Fundamentals of Environmental Pollution and Control
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Lecture No. # 08
BOD Modelling Part – I

So, we were discussing about this BOD that the biochemical oxygen demand and then let us find out you know initially in the beginning you know that we have said say this determination of one important thing that is determination of BOD, determination of BOD. The standard let me go it by, do it by step by step.

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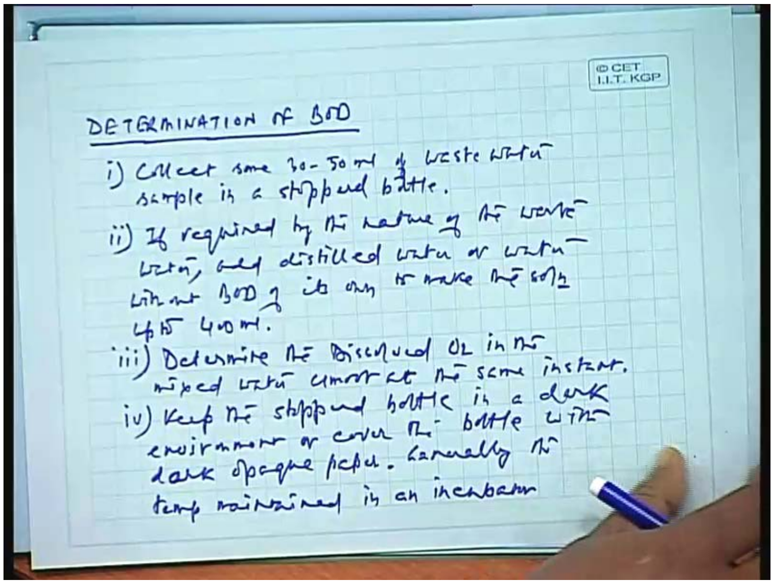

DETERMINATION OF BOD

i) Collect some 30-50 ml of waste water sample in a stoppered bottle.
ii) If required by the nature of the waste water, add distilled water or water without BOD of its own to make the soln up to 400 ml.
iii) Determine the Dissolved O_2 in the mixed water almost at the same instant.
iv) Keep the stoppered bottle in a dark environment or cover the bottle with dark opaque paper. Generally the temp maintained in an incubator

Say this is number one collect, collect some 30 to 50 milliliter of waste water sample, remove this waste water sample in a stoppered bottle, in a stoppered bottle, in a stoppered bottle. If required, if required by the nature, nature of the waste water, waste water add distilled water or water without BOD of its own to make it, make the solution up to 400 ml, 400 ml, up to 400 ml, 400 ml. Determine the, determine the dissolved oxygen, dissolved oxygen in the mixed water almost at the same instant, almost at the same instant. Keep the stoppered bottle, keep the stoppered bottle in a, in a dark, a dark environment, environment or cover the bottle, cover the bottle with dark, dark opaque paper, dark opaque paper right dark opaque paper. Why it is done?

There is very simple, very small reason for that is that there are certain you know certain organic substances in water, there are certain organic substances in water which can which are mostly of say algal variety, which are mostly of algae variety. They can photosynthesis under normal lighted condition, under normal lighted condition. So if they are doing that so you know they would add oxygen to the water, so this is why you know this precaution is generally kept okay opaque water, a opaque paper.

Generally you know for European standard we generally say if the temperature generally, generally if the temperature, the temperature maintained in an, in a, in an incubator, in an incubator, in an incubator generally the temperature maintained in an incubator is about, is about is 20 degree centigrade, is 20 degree centigrade.

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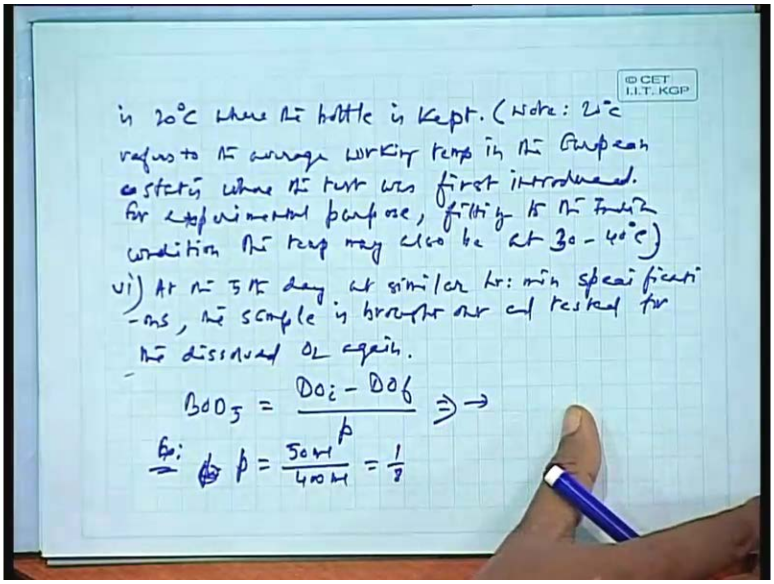

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is 20°C where the bottle is kept. (Note: 20°C refers to the average working temp in the European co states where the test was first introduced. For experimental purpose, fitting to the Indian condition the temp may also be at 30 - 40°C)

vi) At the 5th day at similar hr: min specifications, the sample is brought out and tested for the dissolved O_2 again.

$$BOD_5 = \frac{DO_i - DO_f}{p} \Rightarrow \rightarrow$$

Ex: $p = \frac{50\,ml}{400\,ml} = \frac{1}{8}$

Generally the temperature maintained in an incubator is 20 degree centigrade where the bottle is kept, kept, where the bottle is kept. You make a note here note 20 degree centigrade refers to, refers to the average, average working temperature in the European, European cities or European states where the test was first introduced for experimental purpose, purpose fitting to our condition, fitting to, fitting to the Indian condition, condition. The temperature may also be at 30 to 40 degree centigrade, 30 to 40 degree centigrade okay, 30 to 40 degree centigrade.

So, remember this is you know this is an important thing particularly for European states, you know some times we also reduce the number of days. So, say after this, this is how it is kept in a 6 day, this is, the sixth step is at the fifth day at similar instant, at similar instant hour and minute specification, the fifth day at similar hour and minute specification. The sample is the waste, the sample is brought out and tested for the dissolved oxygen again, dissolved oxygen again, dissolved oxygen again, dissolved oxygen again. So this BOD 5 would then be known as, dissolved oxygen would essentially be higher in the first case you know a dissolved oxygen initial, dissolved oxygen final divided by p, this p is known as the dilution factor, this p is known as the dilution factor.

So, you can see this is dissolved you can, you can see here which is Do_i is Do initial, Do_f is Do final and this p is the mixing ratio, it is also called a mixing ratio or you know the mixing, this is basically a mixing ratio where p for this case you know, suppose you know for example, for example p may be as I have said p is say, say if you are taking about 50 ml and you are there making it to 400 ml, so this one is 1 by 8. So it becomes 1 by 8 times of the, so BOD becomes, BOD becomes they basically half for this case. Now it will be multiplied by 8. The reason being is you know we just try this dilution. The dilution is generally done so as to, so as to you know so as to increase the rate of, so as to see that the level of oxygen goes down considerably, considerably within a particular time, okay within a particular time. Say you know for example here suppose you know Do_i say Do_i is, Do_i is if we consider Do_i as, if we consider Do_i has generally you say we find Do_i has 10 milligram per liter and we find Do_f has say 2 milligram per liter.

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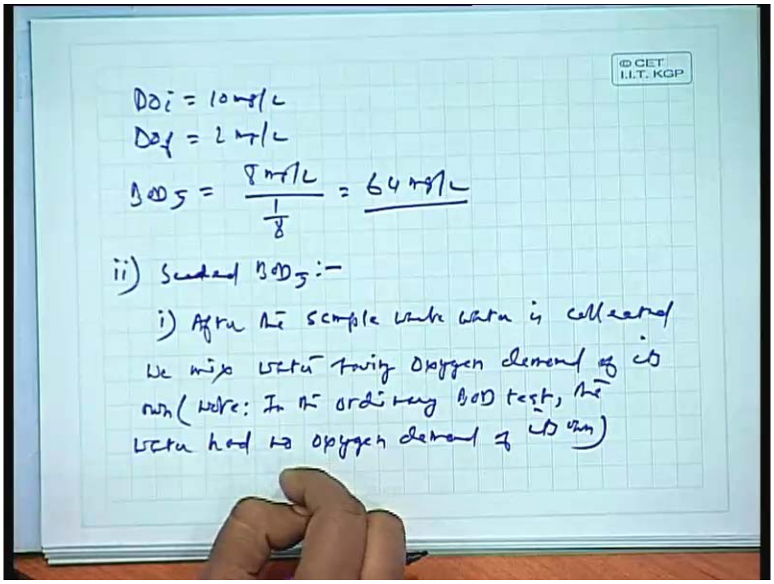

$Do_i = 10 mg/L$

$Do_f = 2 mg/L$

$$BOD_5 = \frac{8 mg/L}{\frac{1}{8}} = \underline{64 mg/L}$$

ii) Seeded BOD_5 :-

i) After the sample waste water is collected we mix water having oxygen demand of its own (Note: In the ordinary BOD test, the water had no oxygen demand of its own)

So this BOD, BOD 5 in such cases would be 8 milligram per liter divided by this one is say it may be, this is a proportionally constant only 1 by 8 so it is finding at 64 milligram per liter okay. This is as simple as that right. This is one test, this is one kind of test, this is seeded test and there is another kind of test, so our BOD we generally call this as seeded BOD test, seeded BOD, seeded BOD 5.

What is done extremely, extra steps that is generally done is after the sample waste water is collected, after the sample waste water is collected. We mix, we mix a, we mix a water, we mix water having oxygen demand of its own, of its own. Note in the first case the ordinary BOD test, ordinary BOD test, the ordinary BOD test, note that in the ordinary BOD test the water, water had no oxygen demand of its own okay. The water that is mixed remember that to make the water, to make it to 400 ml so 50 ml we collected we made it to 400 ml, those 400 ml say 350 ml was water without having an oxygen demands of its own, without having any Do, without having any oxygen demand not Do, without having any oxygen demand of its own but here we use some oxygen demand so that, so that this the decomposition can be initiated, so that the decomposition can be initiated. The idea is to almost immediately initiate the rear decomposition reaction, otherwise if the BOD is very low in a sample waste water, if a BOD level is very low in sample waste water suppose you generally have a water which is having a very low BOD of its own.

So, in such cases you might find at the end of the fifth day there is no depletion of oxygen because the reaction rate is so slow that in no discernable change has taken place, no observable change has taken place. So if you put BOD a seeded BOD if you just use, if you just use some water having its own BOD then in that case we find out that the reaction takes place very at a faster rate and will observe the oxygen, the depletion of oxygen is at a faster rate and we find a considerable decrease in the oxygen, decrease in the level of oxygen in the water okay. So this is why this is called seeded.

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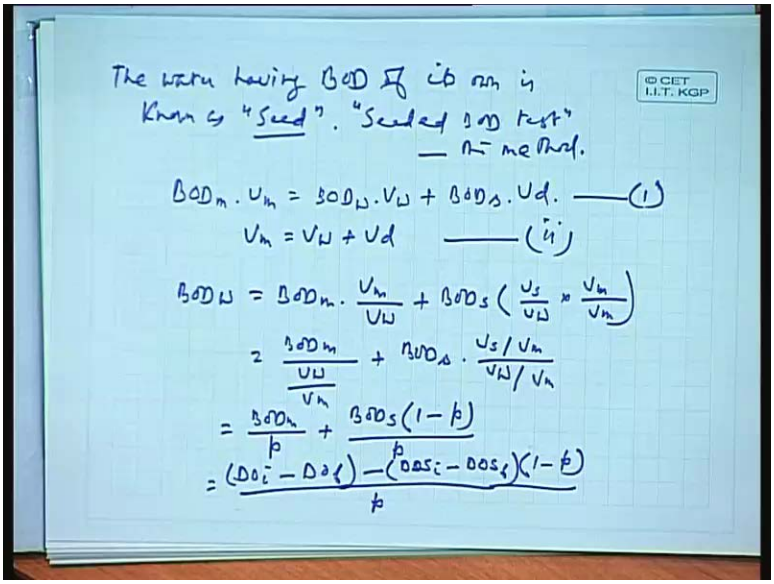

The water having BOD of its own is known as "Seed". "Seeded BOD test" — the method.

$$BOD_m \cdot V_m = BOD_w \cdot V_w + BOD_s \cdot V_d \text{ ——(i)}$$

$$V_m = V_w + V_d \text{ ——(ii)}$$

$$BOD_w = BOD_m \cdot \frac{V_m}{V_w} + BOD_s \left(\frac{V_s}{V_w} \times \frac{V_m}{V_m} \right)$$

$$= \frac{BOD_m}{\frac{V_w}{V_m}} + BOD_s \cdot \frac{V_s / V_m}{V_w / V_m}$$

$$= \frac{BOD_m}{p} + \frac{BOD_s (1-p)}{p}$$

$$= \frac{(DO_i - DO_f) - (DOS_i - DOS_f)(1-p)}{p}$$

This is the water having, the water having, the water having BOD of its own is known as, the water having BOD of its own is known as seed and that the method is known as seeded BOD test. This is known as seeded BOD test, the experiment the method seeded BOD test. So in such cases what we find out is we can very well write is like this BOD of the mixture into the volume of water, volume of water that of mixture, volume of the mixture is equal to BOD_w waste water, volume of the waste water plus BOD of the seed, BOD, BOD okay, BOD of the seed and BOD of the, BOD of the seed and volume of the seed, right.

So in such cases there are other things that we can find out is V_m is equal to V_w plus V_d, so you can find out one this thing here, two here and as you can find out from here this is if you just can find out like this, we can say this BOD of the waste, BOD of the waste can be written like BOD of, BOD of the mixture divided by V_m divided by V_w plus BOD_s multiplied by V_s divided by V_w multiplied by V_m divided by V_m, I mean just to write it like this you know is if this basically to bring in this. So here all this can be written as you know BOD, BOD_m divided by V_w by V_m is very simple I mean you know just is not necessary also we can find it out yourself like this. This is V_s divided by V_m divided by V_w divided by V_m. This is substituting the definitions of p so that the waste water divided by a mixture, this is BOD by p. This is BOD_m by p, p that is we did you know that the mixing ratio this is divided by a, this one is BOD_s 1 minus p divided by p.

So you can find out this is as also you know we can find out from this that you know this can be also be simply used as Do_i minus Do_f divided by, divided by Do you say this is, this is say Do, Do, Ds, Do demand Dos, Dos_i demand of the seed dissolved oxygen in the seed initially this

Dos_f, Dos_f into 1 minus p divided by p, right. We have not done anything very simple you know this BOD_s, this is Do dissolved oxygen of the seed initial and Dos_f also in the, this is final so you make a separate test for the seed. So one is that waste water, waste water and the seed water, seed mixture another is another seed, seed. So you find out the seed, so you find out from this, we find out there the BOD of the waste water. So we can find out the BOD of the waste water like this okay. Having said this, this is of all about you know there are few problem will deal with this problems later on just to go ahead with this. Now next is first order say this BOD modelling then we are coming to this term here is that BOD modelling. Here let me tell you this here, this is, this BOD modelling.

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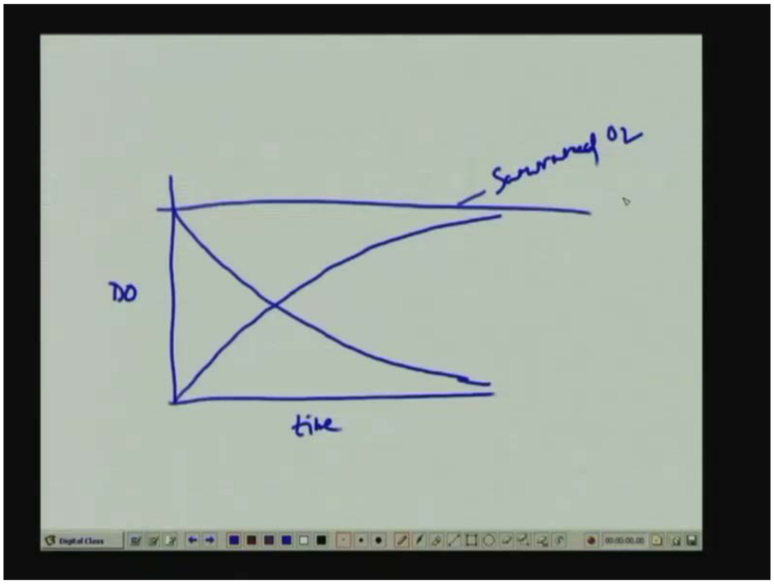

If you can see now what happens is this, say this for most cases as I have said, as I have said if we just observe that this one is if you just observe here that you know as I said that the dissolved oxygen would be you know reducing like this dissolved oxygen Do, Do would be dissolved this is, Do with time. We can find out one you know standard relationship here which would be you know this is as I have said like this, this is, this is what would be, this is this oxygen BOD. This is on the other hand the BOD would be like this, on the other hand the BOD would be this, this complementary of that complementary and this should be finally the saturated, saturated value, saturated, saturated, saturated oxygen, saturated oxygen in the water. So here if we just say if we just take breather from here we know will try to see that this you know in the first case of a BOD modelling, this is quite interesting to observe. This is BOD modelling.

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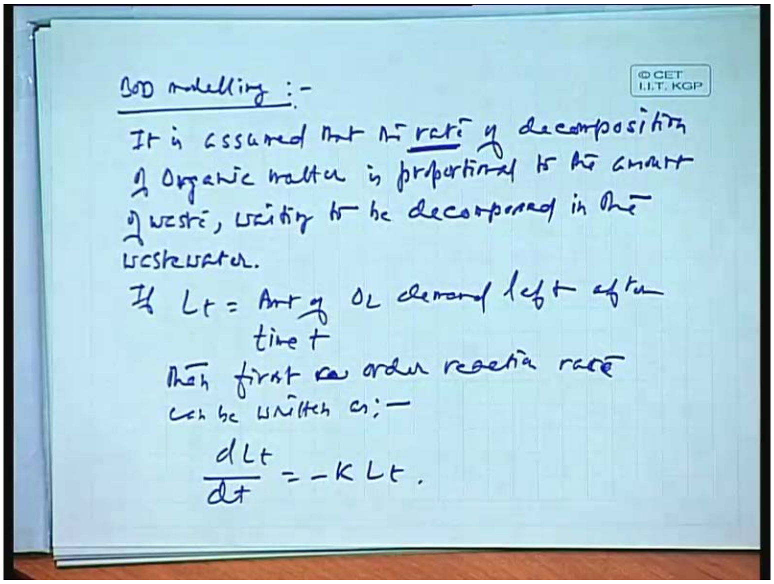

BOD modelling :-

It is assumed that the rate of decomposition of organic matter is proportional to the amount of waste, waiting to be decomposed in the wastewater.

If L_t = Amt of O_2 demand left after time t

then first order reaction rate can be written as:-

$$\frac{dL_t}{dt} = -K L_t .$$

This is a first order reaction rate modelling, this is first order modelling. Generally first order modelling what is done is what it says is that it is assumed, it is assumed that the rate of, rate of decomposition of organic matter, the rate of decomposition remember this the rate of decomposition of organic matter is proportional to the amount of, amount of waste waiting to be decomposed, waiting to be decomposed, waiting to be decomposed in the waste water, waiting to be decomposed in the waste, waste water. If say, if we say this if L_t is equal to represent the amount of oxygen demand left, amount of oxygen demand left that is you know signifying the amount of waste left, signifying the amount of waste left after time t, after time t, after time t. Then first order, first order, first order reaction rate, first order reaction rate, first order reaction rate can be written as, can be written as dLt divided by dt minus K into L_t okay, minus K into L_t minus K into L_t.

So what it says is K into L_t is that you know is also the minus is minus signifying that it is also already a decreasing function, it should be always continuously decreasing. The rate would continuously decrease. This is what it signifies L_t minus K into L_t. Now here this one needs, needs a sudden kind of investigation. This particular reaction rate you know this is particularly true, this is particularly is a, this is one aspect only. Suppose if you see now that you know okay here you can see this, this is if you just observe as I have said, as I have said say you know if you have just considering L_t here L_t and this is time, this is time.

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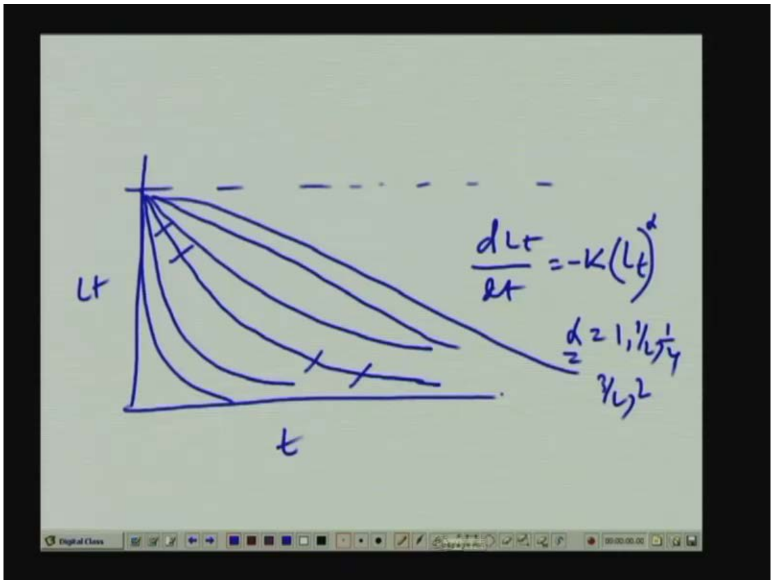

See here this particularly, this is particularly a plot which it talks like this which is which it talks like this you know where it says that the rate of, the rate of depletion at any point of time in an exponential distribution as you know is a say you know if it is e to the power minus say some constant into t, in such cases that constant is remains constant throughout the, through the line of the plot. So, at any point of time the rate of change would remain same. This is mostly the typical thing that we generally observe but generally is also in the very important thing here is this is has to be understood is not necessary that all organic substances would follow this plot.

You know here we can observe as we have said this is there will be plot like this there will be situations like this where it will be further plotting like this. so in many cases though the first order reaction rate is known as it is written you know in many cases it can be written as L_t, L_t dt dt is equal to if it is just K, K, if we just consider K if you are not trying to change this K as a time rated function we can at least write it like this as a power. This is in the form of say alpha, this alpha for these cases as you can see here it can be one it can be half it can be 3 by 2 it can be 2 like this it can be, it can be sometimes it can be 1 by 4 like that depending on the nature of, nature of the waste, nature of the waste depending on the nature of the waste, depending on the nature of the waste, all right.

So, you know is not necessary for all of you, for all, for all cases to find out a first order reaction rate modelling in the first order when it is consider as a first order reaction rate then you can see this one is should be a in the form of an, it can be also you know is not necessary that it would be a L_t power 1, it can be different power also depending on the nature of the waste, depending on the nature of the waste okay.

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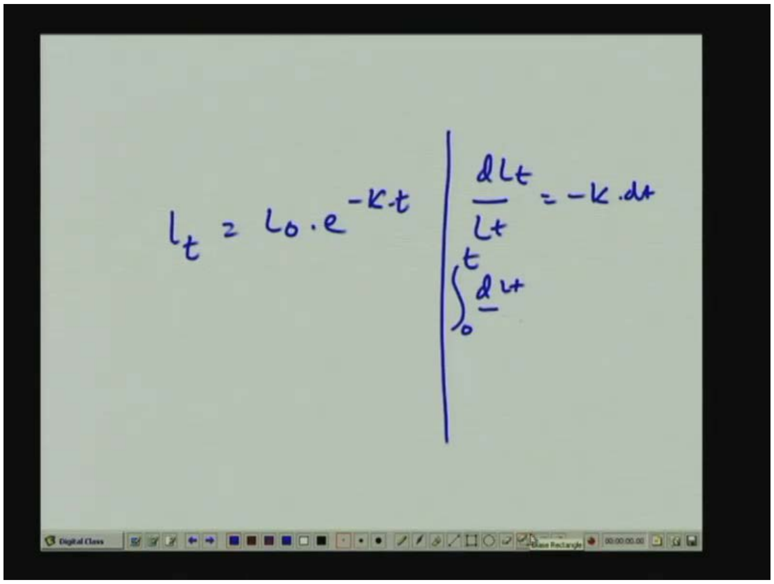

$l_t = L_0 . e^{-K.t}$

$\frac{dL_t}{L_t} = -K.dt$

$\int_0^t \frac{dL_t}{}$

Now having said so, having said so we can see now that you know this if we just try to do it you know if we just say in such cases what is, what we can think of is L_t is equal to, L_t is equal to, L L_0 e to the power minus minus K into t, minus K into t or else you know as you can see this is, this can be finally this is the derivation of it is very simple. So you can see dLt, dLt say dLt Lt right this is into K into dt, dt this is 0 to t dLt dt sorry Lt just one minute okay, you just make this okay. Now it doesn't go fine. This is all right, this coming as, this one should go now okay anyway, so okay let us not further waste time on this. Either will this as you can see here K to the power minus L_t so from this we can further go on to say this as you can as or dLt Lt is a basically K into dt.

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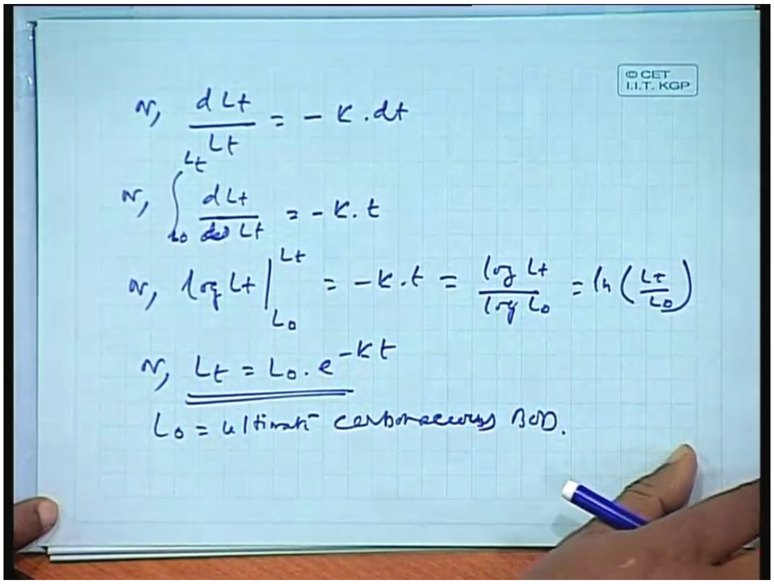

or, $\frac{dL_t}{L_t} = -K.dt$

or, $\int_{L_0}^{L_t} \frac{dL_t}{\cancel{dt}\, L_t} = -K.t$

or, $\log L_t \Big|_{L_0}^{L_t} = -K.t = \frac{\log L_t}{\log L_0} = \ln\left(\frac{L_t}{L_0}\right)$

or, $\underline{\underline{L_t = L_0 . e^{-Kt}}}$

L_0 = ultimate carbonaceous BOD.

So is on integration this is 0 0 2 t_0o to t dLt dt sorry L_t, this is as an integration here it is just, so it would begin from L_0 into t, L_t L_0, L_0 into t when there is no demand, when there is there is no demand this is say this should begin from here and this one is minus K K_t as you can see here. So here it is log, log, log L_t, this is L L_0 to Lt and this one is minus K_t or you can find out that this would be essentially this is what we can find out L_t is equal to, L_t would be, L_t is equal to L_0 into e to the power minus K_t. Minus, so it comes L_t log L_t divided by log L_0. So this one is if L_t by L_0 would be e to the power minus K_t so L_0 your bringing in there, so L_0 into e to the power minus K_t. So this one, this one is it says that that at any point of time L_0 is known as, L_0 is known as the ultimate, ultimate carbonaceous. Remember this carbonaceous, ultimate carbonaceous BOD, this is known as ultimate carbonaceous BOD which is nothing but as you can see log, log as say L_t, this is log L_0 or say this one is e to the power so you can find out this. So this is, this is, this is log L_t divided by L_0 so you know you can find out like this.

So, here as you can see this one is the ultimate carbonaceous biochemical oxygen demand, ultimate carbonaceous biochemical oxygen demand. So you know in case if we are just plotting it now this you know this you try to see this.

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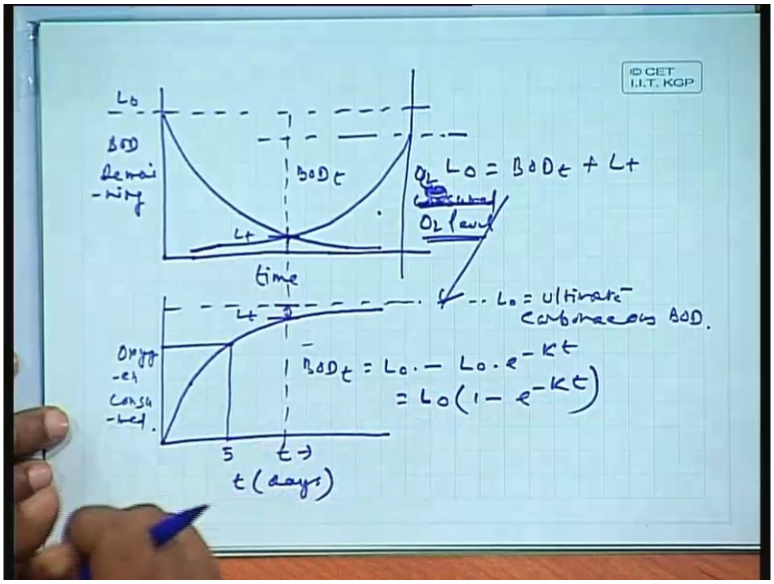

BOD remaining and if we just put time here BOD remaining and if we put time here, this we can see that this one is this one would be, this is going finally you know as this is say this should be an asymptotic term. The modelling part as you can see this one is, here this one is BOD_t, BOD_t this one is L_t, the remaining L_t. This is the ultimate, this is the ultimate demand at the start, so this is L_0, this is L_0 ultimate demand remember this don't confuse with that saturated value of oxygen, these are two different things okay. Remember don't confuse it saturated value of oxygen. Here it is say there are two different things, this is BOD_t, so this is L_t that you can find out BOD_t, this is, this is the L_t plus BOD_t so at any point of time we can also see L_0 is ultimate a biochemical oxygen demand is BOD_t plus L_t. So the demand already, already consumed plus demand remaining, demand remaining this ultimate carbonaceous oxygen, biochemical oxygen demand.

On the similar light on the similar light if you just observe this, this is oxygen consumed, oxygen consumed, oxygen consume. So you can see this, this is what is, this is BOD_t, this is L_t, this is L_0, this is ultimate biochemical ultimate carbonaceous, ultimate carbonaceous BOD right. So let me again begin this discussion here, I mean later will conclude here today but as such you know let me explain this things again to you. So, at the start you can see this, this is where, this is the oxygen depletion if you just observe this oxygen depletion, if you can find out you know if you just oxygen, oxygen here, oxygen consumed, oxygen consumed here this is say this is oxygen, oxygen consumed or oxygen level see oxygen you can write out oxygen level, oxygen remaining or oxygen level, oxygen level or oxygen remaining. Oxygen level you write oxygen level, O_2 level, O_2 level.

If this is O_2 level I am just plotting a different point here, it is not, not to coincide with L_0 you can see this oxygen level, oxygen level would essentially decrease like this. This is oxygen level, oxygen level would essentially decrease say from its saturated value, from the saturated value at that salinity the oxygen level would going to go down, this should be it is going to, going towards zero okay, all right. So, this is BOD remaining, at the beginning the BOD, at the beginning, at the beginning there is no demand because at the start, at the start there is no demand. As soon as more and more carbohydrates go to the, go to the, are used for the decomposition the rate of, the rate of BOD remaining goes down but the BOD essentially goes down steadily but at the same time the rate the, rate of BOD, BOD also slow down, slows down as more and more BOD are consumed. And as you can see here that is you know in the oxygen consumed, oxygen consumed here or oxygen level at that point of time would begin to decrease also that means you know this a reciprocal of this, if a reciprocal of this can be drawn here this is what it is generally observed like this.

So oxygen consumed or it is the oxygen level. So this is what essentially takes place in water. Now there is one important assertion here, I just want to make this thing is very important for all of us. This is mostly takes place when this is, this is particularly this kind of plots are this are, plots are true and particularly important when this is the waste is, waste is of biological, biological or biochemical in nature, of biochemical or biological in nature.

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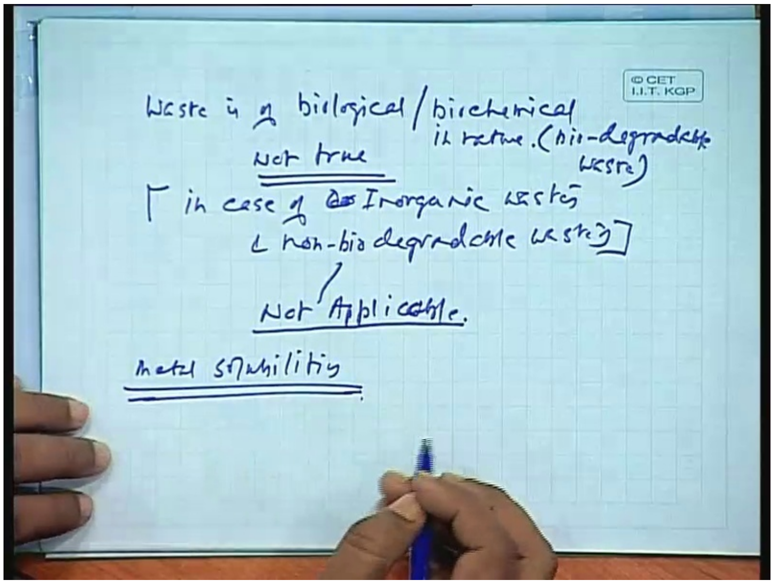

Waste is of biological / biochemical in nature. (bio-degradable waste)

Not true

[in case of Inorganic wastes & non-biodegradable wastes]

Not Applicable.

metal solubility

But it is not true, not true, not true or not applicable essentially never use not true and not applicable in case of, in case of organic inorganic wastes, in case of inorganic wastes, in case of inorganic wastes and inorganic and non-biodegradable waste. This is also biodegradable waste right. In case of use waste is of biochemical, biological or biochemical in nature, biodegradable waste and in case of inorganic waste and not only this not applicable, this particular modelling is not applicable. So this is not applicable. What is important in such cases in cases particularly there may not be any demand of oxidation, there may not be any demand of oxidation of an inorganic substance right.

Organic substances have a demand because this particularly the microns have a demand for a biochemical wastes because for their food they use it but generally in metals say inorganics, inorganics there is no necessity there may not be any necessity for the microbes to decomposite and using oxygen remember it. When it can decompose it may not require to decompose with the help of oxygen or in the presence of oxygen. So in such cases this is not absolutely what is more important in cases of this are the metal solubilities. We would see this you know in one of this classes metal solubilities, this metal solubilities, this metal solubilities deal with, metal solubilities deal with you know this particularly the when the soluble you know in a partial pressure conditioning in water how one metallic ion gets released in preference to another metallic ion right and in what's in such situation we would see this as I have said in many cases the spacious becomes different you know just let me give you a simple example here, let me give you a simple example here you know where we could observe this. This particularly this metal solubilities, if you just see this metal solubilities here you can see this say as you can see in our mostly dissolved molecules, dissolved molecules, molecules of inorganic substances, substances break into, break into charged ions, charged ions, ions break into charged ions right, break into charged ions.

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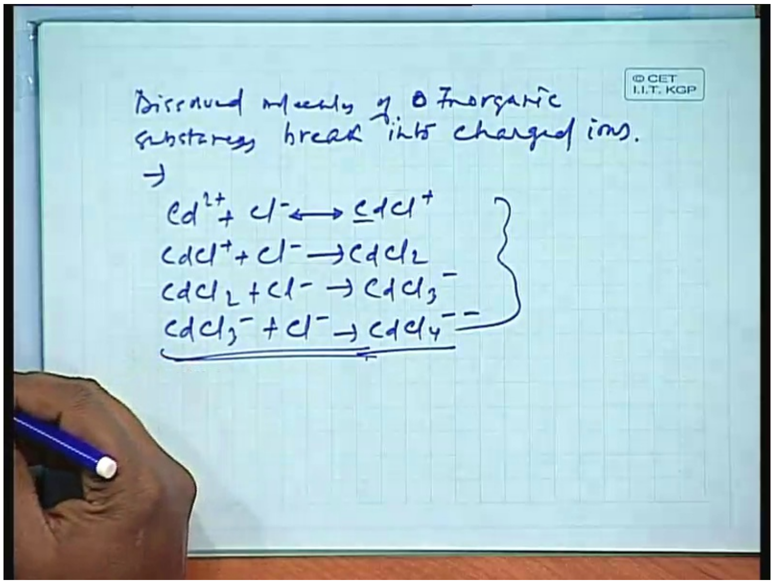

Dissolved molecules of Inorganic substances break into charged ions.

→

$$\begin{aligned} &Cd^{2+} + Cl^- \longleftrightarrow CdCl^+ \\ &CdCl^+ + Cl^- \rightarrow CdCl_2 \\ &CdCl_2 + Cl^- \rightarrow CdCl_3^- \\ &CdCl_3^- + Cl^- \rightarrow CdCl_4^{--} \end{aligned}$$

This charged ions you can see this, this is you know charged ions you see this cadmium. This is quite interesting to observe that cadmium in the presence of chlorine ion is a reversible reaction of cdcl, see this cdcl plus it can also cd say the cdcl, cdcl, this cdcl plus would be a then cl minus can form cdcl$_2$, cdcl$_2$, cdcl$_2$, cdcl$_2$ plus cl minus, cl minus can cdcl cl$_3$ minus. This cdcl$_3$, cdcl$_3$ minus can form with cl minus, can form say cdcl, cdcl$_4$, cl$_4$. So you can see this we just observing we are just seeing that here cadmium can stay in water, can remain in water in 4 species, having 4 difference valencies. This is number 1, this is 1 valency, this is 2, this is 3, this is 4, in 4 valencies there. Interestingly, interestingly all species of cd cadmium may not be, may not be toxic but 1 or 2 species may be toxic. So will use this in a different context in a, in a different lecture okay. We, conclude today's lecture by this I mean you know will take up this issue of first order BOD modelling again in the tomorrows class, okay.