Advanced Chemical Reaction Engineering
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Lecture - 39
Oxygen Sag Analysis in Rivers

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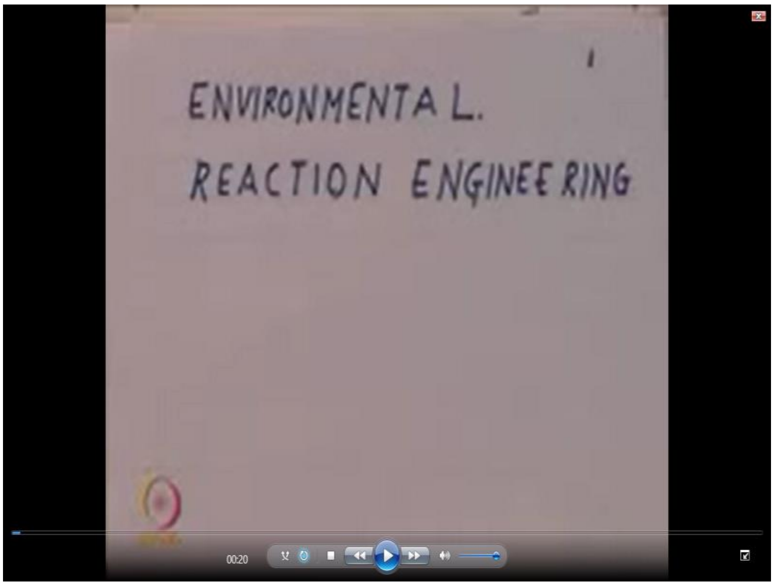

So, we look at a problem in environmental reaction engineering and the background to this is as follows let us looking at what happens in real world?

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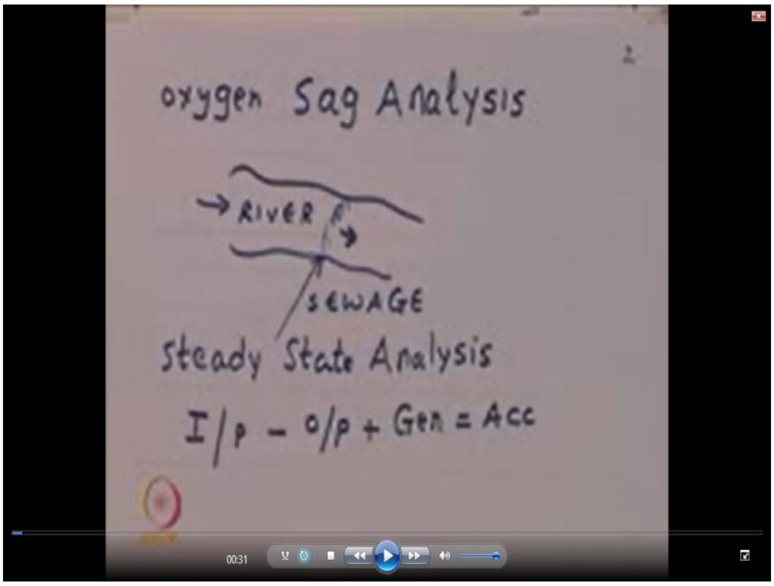

See all over the world there is a general tendency to put waste water particularly sewage into the river and do your designs so that the river is able to take care of the pollution in the water. This is a practice that sanitary engineers have evolved over a long time and there are some guidelines which you are suppose to follow. And this whole oxygen sag analysis tells you what those guidelines are and what it that you are is supposed to do? The general approach here is that the river comes with relatively clean water and the river has a natural mechanism for oxygenation. And therefore, that oxygen capacity that the river has they are able to utilize to treat your sewage. This is the general thinking that river has lot of water the river water is relatively not polluted. And there is natural re aeration capability that the river has and consequently you are able to treat sewage.

And there are some numbers which are you take care so that the sewage is treated in an appropriate way. What you want to do is to do this exercise we do it for a steady state assuming that the river flows are known and the sewage flows are known and that steady state our inputs outputs generations in accumulations this accumulation is taken as 0 we take this as 0. Now, what is this balance is for the amount of oxygen that you are able to supply to the water in the river basically that is the balance. On other words how much of pollution load is coming in how much of pollution load will go out? And then how much of oxygen you can supply how much of oxygen will get consumed and that balance if it is at steady state goes to 0 that is the balance that we want to write and understand how to write this?

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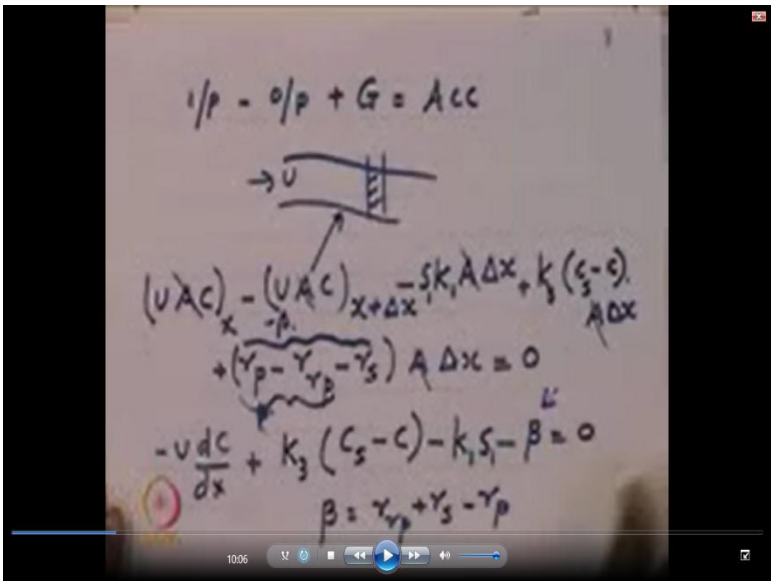

So, this is what I have written let us spend some time on this we have taking a elemental volume this is a river flow at velocity u input output generation accumulation. So, I have taken an elemental volume, so much what is C? C here represents the oxygen that is present in the water what is the dissolved oxygen in water? So, C is the dissolved oxygen in the water, u is a velocity of water, a is the cross section area of the river at x and x plus delta x. The first term here this first term here what is this first term? It represents the amount of oxygen that is consumed by the respiratory organisms in water which uses the pollution s 1 what is this term s 1 times k 1 times a times delta x this is the amount of oxygen that is consume by the respiration in the of the organisms which using this pollution s 1. For example you know when we through let us say carbohydrates into water carbohydrates you know the it requires certain amount of oxygen and that s represents the oxygen demand of that water. Suppose I give you waste water and ask you what is this oxygen demand we to we said it earlier also we do a simple test to find out how much oxygen is required oxidized it.

And that determines amount of oxygen demand of that water. So, s 1 is the oxygen demand of that water and k 1 is the rate constant. The rate at which this gets consumed therefore, this term represents the rate at which oxygen would be consumed by the pollution load in water. The next term which is k 3 times c s minus of c this is the driving force that means solubility of oxygen in water is c s, oxygen concentration in water is c this is a driving force this is a rate constant for re aeration what is k 3? K 3 is rate constant for re aeration, so much of oxygen gets consumed and because of the pollution load so much of oxygen is supplied, because of natural re aeration. This is the pollution the oxygen consumed by the pollution load in water. This is the oxygen that is available to water, because of natural re aeration. So, this now, this term r p r r p and r s r p represents the amount of photosynthetic oxygen supply, r p represents the amount of photosynthetic oxygen supply, r r p is the respiratory oxygen consumption by the natural organisms of water. On other words the absence of this term for example, the river would flow k which means there is natural re aeration and that natural re aeration would we consumed by all these activities only there is a natural respiration photosynthesis natural respiration there lot of sediments in water which will also consume oxygen.

So, what we are trying to say is that in the absence of adding sewage into water. So, what you have having is a there is a natural re aeration from atmosphere there is oxygen supply, because of photosynthesis and there is oxygen consumption, because of respiration in the absence of our pollution load. Even when there is no pollution load there is a natural pollution load, because of various organisms present in water. And this is the sediments which are present in water. The statement of material balance is what is important there is to very straight forward.

The statement of material balance is that there is pollution load in water and that we are adding this sewage this, because of this sewage. So, this is the amount of oxygen there is consumed by that sewage this is the oxygen that is supplied, because of re aeration what is meant by natural re aeration. This water of the river is in contact with the atmosphere there is atmospheric turbulence and as a result there is oxygen transferred to the river that is this term. Now, there are these 3 terms here which is oxygen generation due to photosynthesis. This is oxygen consumption, because of respiration in the natural environment. This is oxygen the consumption, because of various sediments that is present in the river basin.

So, even in the absence of suppose even this we are not there you have all these terms which means that there is natural re aeration there is natural photosynthesis there is natural respiration there is natural sediment respiration. So, when you add this an additional term the object of this analysis is that what is the effect of this additional term on the water quality of the river? This is the problem we are trying to solve. Now, these numbers k 1 k 3 etcetera is fairly well documented for example, different climatic regions of the world there are got lot of numbers which are available readily. This term r p r r p and r s lot of material is available what is important to recognize is that this term is generally considered as 0. On other words what we are saying is that the oxygen that is supplied by photosynthetic organisms of water is essentially to serve the respiratory needs of the water environment. The oxygen that is produce by the photosynthetic organisms of water is the oxygen that is used up by the respiration of the natural organisms of water. Indicating that really speaking the natural environment really does not have much surplus oxygen natural environment does not really a surplus oxygen, because this r p is essentially meant for the respiration respiratory oxygen demands of r r p and r s.

But because urbanization and so many other issues what we have said what sanitary engineers are said is that we can put certain amount of waste into our water bodies and that would not harmed a water body. This is the argument that our friends in sanitary engineering are saying we will see what kind of result we get. Now, we can represent equation 1 whatever that in this form you can knock off the appropriate terms a goes off a goes off. So, is this what I have done I had knocked out a and all that and I put it in this form that is look all right. So, this is the statement of material balance for c represents the oxygen concentration in water k 3 is re aeration constant k 1 is what they call as I mean BOD consumption rate constant. And beta is this term you cannot read this now this whole term is beta i it is written minus beta it is minus beta sorry it is minus beta. So, as you can see here if you should divide x by u it becomes residence time. And the rivers can be considered to be in reasonably in fluke flow the dispersion coefficients are not very large. So, it is it is first order differential equations d c d tau that is what we called.

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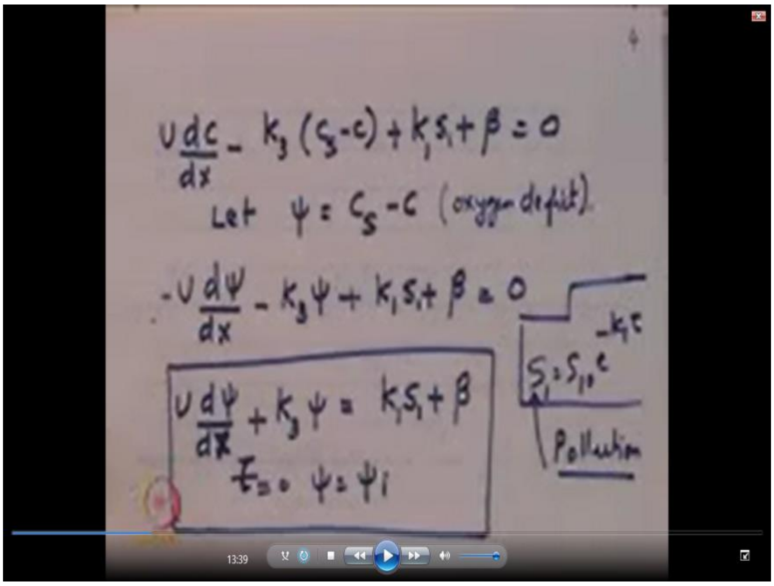

So, the equation that describes what goes on in the river is this. Mixture all the numbers are minus plus seems all right. So, our differential equation is the rate of change of dissolved oxygen in water with respective distance is given by these equations. Now, I put the sanitary engineering literature uses this symbol to call it as oxygen deficit. This is called as oxygen deficit psi is a measure of the deficit. Deficit means what is the difference between saturation solubility and the present concentration put it in that form our equations looks like this so this is what you have to solve. What is our is tau equal to 0 not t here tau equal to 0 our tau equal to 0 do we know this what is the initial state. As a river starts of do we know what happens this where the waste is entering in the river do we know what happens here? Generally you should be able to take a sample and find out what is the oxygen concentration c i and what is the pollution concentration s 1 both are something that can be you know determined experimentally. So, the initial state of the system is fully known c i is known s 1 is known, because all the numbers are known in the x. So, what is being said here is that the initial conditions psi is fully specified therefore, it can be integrated to find out the solution. Can you please quickly solve and see whether the result that I get is satisfactory please quickly solve this quickly. So, this is a solution that i get it does not mean that it is right.

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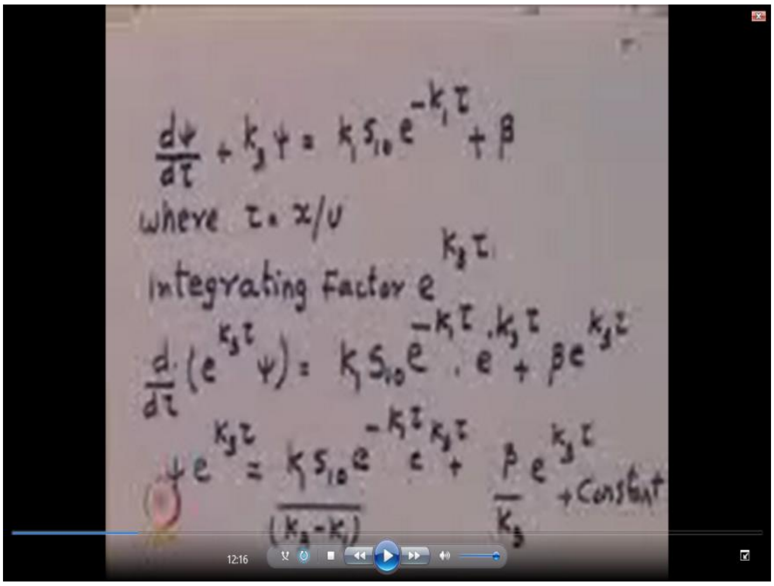

So, please confirm to me it is, so this is the solution I get please see if it is this is my solution please see if it is ok. Now, I want to draw attention to this term please this is an important term see this term k 1 s 1 this term s 1 is written as s 1 0 e to the power of minus k 1 times tau why it is written like that is that the assumption is that this material which is the pollution loads in the water it will decay as per the rate constant k 1 in the time of residence tau? On other words during the period of tau of residence time in the river this would consume so much of oxygen that is what we as we it decays like this and therefore, it is has an effect on the oxygen. So, what we are saying is that this term this s 1 which is the pollution load in water it will decay as per the exponential rate law which means at s 1 would change as s 1 0 exponential of minus of k 1 t while k 1 is the decay rate constant for the pollution load where s 1 is the pollution load. So, this comes from our first order law that if s 1 0 times e to the minus k 1 k 1 is a rate constant for the decay of pollution.

So, on the other words what we are trying to say here is that the oxygen that is present in water it will decay and that is, because this is consuming that oxygen. And it is consuming their oxygen at this rate where s 1 is going to decay like this s 1 0 it is a minus k tau. And beta is generally taken as a constant, because it does not change if the environment is fix beta is fixed. So, our solution looks like this. This is my integrated form of the solution please tell me if this, so k s 1 is replace by s 1 0 e to the minus k 1 tau beta constant it is taken as constant I have put the integrating factor. And this is the solution. So, what I have done my friend it is at I have put x by u s tau is it x by u I should have mentioned here u s. Let we write it here tau equal to x divided by u that is why I have put it in that form in the next page is this here. Can we go forward the integrating factor i put it in this form I am integrate in both sides shall we go forward. Now, you divide throughout by e to the minus k tau and you get the final form.

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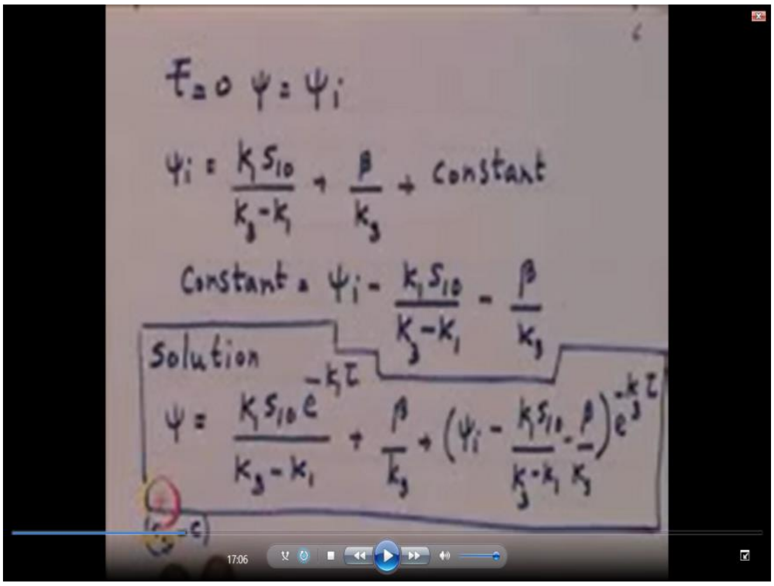

So, the final form I will get is this tau equal to 0 sorry tau equal to 0 psi is psi i and how do you find out the values of constant of integration? How do you find the constant of integration tau equal to 0 psi is psi i what is psi i? You ask yourself psi is defined as c s minus of c this is known; because you have taken sampled you can find out the oxygen level in the water at the point while you are starting your tau equal to 0. So, c is c i is known c s saturates solubility is known therefore, phi i is known. On other word initial deficit in that water is known, because c s minus c is called as deficit w psi i is known from our initial state. So, psi i is known therefore, the constant of integration is given by this and solution looks like this. So, if you want to put our waste into our rivers you must look carefully at this equation.

So, this tells us what will happen to our river when we put waste into our rivers? So, what are we saying that psi which is the oxygen deficit psi is oxygen deficit c s minus of c psi is c s minus of c. That means saturation solubility minus the actual concentration that is psi that is given by k 1 s s 1 0 is what is s 1 0? s 1 0 is the concentration of pollution after it is gotten mixed with the river our model is this pollution is coming in here. It mix up mixes up and the concentration s 1 0 represents the combination of river water as well as the waste water so this is s 1 0. So, s 1 0 is known, because the river flow is known amount of waste water coming is known therefore, from material balance you can calculate what is s 1 0? Now, k 1 and k 3 are k 1 is the constant that is responsible for the d k of the pollution k 3 is re aeration rate constant which comes from our experiments that is available for that environment. Tau is a residence time of the water in the river. So, all the in this equation everything is known therefore, if you put in a all the numbers we should able to tell what is the deficit of oxygen in our rivers?

Now, there is 1 point that we must bear in mind is that this saturation solubility of oxygen in water is the very strong function of the environment. For example, in our kind of climate where the temperature is of thirty plus typically solubility of oxygen is about 6.2 or 6.3 milligrams per liter. While if you go to cold countries where the ambient temperature is typically 14 and 15 the solubility is 10 milligrams per liter. So, 6 and 10 almost is not doubled, but significantly higher. So, you will find that the aquatic organism that live in very rich oxygen and very lean oxygen they are not the same. So, you should recognize that fact that you see in the natural environment is great bio diversity depending upon the environment itself. So, if you take a if you take a fish which is suitable for a warm climate and put it into another river which is it does not work out very well, because it is not suitable suited to that kind of environment. So, we have to appreciate all those features when we try to designs systems like this where we put our waste into our rivers. Let us ask a small question. I will just rearrange this in this form so that we understand each term a little better.

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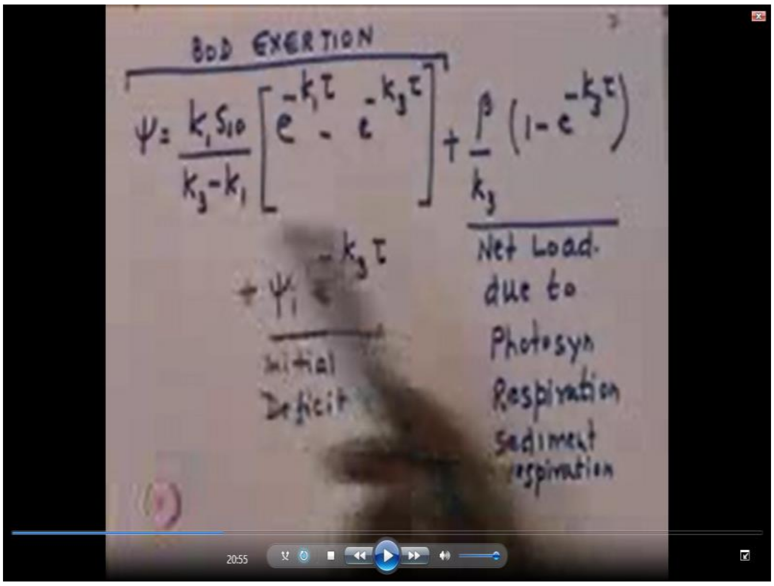

So, this is how the solution is available in the literature. The first term the same thing is arranged slightly differently what is this term? This is due to pollution while the second term is re aeration. So, this whole term essentially tells you what is the effect of the pollution that you are put in? That means what is the oxygen demand that your pollution load this you are putting into the water this is the first term. The second term which is beta divided by k 3 and all that this is a term which comes from the fact that the natural environment there is lot of load due to the natural environment itself. Respiration sediment and photosynthesis all these we taken together are what affect this term. The third term is what is called the initial deficit? That means when we mix the waste with our river you start with some initial deficit it is not saturated water it will be some deficit. So, essentially what you will see is the net result of what we have put in terms of what is a natural environment and what we start with initial deficit? There are 3 components to what will affect your deficit.

This is a for a long time for a long time I mean this goes on even today, see situation is western in world is slightly different while the density are not very large we say, but the density in this country is very large. And therefore, to assume that our rivers have the capacity to receive pollution is generally not correct. Number 1 there is not enough flow in the river so our river flows Deccan rivers flow only for a about 2 months in year. Because the rain fall is only 100 days not even 100 days maybe 50 days in a year. So, the Deccan Rivers do not have much flow. The Himalayan rivers has flow, but flow vary is a lot and huge amount of water is taken by irrigation other purposes the river flows a very low. So, what is being said in most places now a day is that rivers do not have adequate oxygen to manage your load? That is the kind of the argument people are giving therefore, we should not put our waste into a rivers that is the kind of arguments. But when you do some of these calculations sorry exercise here see if it is I want look at the first problem so that we can appreciate what I am saying?

This is a river 30 million gallons per day 30 million gallons means what? 1 gallon is 3.8 litters so 100 million litters 100 m l d Bombay city is about 4000 m l d. So, we can see 100 m l d is not very large, but it not very small either. So, this would be a small town 30 small town cities like puna is about 6 700 m l d puna, so not it is not very small, but substantial. This sewage goes into the river with the flow 10 cubic meters per second 10 cubic meters per second is not a small flow. You will find most Deccan rivers I mean when I say Deccan rivers I am not talking about Godavari and Krishna they very big rivers. I am talking about small many of the small tributaries in rivulets during the monsoon they will have this kind of flow. The river will have bigger flow, but may of this small say bheema for example; this will have this kind of flow during the monsoon for 50 days or so.

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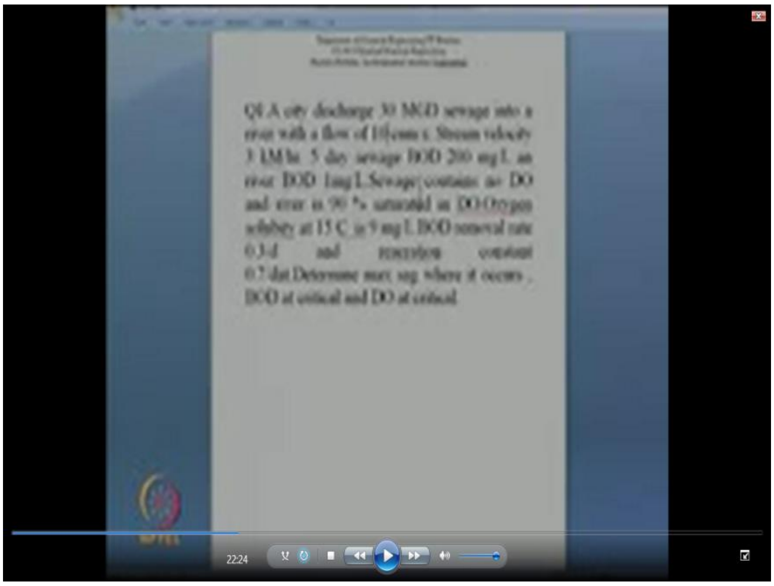

Then if you are going to put your waste into this at that time these calculations would be relevant. But if you going to do it any other time these calculations will tell you there is not enough flow and these calculations are not very relevant. So, we are looking at instants where there is lot of flow in the river number 1. To see what happens when you put sewage in to the river at a time there is a plenty of flow when there is very little flow it is a different scenario which will we do later. So, what it is says is that stream velocity is given 5 days sewage what is meant by 5 days sewage BOD means? I am sure you understand this when you try to determine pollution load in the water we said there is 2 ways there is pollution is the water is determined. You take that water and try to oxidize dissolved organic potassium di chromate this is standard oxidation. Now, amount of potassium di chromate that is used for oxidation of the pollution is a express in terms of milligrams per liter. How many mile grams of oxygen is required per liter of the solution for oxidizing this is the this fally standard. But BOD actually is a slightly different technique.

In BOD what you do is that you take a let us say a litter of water which is saturated with oxygen. You inject your sewage into this water so you know initially contains so many milligrams per liter of oxygen. You wait for 5 days and you measure how much of the oxygen that you have put in got consumed, because of the sewage that you have put in. This is what is called as d o b by chemical oxygen demand that means oxygen that we have put in has been in consumed by sewage organism and that is what determine by BOD. And this is done after a 5 day period is the send that we can wait for 10 days 5 days 3 days 2 days that choice is yours depending upon the how long you can offer to weight. The standard technique around the world is you should a 5 day BOD. That means you take the water saturated with oxygen inject a sewage wait for 5 days. And measure the difference in the concentration of oxygen whatever is the oxygen that is consumed divided by the volume of the water will fill it a the amount of oxygen consume per liter of water that is how they express BOD when you say BOD of 200 milligrams per liter. See which means that it has 200 milligrams per liter of oxygen demand that is coming from sewage organisms it is coming from sewage organisms.

Let us just try to make a quick calculation. Most of us excrete typically about 80 grams per day most of us. We as we supposed to consumed something like as per w h of norms 180 liters of water per day consume means in varies ways drinking wearing washing all other excreta. So, 80 divided by 180 is the likely pollution load in that water how much is that 80 divided by 180? It something like how much is that 80 divided by 180 0.4. So, 400 milligrams per liter is the kind of oxygen low out that we should expect in the waters that even die dispose. But if you consume instead of 180 400 liters as we do in IIT Bombay for example that is our average highest in the world. So, that becomes 200 what I am trying to say is that this figure of 200 milligrams per liter depends upon amount of water you consume. There are places in India where the consumption of water per day is only 50 liters therefore; the load on that pollution will be 8 in 50 liter 80 grams would come. So, that will be 1600 milligrams per liter what I am trying to say is that if you go to the villages of this country where the availability of water is low the pollution load is very high.

That means so much of oxygen is required to oxidize the waste water. So, you cannot look at waste water in terms of m g d only is not enough? How much pollution load is present in the water is equally important. Because that much oxygen we will have to be provided for it to be oxidized. So, when people say 30 m g d containing 200 milligrams per liter of pollution load. This is the important figures that we should bear in mind. Now, tell me if the river is coming at 110 cubic meter per second it is mixing with 30 m g d what will be the concentration of pollution at the point of mixing? At the point of the mixing what will be the concentration is that question clear all of us let me repeat the question. The question is the following. Question is that the waste water and the river is mixing here, so what will be the concentration waste water is coming here this is a river this a mixing here what will be the value of s pollution load here how will you calculate? To calculate this you can see here 30 m g d 31 gallon is 3.8 liters. So, you know the total volume flow it coming at 200 milligrams per liter. So, you know 30 multiplied by all those and then this particular river water is coming with the BOD of 1 milligram per liter what I am saying can you calculate what is the value of s? I have done this calculation here.

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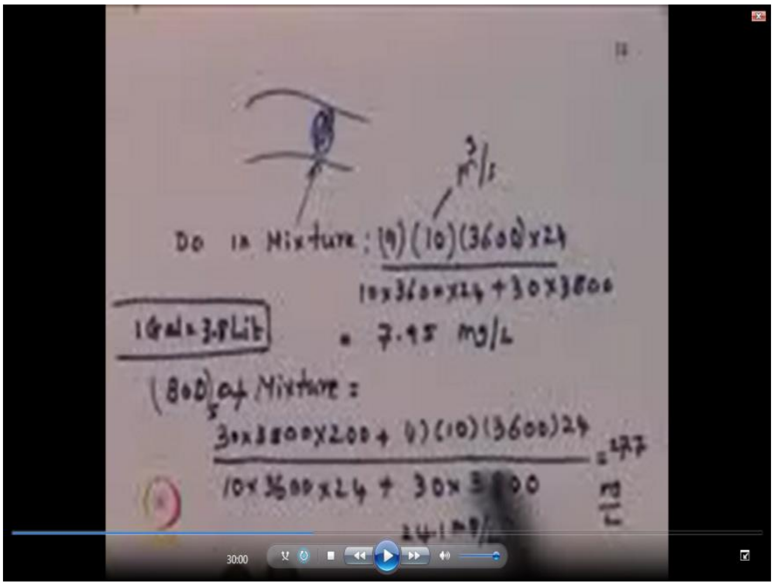

See I have done this I hope it is correct you can tell me whether it is correct I calculated that d o in the mixture and BOD of the mixture is this correct please tell me what is dissolved oxygen in the mixture? It says solubility oxygen is 9.9 now, please tell me what is the d o in the mixture what is the BOD 5 of the mixture? This is the calculation I have done you please tell me whether my calculations right I have done with 9, because 90 percent of this what it says here 90 percent saturated. So, the river does not come 100 percent saturated it is comes with 90 percent saturated. So, I have taken 90 percent of 9.9 as 9 are it cleared what we are saying? We want to calculate what is the d o in the mixture we want to calculate this how did you calculate this? How much of oxygen is coming in divided by the total flow is it is this number correct 7.95 can you please calculate and tell me 10 cubic meters per second this is cubic meters per second this is there is only 1 s 2 s any more is it all right.

So, what are we saying is that seeing most of this data that first to cool country I have taken this data from cool countries? So, why this salability of oxygen is very high and then therefore, your d o in the mixture is 7.95. Now, I want calculate what is BOD 5 of the mixture that means how much this pollution is coming in here there is some pollution in the river itself. So, when the 2 mix what is the BOD 5 I have just calculated here tell me whether this i get is 27.7 30 m g d 3800 200 milligrams per liter and this is the river total flow denominator. See most of this calculation I have done mentally so I am not too sure whether this is right 24.1 anybody else is that consistence everybody is agreed with this how this is it clear what I have done. So, this total amount of pollution coming in this is the pollution in the river divided by total flow. This is we will go forward d o is dissolved oxygen in the water. See aquatic life requires oxygen fish for example, requires dissolved oxygen. So, this tells you how much of oxygen present in the water this tell you how much of pollution is in the water.

Let us ask a few questions now, what do we expect to happen to this river as it goes along? What will happen to psi and what will happen to s what is our understanding? What will happen to psi refers to oxygen deficit? That means how much below saturation it is there what would happen to psi? It will go up or come down what do we expect now we should expect that, because of pollution the oxygen concentration will come down. Because of re aeration the oxygen concentration should go up the net result would be that for some time the concentration will keep on going down and then it will come up. On other words the sag will keep on sagging and then will it come up. This is what we would expect, because we have put lot of pollution load as a result initially the pollution load will consume the oxygen and therefore, it will keep going down and then it will come up.

So, the concern in of people who are looking after rivers and lakes etcetera is that the extent to which goes down should not be detrimental to aquatic life. See we allow it to go down yes how much we allow it to go down? Now if there is no oxygen of course, fish will die weather the fishes can live with 1 milligram per liter or 2 milligram per liter or 3 we do not know. But our friends in environmental will know they will tell no we should allow it to go beyond whatever is the critical number that is specified for different environments. The objective this analysis is to determine what is the likely sag that will the experience if we put this sewage into the river. Before you do it when we do it calculations you will know then accordingly we can do your design making sure that the bad effects will not follow. We have been talking about oxygen sag analysis we have derive the equations that describe the consumption of oxygen in the river and so on.

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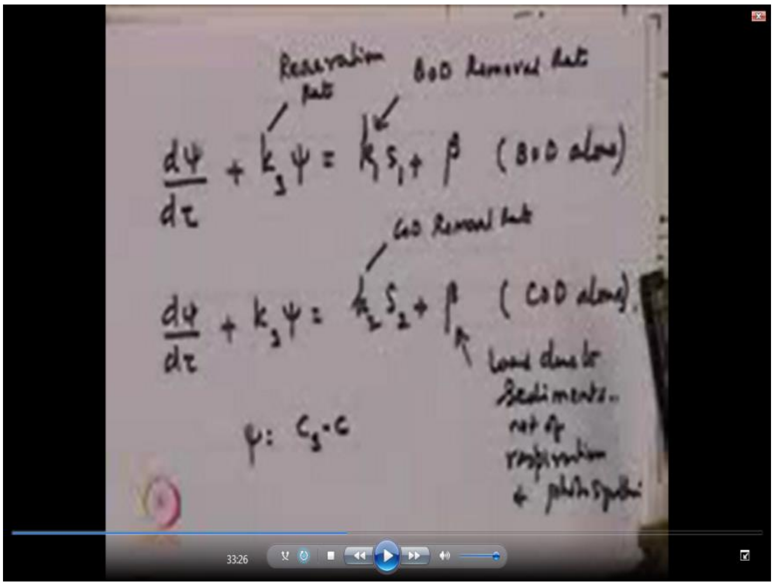

Now, just to summarize let just put it in the context saying that if psi is the oxygen sag and this equation represents what happens when there is BOD al1 acting on the water? That means d psi d tau plus k 3 tau equal to k 1 s 1 plus beta when this BOD al1 what are these terms? Size the oxygen sag, tau is the residence time in the river k 3 is the re aeration rate constant k 1 is the BOD removal rate constant. And beta is the oxygen load that is coming from respiration and sediments these consumes oxygen and photosynthesis supplies oxygen and generally this difference is denoted as beta. Now, you can have a situation in which you have only COD that is entering the river. Now, as you all know most of the industrial waste waters the BOD is very low most of it is COD only. Therefore, there could be situation entering the river is only is COD which is s 2 or it can be only BOD which is s 1 or in mixture of 2 both are possible. We will consider all these situations as we go along we have already solve this case for the case of BOD al1.

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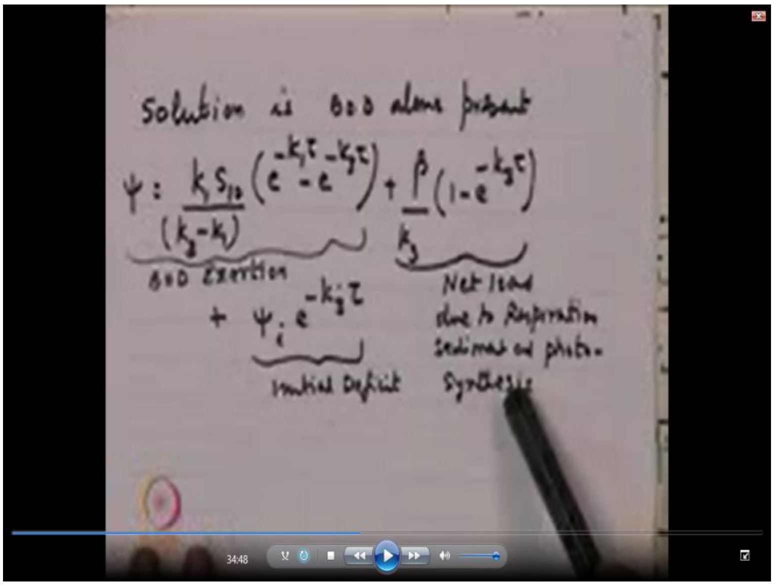

We gave the solution already we will not do it again, because we have done it. But what is important to recognize here is the oxygen sag is actually affected by 3 important factors as you can see here. 1 is the effect of BOD that is what is the exertion due to BOD to bring about reduction in it to sort of change the oxygen sag? And this is what is this? This is the effect due to photosynthesis respiration and so on and this is the in initial effect that means at the point of entry, because of the waste coming in there is an initial deficit. On other words what we are saying is the BOD the effect of BOD on the oxygen levels in the river this is the oxygen sag. The oxygen sag is the effected by BOD exertion affected by initial deficit it is the affected by the net low due to respiration sediments and photosynthesis.

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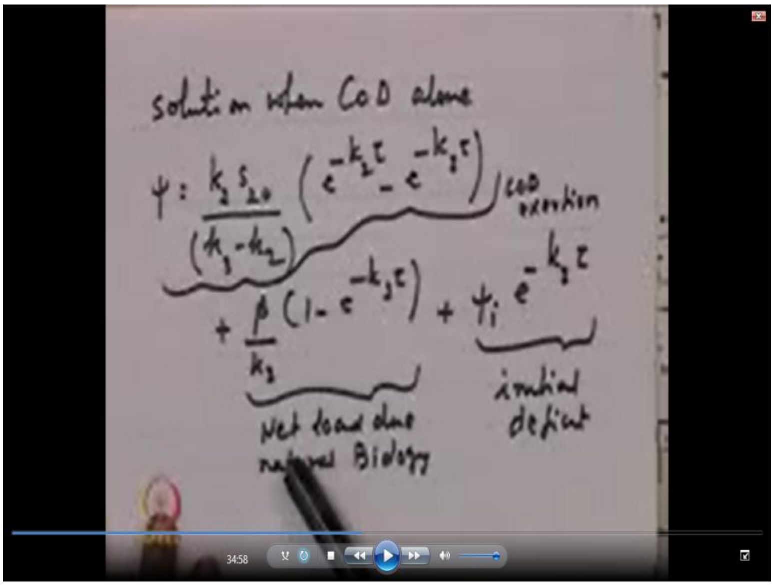

Now, if instead of BOD we had a COD this is the same with the sense that all the affects are due to COD. This is due to COD exertion this is net load due to natural biology and this is the initial deficit. So, the form the 2 equation are identical please notice where s 1 0 it becomes s 2 0 there is no difference the form is the same only thing is the here it is k 1 rate constant here it is rate constant is k 2. So, the form of the expressions are identical when there it is BOD or COD only when there as when there mixed the expression of slightly different will come back to that a minute. Now, we have shown this I will not shown this.

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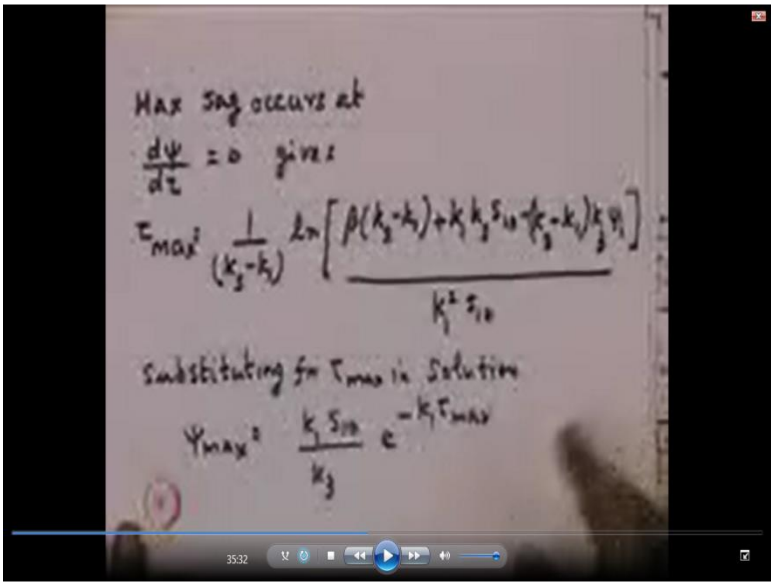

Again you have already shown that for the case of weather it is only BOD or only COD that the pointed at which the maximum sag occurs is given by this expression. They are not derived this I have left it is an exercise to the class I make request all of you that in you please substitute in convince yourself that is correct. If necessary I will take it up in tutorial class. So, the point of maximum sag is given by this and the value is maximum sag is given by this that is what is the important point. So, what have we said so far what have we said so far is that we have set up the equations for the level of oxygen in the river after there is some amount of contamination due to pollution. Then we express this effect on the oxygen in the form of oxygen sag where sag is defined as sag itself is defined as psi equal to c s minus of c where c is the saturation solubility of oxygen and c is the local composition. Now, we said that we know the oxygen sag in the river at any position given in terms of residence time can be related to the system parameters which we have done. Now, we are now in a position to actually see how best we can use our results to understand how a thing performs in a river. So, we want to see how our formulation is able to explain what goes on a river.

Now is the question that may be relevant to all of us is how is oxygen sag analysis of river relevant to chemical reaction engineering is something that we would all like to know. It seems to be a problem in environmental engineering what I am trying to put across here is that whatever happens in a river is due to chemical reaction what is that chemical reaction? There is a chemical reaction which is consumption of oxygen of the river due to the biology biological reaction which a leads growth of that organism. Now, that means the consumption of oxygen by the biology is a chemical reaction. Now, that oxygen that is been consumed must be replenished. That replenishment comes by a physical mass transfer. On other words here is an instance of a reaction problem where there is mass transfer and chemical reaction. It is a very interesting example and how mass transfer in chemical reaction inters play to ensure that the river has a cretin oxygen level that we see. I mean our interest inter play to ensure that a river has a certain oxygen level what we see I mean our interest in looking at this kind of reaction engineering problem is to see how best can we look after our natural systems

How best we can manage these natural systems in the context of so much of pollution load coming from human activities? How best can the rejuvenate these systems so that they remain in good shape so that they serve our lively hood purposes as well as we would like to be. In fact, it is the most important point that we want all our natural systems we good health so that they serve the livelihood purposes not only for us, but for all the living organisms around us. So, our object of looking at problems like this is to apply fundamentals of chemical reaction engineering to understand the system formulate the mathematics. So, that mathematics able to tell us how we can manage our systems better than let me does now? That is the object and therefore, it is a very core problem in reaction engineering therefore, it is we are not going away from the fundamental mandate of chemical reaction engineering. Having said this a few point that I like to draw your attention is that in our formulation we said there is something called BOD we said s 1 0 is the BOD of the river as soon as it receives pollution.

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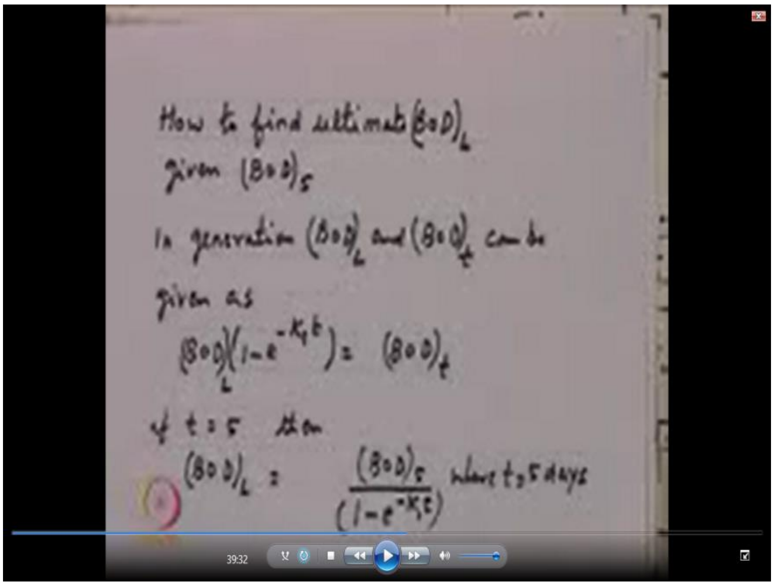

What are we saying? What are we saying is that the river has water and this water gets mixed up with pollutants? And as a result the river has a concentration of pollutants which is given as s 1 0 how do we calculate s 1 0? You know the flow of the river because of flow of the of the pollution therefore, you can do a material balance and find out what is the pollution level. Now, when we trying to measure pollution. We say there are 2 kinds of measurements that we normally do what is the measurement? 1 is we do BOD 1 is we do COD third is we measure oxygen concentration or also called dissolved oxygen. Now, BOD is a measurement which takes 5 days that means whenever we he take a samples determine BOD it is as a end of 5 days. That means you put a you take a sample you enrich it is the oxygen generally use this enrichment is done by putting good water which is saturated with oxygen. And then you wait for 5 days at the end of 5 days you find out how much of the oxygen that you have put in is still remaining? The difference between initial oxygen level and the present oxygen level the end of 5 days is called as the amount of oxygen that is consumed and related to amount of pollution water that you have charged into the vessel. So, this is how it is calculated in laboratory? On other words what we are saying is that BOD 5 is a measurement that you want and I will do in a laboratory by taking a sample.

But as far as the oxygen consumption of the organisms in the river what matter is that the ultimate level of the BOD we have done only 5 day BOD. But actually what matters to the river is the ultimate BOD of the pollution. Therefore, given 5 day BOD we should calculate what is the ultimate BOD how do we calculate ultimate BOD given 5 day BOD? Now, there are various ways in which we can do this I find it convenient to do an induction what is induction? I say induction means that I take this polluted water and I put this polluted water into my water containing saturated with oxygen. Now, that means that time t equal to 0 I have put my pollution into this glass containing good water which i am going to taking to my laboratory. Now, at time t equal to 0 what happens how much oxygen is present in that in that vessel? Very clearly we are not allowed any time for the organisms to consume that oxygen.

Therefore, at time t equal to 0 in your bottle where you have good water containing oxygen and bad water which consumes your oxygen. At time t is equal to 0 no amount of oxygen would have been consumed therefore, t 0 means what? The BOD that you will read at time t equal to 0 is 0. Let me says once again what is BOD test? BOD test is a test in which you take waste water maybe 1 ml 2 ml whatever then you put this waste water in to a beaker into a flask sorry not a beaker into a flask containing good water which is saturated with oxygen. You know the total amount of oxygen that is in that flask. And you put this 2 ml or 3 ml of your sewage and a close that flask now, what you expect? As soon as this organisms present in sewage of yours starts to consume the oxygen that is present in your flask which is closed. So, no more oxygen can come from outside now you wait for 5 days and find out how much of oxygen that you have initially in the flask how much has been consumed?

Since you know the amount of the oxygen consume you know amount of sewage that you have put in you are able to determine the oxygen demand of your sewage. Now, what I am saying now, is something else what i am saying now is you have a beaker which containing good water saturated with oxygen you are put your sewage at time to equal to 0 and immediately took a sample and measures the amount of oxygen that is present you will find no difference. On other words when you allow only 0 time for the for the sewage to consume the oxygen you will find the BOD that you will measure is 0, because you have not allowed any time for your sewage organisms to consume the oxygen of your flask. Now, if you allow infinite time it will consume a lot more oxygen. On other words by induction if you look at this formula here if you look at this formula here when time t equal to 0 u to the power of 0 is 1 1 minus of 1 is 0. Therefore, time t equal to 0 BOD 0 time is 0, because you have not allowed any time at all for the organism to consume the oxygen of the vessel.

Therefore, BOD infinite time will vary that is wills you what? BOD infinity put t equal to infinity it will be BOD l so it will give you BOD l or on other words what we are trying to say is that. Now, the BOD that you will measure at the end of 5 days divided by 1 minus e to the power of minus k 1 t where t is 5 is the ultimate BOD of the sample that you have the charged in your equipment. Let me repeat what we saying is if you want to find the ultimate BOD of your sample. You in measure 5 day BOD of your sample then the ultimate BOD of your sample is 5 day BOD divided by 1 minus e to the power of minus of k 1 multiplied by 5 where k 1 is what? K 1 is the rate constant for BOD removal and that number you know through an independent experiment 0.7 per day maybe or 0.5 per day if it is a cold climate and so on.

So, what we the saying now that once you know BOD 5 you will determine BOD ultimate using this formula. So, when you are trying to determine the effect of the sewage that is entering the river what is of concern to the river is the ultimate BOD of your sample. You are not able to determine the ultimate COD of a sample; because you are experiment goes for only 5 day we are very busy we cannot wait forever. We have to do it very quickly some people do only 3 day BOD now a days in which case this t here is 3 days. So, whether you do 5 days BOD or 3 day BOD point is that BOD ultimate is related to BOD 5 by divided by 1 minus e to the power of minus of k 1 multiplied by 5 days if it is a 5 days BOD. If it is 3 day BOD it is 3 here so you have now, determine the BOD of the sample of the river that you have to which pollution is entering. Now, let us see what happens. Now, what we are try to see here is that after all you see you have in your model.

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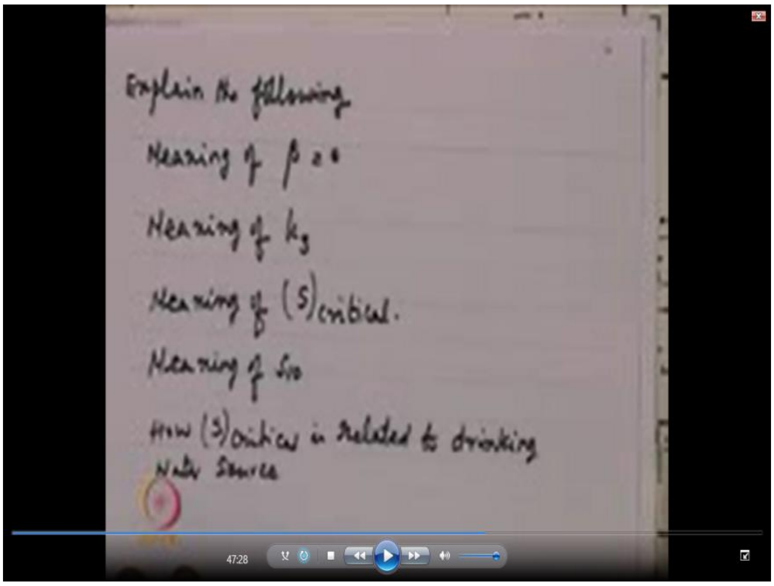

You have beta you have k 3 you have various items that appears in your model at like you to understand the meaning of all these terms what is beta? We said beta is the oxygen load coming from the natural biology of water what is the natural biology of water? There might be sediments, there are organisms which will respire and there is force to synthetic organisms which generates oxygen. On other words natural biology of water that beta is something it is the oxygen that is used by natural biology by enlarge we should not interfere with the natural biology water. On other words the oxygen that is naturally available to the water we should not interfere. The oxygen that be might be able to make use of is the oxygen that is to coming from re aeration k 3. I mean even this there are many environment list who feel that even this is not for us we should not interfere in this also. But the oxygens at literatures just that part of k 3 much still is usable, because the mixture what is the meaning of s critical? S critical means it is the value of s at the point of maximum sag we pointed out just now that when you put pollution into river.

There is a point of the river somewhere down stream where the oxygen becomes very low or the sag becomes very high. That is the point that is the worst point of the river from the point of u of the health of the river. Our interest is to see that the worst scenario of the river still should be acceptable to as per our norms that are what we say the worst scenario should still be acceptable that is why we want to know what is the worst scenario? For example if the s critical s critical what is that means the pollution load in the river at s critical at the point of maximum sag. Let us say this BOD here is 20 then this is the unacceptable, because it is says that drinking water source should preferably have a BOD less than 3. BOD less than 3 is a considered to be a drinking water source which we will take we will purify we will treat we will remove the all the BOD we will the restore the water quality to quality that is required for consumption by humans and our domestic animals. So, that is a meaning of s critical the meaning of s 1 0 what is the meaning of s 1 0 s 1 0 you have this pollution entering the river. River has a certain amount of flow the 2 will mix you can do a material balance and find out what is the pollution load after having the mixed up with the river? The point we are trying to say is that river has a certain flow your waste is coming at a certain flow. So, when they mix the mix pollution load is what is the interest has for as the self cleaning power of the river that is what we are trying to say.

So, most important point that we must bear in mind the whole object of doing this oxygen sag analysis is to determine what is the worst point in the river from the point of view of oxygen sag? Can that worst point us such that it is not undesirable to draw water from that point for drinking purposes? See the worst point also we must have the BOD less than 3 then only it is suitable for drawing water from that point for drinking purposes which we will be treat and then bring it to appropriate norms and then give it to people. Now, if it so happens that point is very bad clearly we must tell the concern municipalities please draw water from that point. Because that water was in very bad shape that is another way of I mean telling the municipal authorities that reason this point is unsatisfactory therefore, we must go down stream so that the water quality is better. So, it is from that point of view of understanding the fundamentals of the reaction engineering that is required to understand what is the status today to understand? What you and I can do to restore the status this is the object of what we are trying to do. Have we said this we want to do a few examples to quickly get to get a feel for what these numbers are and I have take an examples from the different parts of the world to tell you that situations in India are very very different from situation particularly the western world. The western world is there is a water abundant so it is plenty of water in the river they dissolved oxygen in the river.

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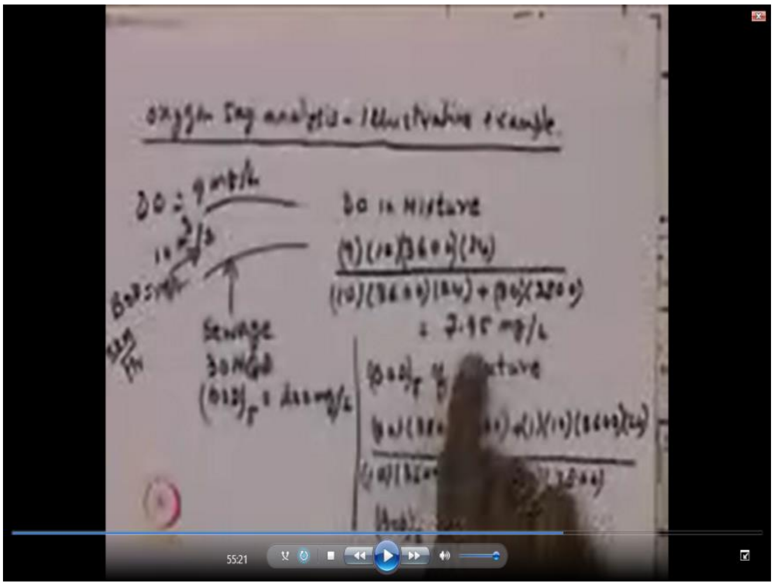

We can see here the dissolved oxygen in the river is about 9 milligrams per liter temperatures are low. And look at the river has huge amount of flow we do not have this kind of flow even during monsoon in many of our rivers you see. So, I mean I am doing this just draw attention to the fact that we know we must look at our systems very differently and to be able to do it differently must appreciate what happens in a other parts the world? So, that we know we take our lessons from them see so what happens in the western world in Europe in America is abundant amount of water. So, even if you put sewage in to the river that is a example we are doing now. It is not very serious as we will see write now. The first example we have taken here is that there is a river with 10 cubic meters per second of flow where the d o of the river is 9 milligrams per liter. And then sewage entering 30 million gallons per day and it coming with the BOD 5 of 200 milligrams per liter it is coming with 200 milligrams per BOD 5. Now, how do you calculate the mixture d o of the mixture? D o of the mixture is hot the 9 is what is coming in this sewage has no oxygen is absolutely no oxygen in this.

Therefore, total amount of oxygen in the river divided by total amount of flow that is coming in plus the flow that we have putting in that is what I am telling here. 10 multiplied with 3600 multiplied by 24 this is the flow in the river 30 into 3800 is the flow of sewage. And the numerator is the total amount of oxygen there is contained in the water of the river which is 9 milligrams per liter and then 10 which is cubic meter per second 3600 per hour per day we do all this calculate we find that this oxygen concentration the rivers 7.95 what is it means? 7.95 itself is a very fally good concentration it is a good water as per as the aquatic life is concerned. And this is what I want to do appreciate that is, because there is a so much flowing in the river. They can do this in fact, much in the sanitary engineering literature books are written from the western world and this kind of numbers are not uncommon we see. Now, suppose I ask you what is the BOD of the river after the after it is got mixed up with sewage once again what I have done?

So much of BOD is 30 m g d multiplied with 3800 1 gallon is 3.8 liters that is why multiplied with 3800. And it is coming with 200 and the river is coming with the BOD of 1. The river BOD of river BOD River is 1 1 mill gram per liter that is I have taken that also that I have taken that. Now, we can calculate of this and we find that the BOD 5 of the river is 24.1 as soon as it mixes. As soon as it mixes BOD 5 is 24.1 the river flow velocity is all given. So, it is river flow is 3 kilo meters per hour took at the long story short. Now, what is the question that we want to answer? The question we want to answer is this BOD 5 which is 24.1 this dissolved oxygen is 7.95 what is the what is the oxygen sag at this point? The d o is 9 minus 7.95 so it 1.05 that means oxygen sag is 1.05. So, what I have done? I have done this calculation, because there not very difficult to do.

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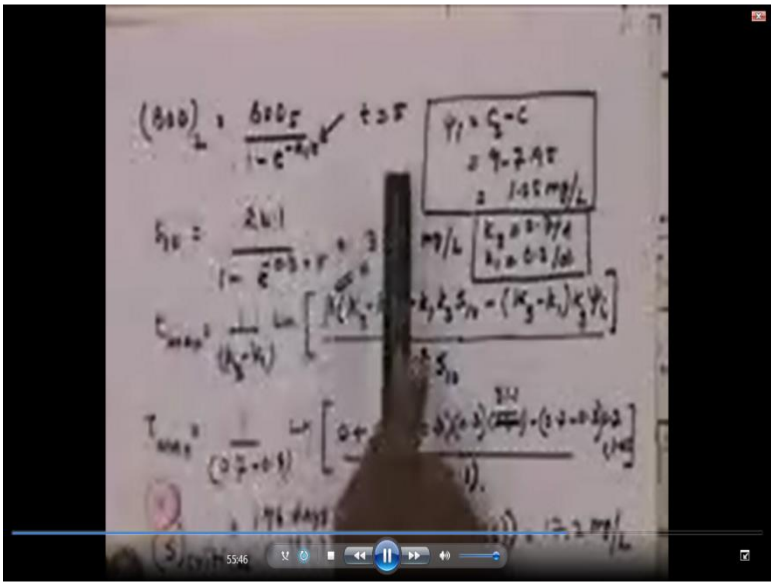

What I have done I calculate the ultimate BOD what is the ultimate BOD is 31 how do you find ultimate BOD? 5 day BOD divided by 1 minus e to the power of minus of 0.3 into 5 what is the 0.3? 0.3 is k 1 that is rate constant for consumption of BOD that is that data is given the lot of data's available it is 0.3, because the cold climate and this rate constants quite low. So, it gives you 31 the initial deficit is calculate as 1.02 what is the re aeration constant is 0.7. Now, notice here that the re aeration re aeration constant of 0.7 if go to cold climates like Canada and the US and there lot of ambient turbulent velocity is the such that this is a plenty of re aeration the temperatures are low oxygen solubility are high. So, there is a benefit of oxygen solubility the driving process are favorable for oxygen supply. So, k 3 is 0.7 k 1 is 0.3 therefore, you can calculate what is tau max where it occurs? I found out it occurs at 1.96 days.

That means suppose you have put the pollution here at this 1.96 days later only you will the oxygen sag becomes the highest. If the flow is if the river is travelling at 3 kilo meters per hour you can calculate what is the distance it will travel may be 100 kilo meters water so what we are saying? What we are saying is that as per the model that we have set up that when you put 330 m g d of pollution 30 m g d of pollution into this river having so much of flow. Then you find that the maximum sag occurs at 1.96 days 1.96 days and that after 1.96 what is the value of s critical s that means what is the value of BOD at the point? Why the oxygen sag is highest then it is given by an exceptional decay in 1.96 it becomes 17.2 what we have said? What we have said is that you have started with s value of 31 it is becomes 17.2 oxygen sag it is started with so 1.05 the maximum sag what is the maximum sag?

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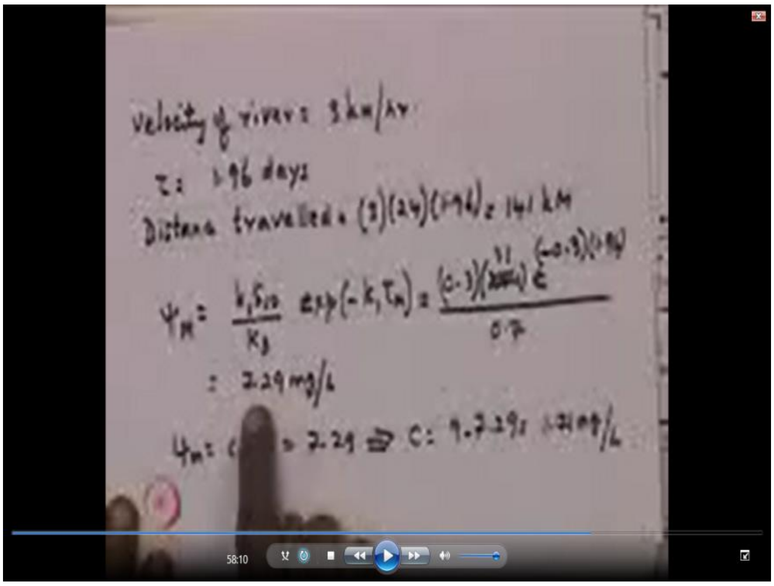

I would calculate the maximum sag say I will calculate the maximum sag here as 7.29e what we trying to say here? Here is a instead of the river where the maximum sag occurs at 1.69 days afterwards. 1.96 days means equal to 140 kilo meters these are all huge rivers this is the huge rivers 114 kilometer afterwards the maximum sag occurs. And plenty of flow in the river and this is the maximum sag itself is 7.29 showing that even at the point of maximum sag the oxygen concentration is about 1.7 milligrams per liter. So, what we are trying to say the rivers of cold climates have plenty of water and even if you put the sewage in those rivers the sag is not it is not very satisfactory. But it is it is not like what happens I will show in Indian rivers what happens? This is not as bad as you would have a thought it is still suitable for many types of fish that is the point we trying to say. The second point here related point which is also of concern to us which I want to draw your attention is the following. That is where are we k here now, we said that at the point of maximum sag the maximum sag is 7.29 we already said how did we calculate maximum sag? We have our equation for maximum sag which is as put all the numbers I have put all the numbers here we get maximum sag is 7.29.

See at the at the point of maximum sag what is the value of s? The point of maximum sag the value of s is given by 17.2. So, what we are trying to say here is that 17.2 milligrams per liter is not acceptable from the point of view of drawing water for drinking purposes. So, what we are saying is that even in cold climates while there is abundant amount of water in the river. If you are putting so much of 30 million gallons of sewage into the river that you find that that 140 kilometers later even 140 kilometers later that water is un suitable for being drawn. And then to be treated for purification that water itself is seen is unsuitable, because this specification is that that the water quality must have a BOD less than 3 that is from that point we should be dry your water that is the point I am trying to say. So, even in the case of cold climates like the western world the putting sewage into the river is creating some difficult as you can see from the data. Now, let us go to the next exercise which is of direct interest to us.

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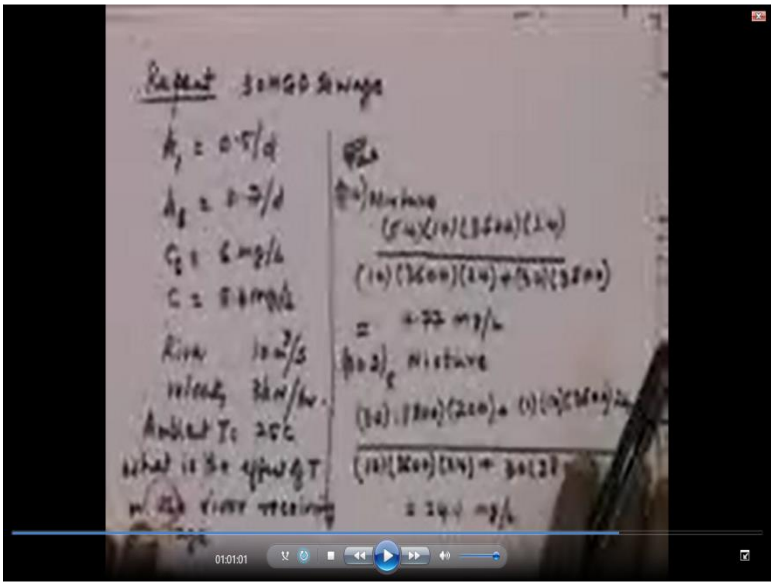

That is suppose instead let us look at a river let us look at a river which is not a cold climate, but it is a warm climate. Let us like for example, in South America see south America is water surplus continent plenty of water when we go for north from the river Orinoco to Amazon to you know laplata it is full of water plenty of water. But even there I want you to understand and appreciate that since the average temperatures are little larger temperatures are not as cold as the united states in Canada and Europe temperatures are larger and as a result your k 1 is 0.5 and not 0.3 k 1 this is the 1 that you know this is the BOD removal rate constant it consumes oxygen see it consumes oxygen. Therefore, this is 0.5 where you do your calculations and you will not do this once again, but if when you do your calculations you recognize that you can go through the same that I will not do it again. You notice that when you go through this whole calculations you find you find that things are a little worst than what we saw in the cold climates.

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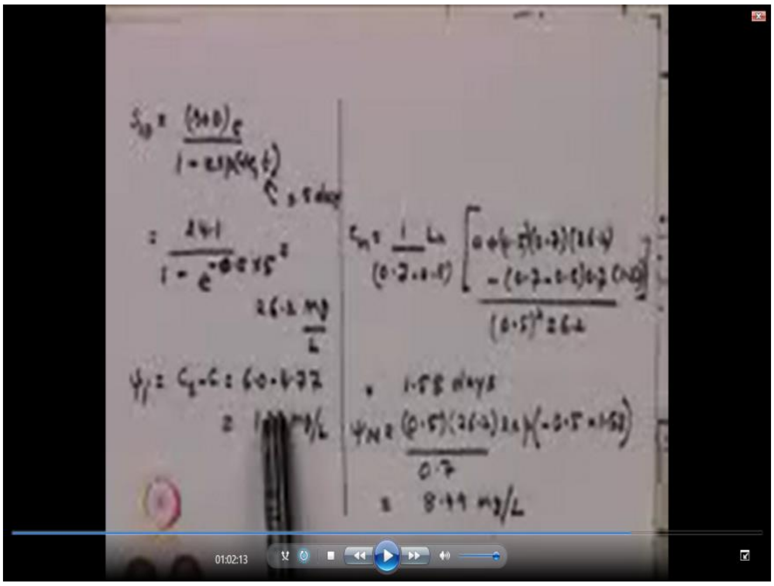

That the initial deficit previously was 1.7 now, it is you can see here that the things are little worst than that we have said before. As a result you will find that the maximum sag is more than what you thought in the cold climates. So, go through this once again what we are saying is that when you have your cold climate and warm climate when it is warm climate you find here is the BOD we started with 24.1, but BOD 5 is only 26. Because it is 0.5 the rate constant is higher that is why previously it was 31 now, it is only 26. So, you will find that the effect of a higher temperature which is important to appreciate these numbers when the temperature is higher the things behave differently and we must take this into account in our design. I have taken these numbers for Latin America, because in Latin America there is a plenty of water plenty of water and therefore, the situations are not I mean so bad, because there is so much of dilution due to so much of water alright. Now what I want to draw your attention is the following even though there is so much of water so much of dilution. The fact that the temperatures are high you will find an interesting result which I have calculated here what the what is the interesting result?

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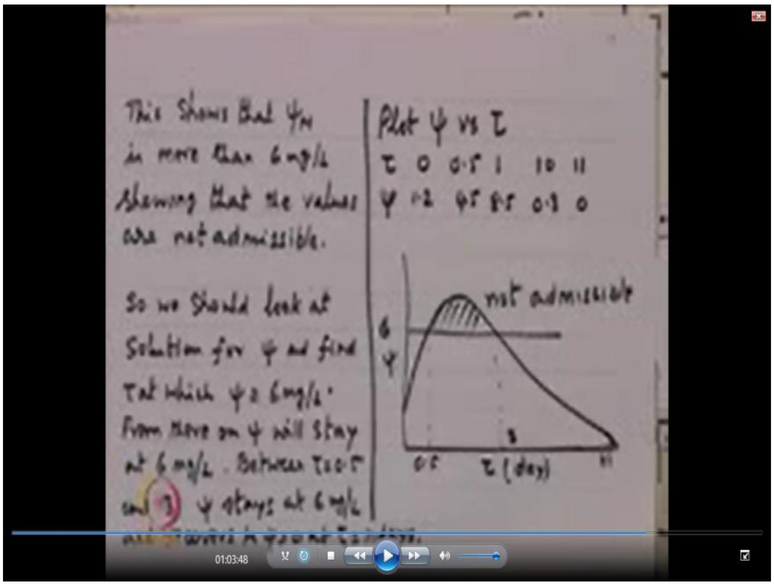

The interesting result is that now, you will find that the after some time after some distance, because this saturation solubility’s previously the saturation solubility at cold climates the saturation solubility is very high close to 10 milligrams per liter. In a warm climate the saturation solubility’s are 6, 6.5 very warm climates. Because saturation solubility’s are low you would find that you should put so much of sewage into the river, river will very quickly you will find that it becomes the oxygen sag becomes very high 6 oxygen sag becomes 6, but 6 means what? It is all that means the d o is 0, because the c s the solubility’s are very low it is not 10 milligrams per liter it is much less. So, what I am trying to say here is that when the temperatures are high you will have this kind of situations where you will find for some distance the oxygen level in the river will be very low. In fact, nil and it will take some distance before it recovers. On the other words it recovers only after about 11 days. So, what we are trying to say here is that in warm climates even in situations where the river has plenty of water even situations where river has plenty of water.

If the solubility of oxygen is low you run into various kinds of problems of oxygen level in the river. And that will lead to various kinds of problems about health of the aquatic populations what I am trying to put across to you here is that even in water surplus regions like Latin America these problems can become quite serious we talked about cold climates there also the problems were of course, I want to say it was very bad, but it is it is serious if you put river sewage into the river. If you go to warm climates if you put sewage it becomes can become very serious. Now, I am looking at a situation where the river has very little water as it happens in our case our rainfall is of only for 2 maximum 30 days in a year that is it. Therefore, our rivers have practically no water. Now, when you put sewage into that river what happens this is what has been done here.

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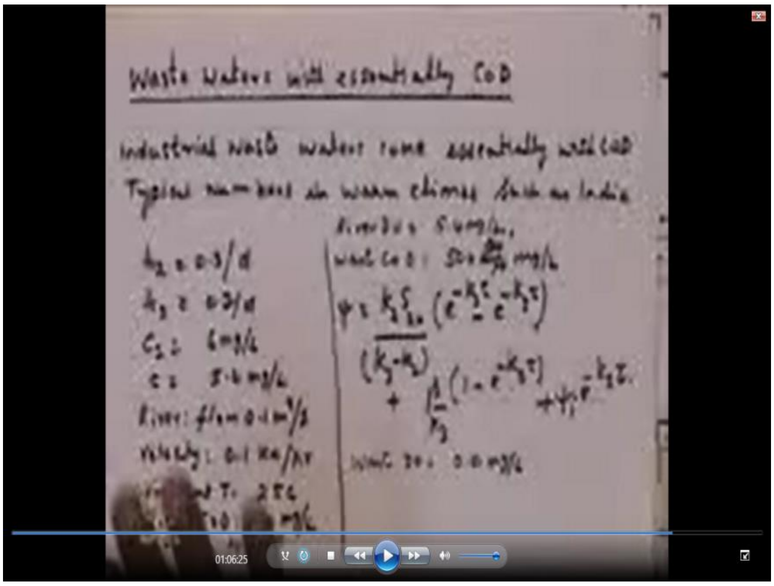

So, we have gone through the same calculations, but this time we are doing for a situation of a river where the river is self is coming with some COD why is that? The river is coming with COD is, because there is so much of interference of the river systems by human activities the river itself is not encourage here. If you go to western rivers in the western world the COD of that river will be 1.5 in our case it will be 10. That is when you do not put sewage into the river when you put sewage into the river things are very different. Now we have done calculations her for the case of a river receiving essentially COD when the river is receiving essentially COD. That the reason why I am doing this for you is that when you are putting COD into the river the rate constants are very low COD is a molecule which is very difficult to get digested consumed by the bacteriology of the water.

So, you do not get 0.5 and all that even in warm climates like ours the rate constant may be 0.2 0.15 things like that I have taken 0.3 here. But I want to draw your attention to this fact that COD is a recalcitrant molecule it is very difficult to digest there are only some bacteria which is able to manage pollute to very toxic chemicals. So, we have done calculation for that case you have taken here this is s 2 and here it is k 2 we can see here. That means you have put s 2 which is COD k 2 is the rate constant for COD remover you have gone through all the calculations. And once again here we are said the amount of pollution that is coming in this 100 k l d the amount of water in the river is only 0.1 cubic meters per second 0.1 cubic meters per second is not small it is still 360 cubic meters per hour per 360 cubic meters per hour this is not small see.

And even this is the kind of river being actually our rivers do not have much flow at all. Even this amount this amount of water might be there in Ganga, but point is that Ganga also has huge amount of you know sewage flows from populations and so on. I have done a calculations just put taken some numbers just to draw tension to the factor what is that kind of a you know river behavior you will see. And then the numbers have gone through all the calculations let us not spend too much time I calculate the COD I have calculate at the oxygen deficits. So, what is the deficit and so on we starting well it is 0.66 now, you notice when you do all these calculations you notice the same problem that I have said before what is the problem?

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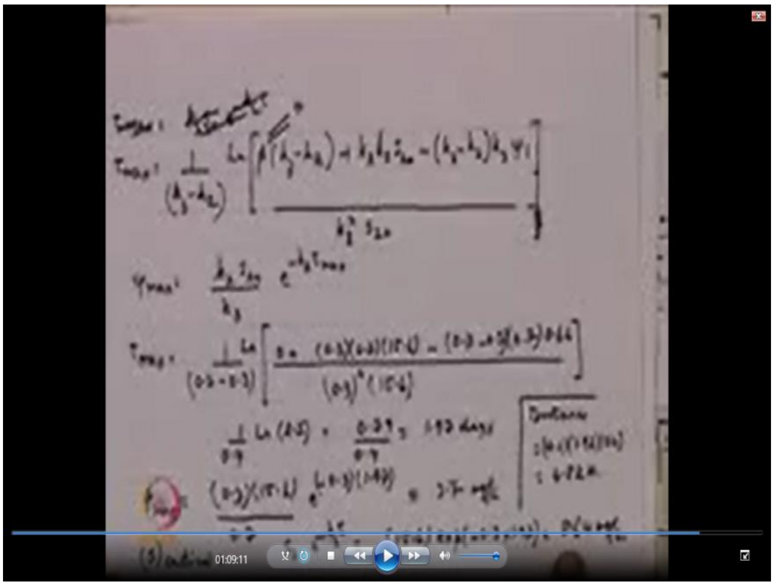

The problem is that the s critical are very large s critical are very large so unacceptable. Alright so what is the what is it that we are trying to say? What we are trying to say is that whether it is rivers of the western world whether it is rivers of the I mean Africans or in south American continent when it comes to rivers of Indian sub continent. Since the river flows are very low the river is just not having in the enough capacity to manage pollution. And therefore, we are really not able to draw water from the river for supplying water to our population, because that water itself is not in good shape. So, that is why we have to ensure that that we do something about this whole problem. Now, a related a related issue I have considered here which is important that is also not forgets.

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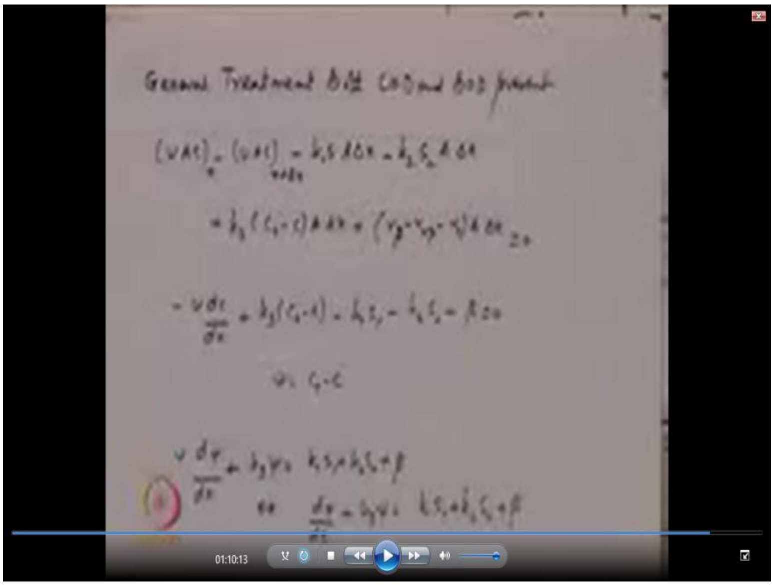

That you see what actually happens ah is that our waste waters contains both COD and COD and BOD both are there. That means our situation that we must handle is that there is both c o BOD and COD which we have to take care. On the other words our solution to the problem should actually treat both the cases.

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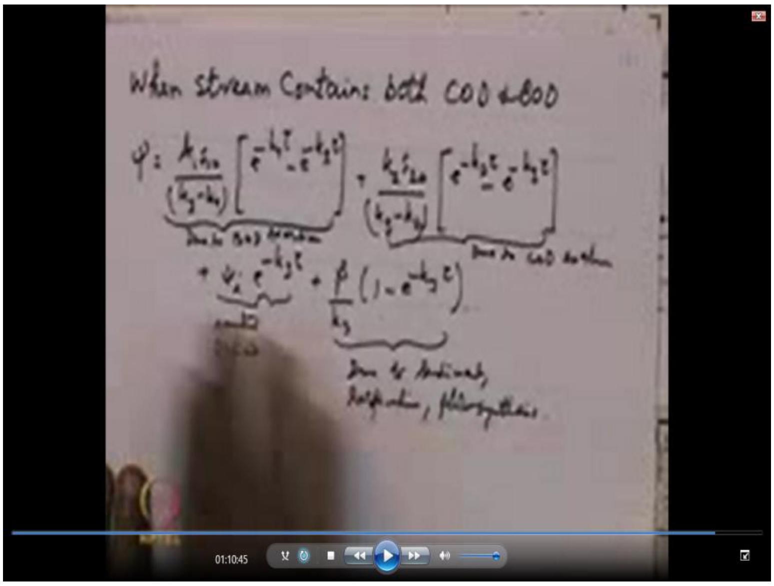

And I have done that I am please I am not showing you the detail because fally straight forward integrations. So, when we integrate the whole situation this is what you find what you find here is that there is effect of BOD there is the effect of COD there is the effect of initial deficit there is effect due to natural biology BOD COD effect. BOD effect initial deficit effect and then the effect due to the natural biology all the effects are present in the river that is what is the situation that you and I will have to contain with.

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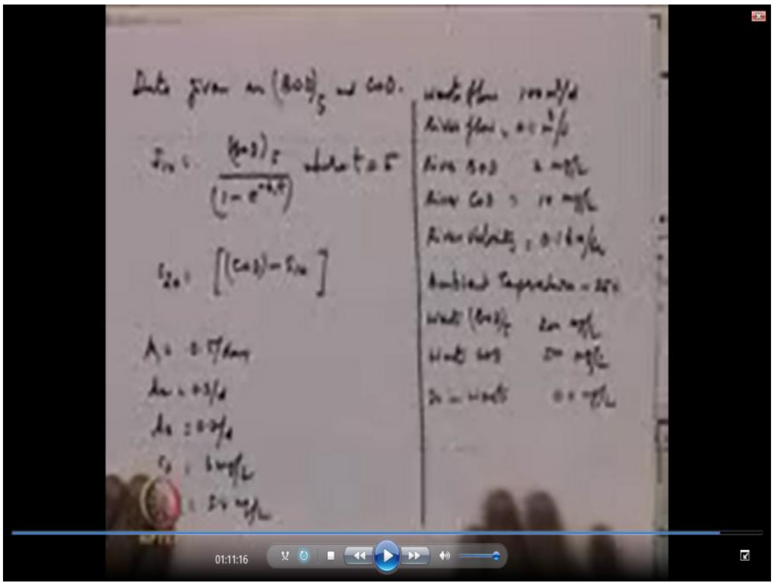

Now at the last example 1 more example where I have taken both COD and BOD into account. And then I have taken some flows till this point 1 cubic meters per second and still very large and many of our rivers are not satisfactory in terms of this kinds of flows. But I have done some calculations, but I am sure you know once you have a this numbers. So, you can do this calculations yourself I will just these are some illustrative examples to draw attention to the fact that putting waste sewage or waste water industrial waste water even if it is treated waste water into the river is absolutely unacceptable. Because they just simply destroyed the biology of the river that is the point I am trying to draw your attention that really speaking there is no oxygen capacity in the river to manage human generated pollution. I have done these calculations here and the net result the net result is saying the same thing that you know our rivers do not have any capacity to manage our pollution. In fact, the kind of answers that I am which kinds of calculations that may be just go through this now there I have done this calculations.

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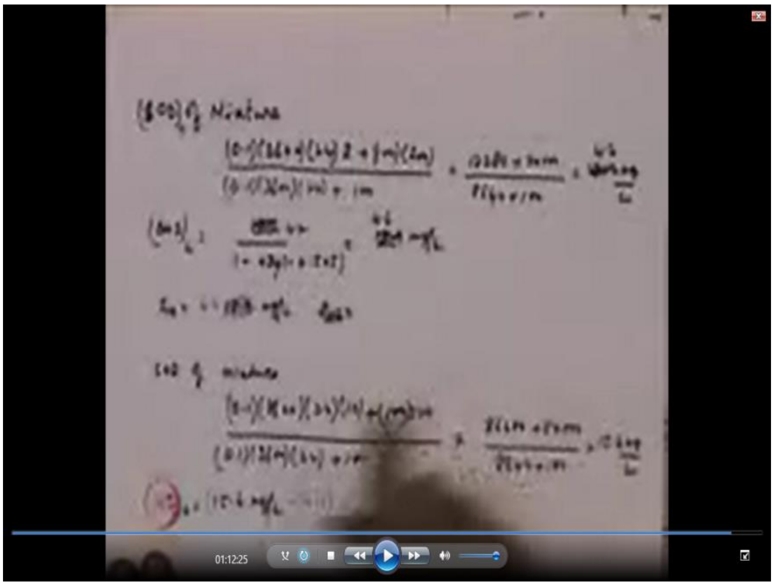

I have done calculations for the case of the river with 0.1 cubic meters per second. So, you get a BOD of 4.6 that is the ultimate BOD of 4.6 and then COD comes out to be of 15.6. Therefore, this the COD level that we have to content with this 11 and BOD level you have to do is 4.6 when you put all these things into our into our equations you find we find that it is the same kind of behavior we see.

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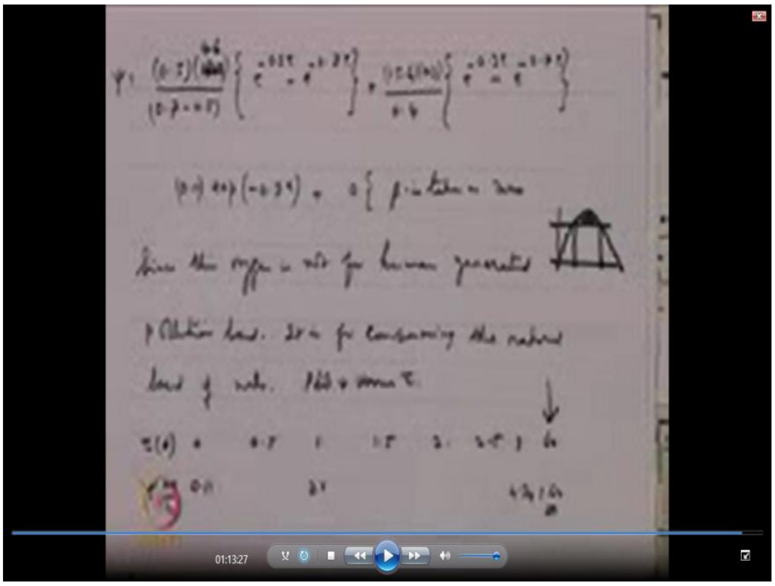

What we find is that? For a very large section for a very large section you know the river is like this. You know this is the saturation have there is a large region where the oxygen is very actually is 0 you see something that we are unacceptable. As you can see here now you have to go up to about 6 you know 6 days of residence time before the river becomes a little better. So, cut the long story short what I am trying to put across to you is that the tropical river system of this country with the flows are so small that they do not have any capacity to manage pollution load from human activities. Therefore, to actually accept a fluid norms of 250 milligrams per liter COD. And all that it is something that 250 milligrams per liter COD if you would let out into this is into the environment where does it go?

It will go into the river or into the lake or into a ocean none of these systems have the oxygen that is required to manage all this. So, let us resolved and to recognize that we must design treatment systems which are all reaction equipment all treatment plans are reaction equipments in which we must remove the pollution level to such levels that. Our natural systems can handle this pollution which means COD less than 10 I would say COD less than 5 BOD less than 2 d o at least be close to saturation. This is what we should let outs so that our river systems our lakes our rivers our oceans are in good shape.