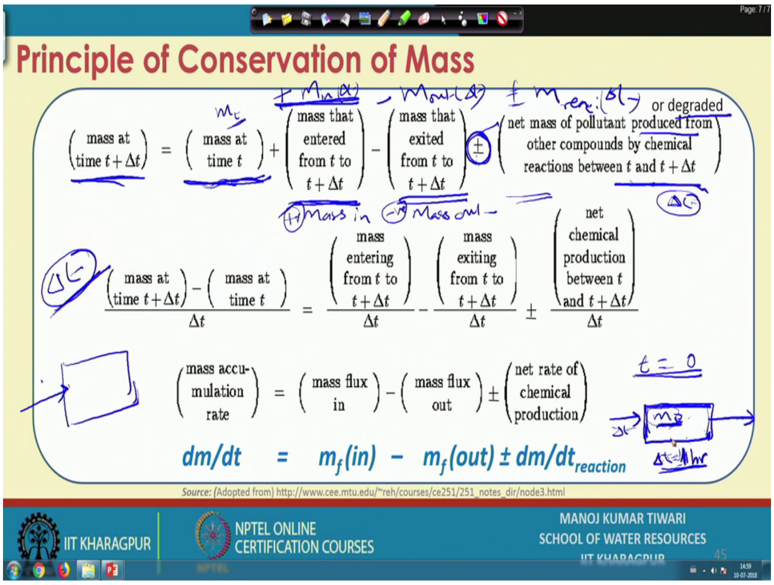

Now, if we see this equation in a mathematical form, so our principle of conservation of mass will guide us through that. So, let say we have a system ok, any system, where some mass is entering at any given time t ok. So, any given time t mass has entered, let say this is mass at any given time t has entered and mass that has entered from time t to t plus delta t right

So, or instead you can see that let us, let us have a unit time delta t ok. So, we have a unit time delta t in which we are trying to analyze what has happened in this system. So, there is some mass which has entered in this unit time delta t, so that is the mass entered from time t to 2 plus delta t; that means, within time delta t ok. From t to t plus delta t essentially means the time interval becomes the, our time interval becomes delta t. So, the mass that has entered in time delta t and similarly the mass that has exited in time delta t.

So, we have accounted for the mass in and mass out ok. Further, if there is any production or degradation of the mass within this time t plus delta t in the control volume or in this. So, net mass of the pollutant which is either produced or degraded from other com, degraded to other compound or produced from other compounds by certain reactions between time t plus delta t, will be also added. Now this plus minus sign will depend on, whether it is being produced or it is being degraded, if something is being produced so it will be added.

Now if let say this is our system, so this much mass has entered in the system, so this is positive, mass in is positive. This much mass has left in the system so this is negative, because it has left our control volume and mass which is either produced or degraded, sign will depend on whether it is produced. If it is produced, so it is being added in the system so then there will be a plus sign and if it is being degraded, so that means, it is being removed from the system. And then there will be a minus sign and we as taking all this in a time interval delta t which is from t to t plus delta t.

So whatever has entered, whatsoever has left and whatsoever has either produced or subtracted, if we add all these. Means if we, if we sort of account for all these, not adding; of course, the mass which is leaving the system will be negative. So, if we account for all this is what we get is net mass increased or accumulated in the system ok. So, how much mass accumulated in the system, that will give us the mass which was there at time t and what is the mass now at time t plus delta t.

So, the difference of these two will give us the mass which is accumulated in the system or if let say we want to know that what will be the mass at time delta t after time t plus delta t. Means we started from let us say any time consider t is, let say 0. So, we started at 0 and we try to figure out the net mass stored in this system after 1 hour, so our let say delta t is 1 hour for say. So, in this 1 hour time how much mass is accumulated in the system?

So let say in the beginning there is some mass available in the system as empty, this is a initial mass. So, there is some mass available in the system at time t empty. Now, whatsoever mass has come in that time delta t, so let us say this is m in delta t, mass n in time delta t and this is the mass that left this system in delta t, so mass out in time delta t and any reaction or any addition or subtraction due to reaction in time delta t, so the mass due to reaction, let us say in time delta t within the system and this will be have; obviously, this will, this is being coming in so plus, this is leaving out so minus and this could be plus minus depending on that.

So, if we add the inflow, subtract the out flow and accordingly add or subtract the change of mass, we can and with the, to the initial mass which are present in the system, we can get the mass after time delta t, so that is what this expression is all about. So, what we get is mass at time delta t is equal to mass at time t, the beginning of time t mass entering in time delta t mass leaving in the time delta t and mass adding due to reaction in time delta t, which is and your delta t is from t to t plus delta t.

So, if we take this component to the left side what we get mass at time t minus mass at time, mass at time t plus delta t minus mass at time t divided by delta t. And here what we get, that mass entered in time in delta t, mass exited in time delta t and mass produced or consumed a, produced or degraded in time t delta t.

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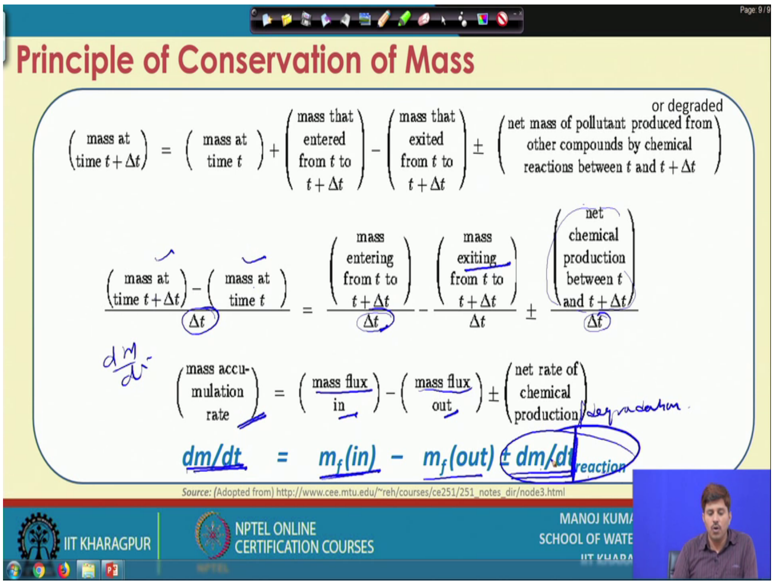

So, we rearrange this equation like this and now if we divide both side or all terms by delta t, so what we get here. Now this is mass at time t plus delta t minus mass at time t ok, so that is something like m t plus delta t m at t plus delta t minus m at t divided by delta t. So, from very first principle of the calculus this becomes d m by d t or rate of mass accumulation, because there is the final mass, there is the initial mass so how much mass as accumulated in the system. You subtract initial from the final, you get how much accumulated and you divide it with the time so you get how much accumulated per unit time ok, and when you express is at a per unit time what you get is mass accumulation rate.

So, here we are able to identify, we are able to get the mass accumulation rate right. Now you see the mass entering in time delta t per unit time again, so in is specified fine how much mass has entered into the system ok. So, mass entered in the system per unit time, when we are dividing with delta t we are taking about mass entered in the system per unit time, so this we called mass flux. So, rate of mass entering or rate of change of mass per unit time is typically called as mass flux, so when we are talking about mass entering so this is mass flux in. And similarly when we talking about mass exiting in time delta t per unit time or mass exiting from the system per unit time, we are talking about mass flux out, rate of change of mass which is leaving the system, so that is why it is out. Otherwise this these two terms rate of change of mass per unit time is mass flux, and so we see how much mass flux coming in the system how much mass flux going out of the system across the system boundary.

And similarly here the net change of mass in time delta t per unit time will give us the net rate of the chemical production or degradation. So, either mass is getting produced or mass is getting degraded, so what is the rate of change of mass through that reaction per unit time right. So, this becomes dm by dt rate of change of mass per unit time, this is your mass flux in, mass flux out plus minus rate of change of mass due to reaction.

So, we have two terms dm by dt in, this is the net rate of change of mass in the control volume, whereas this particular term is rate of change of mass which is happening due to reaction only ok. So, this term is attributed to the chemical reaction or transformation. If there is no transformation taking place this term would be zero, whereas this term is a much larger term rate of change of mass in the entire control volume, so that is what it is.

So, that is how we get sort of generic mass balance equation or mass term equation.

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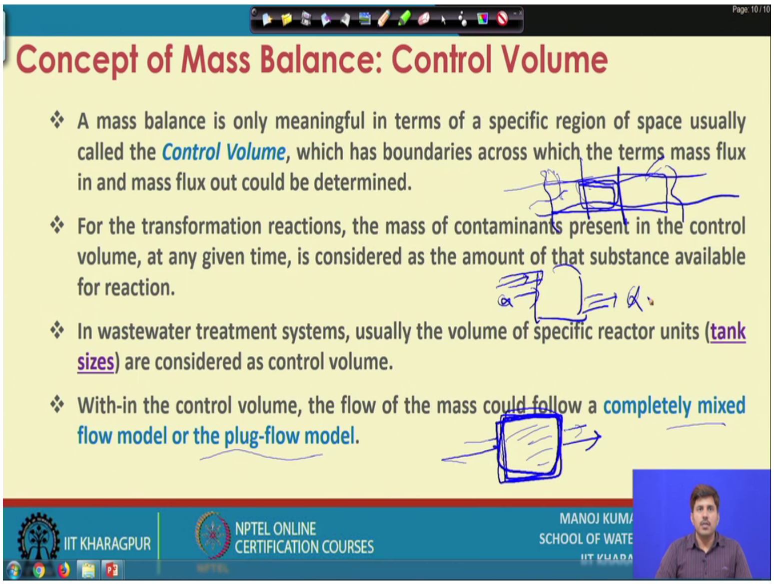

Now, the concept of control volume is very important for the mass balance. A mass balance will only the meaningful in terms of specific reason of a space. So, if we are talking about, let say we have a reactor or we have a tank system. This tank volume we are considering as controlled volume. So, wish we will consider the mass entering in the tank mass leaving or the time so or the boundary or control or boundaries are confined or boundaries are fakes, system boundaries ok, if we have river.

Now if I getting this stretch of river I can do a mass balance for this, but if I am taking a much larger stress, the mass balance for this may be different than this, because amount of things entering here or amount of things leaving there could be different. So, there could be different rate of mass flux in, your mass flux out for your different controlled volume.

So, a particular mass balance or a specific mass balance is defined only when we define in terms of specific reason, which is called controlled volume. And this control volume has boundaries across which the terms mass flux in and mass flux out can easily be determined if they are. For the transformation reaction, the mass of contaminants present in the control volume at any given point of time is considered as the amount of that substance available for reaction.

So, what whatsoever amount of that substrate is available is only which what, only what is present in that control volume. So, beyond the control volume whatsoever amount of the organic matter or contaminant present is not of bother for this mass balance thing. In typical waste water treatment system, usually the specific reactor units, the tanks that we have of different sizes, so these tank sizes are considered as control volume ok.

And within the control volume the flow of mass could follow a completely mixed model or plug flow model that depends on how we are considering. So, we will describe what is completely mixed and what is plug flow model, this are the different type of flow resumes in the system, which governs how the contaminant is moving or how the contaminant is, how well the contaminant is mixed in the system. So, that is the concept will discuss in the next lecture.

So overall this, the concept of mass balance which we are discussing applies nicely to the engineered system, because we have a defined control volumes if we. Concept of mass balance is applied to natural systems as well, we can apply concept of mass balance to a lake, to a section of river or to a pond, to means all such systems can be used for applying the concept of mass balance, but there in natural system your boundaries or estimation of the net flux across the boundaries at times can become very difficult, but in engineered systems its quite easy. You have a tank and you are having a inflow, so you know what flow rate you are letting the contaminant or letting these substance go in the in your control volume, you know at what flow rate it is leaving the system.

So, the inflow and, inflow and outflow mass flux becomes very easy to assess ok, if it is their existing in the system. So, that was about the basic of the mass balance. And in next class we will see how the different specific cases can be applied for analyzing mass balance in the reactors.

Thank you.