**Aspects of Biochemical Engineering**
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**Lecture – 50**
**Transport Phenomenon in Bioprocess IV**

Welcome back to my course Aspects of Biochemical Engineering. Now, today I think last couple of lectures I try to discuss transport phenomena, as I told you that transport phenomena is very important that unit operation process that is involved, in chemical and biochemical industries.

Now, this transport phenomena that comprises of a transfer or transportation of the different transportation mechanism of the process and, this is and three different mode of transfer phenomena is there one is momentum transfer, another is mass transfer another is the energy transfer, or the heat transfer.

Now, we already discussed the momentum transfer, which deals with mostly the flow of the fluid and through the through the flow of the fluid, we can have the mixing of the of the liquid mixing of the solid and the liquid, and also it involves the mixing time determination, in the last lecture of we try to find out what is the power minimum power requirement for the minimum mixing time that, you know those kind of information we can generate from that.

After that I try to discuss the heat transfer, or the heat transfer basically it is very important till the in the biochemical industry because, because it required the environmental parameter for the microorganism plays very vital role, once one important parameter is the temperature and, and as we know that the biochemical reaction mostly they are exothermic in nature. So, exothermic means heat liberating that, you know that process that we have and most of the biochemical process usually operated in between 30 235 degree centigrade.

So, particular when we are since we are in the tropical country, our ambient temperature particular in the summer season is quite high. So, we required lot of cooling arrangement particular during summer season. And for winter season we required some kind of heating of the fermenter to maintain the temperature.

Because those thing is very that you know we determine on the basis of heat transfer and, these heat transfer also involve the sterilization of the process, because the I told you that sterilization means that we, we are killing all the microorganism present in the liquid; So, that our desired organism can grow in the in the particular medium, so, that we can get the desired product.

So, heat transfer plays very important role in the last lectures, I tried to discuss the heat transfer, how we design the length of a that cooling coil and also the temperature of the outgoing liquid in the pulling coil. So, those problem we try to solve in the last lecture.

Now, today I am going to discuss another very interesting topic, what you call mass transfer and mass transfer it is always a required usually take place the transfer of the mass between the phases, as per example that we know that most of the microbial fermentation process, they are aerobic in nature and, aerobic fermentation process. We required dissolved oxygen because, in the fermentation medium because microorganism can neutralize the oxygen which is dissolved in the fermentation medium.

So, that plays very important role. So, how we increase the dissolve oxygen concentration is passed the air through the medium so, that the air oxygen present in the air as it transferred in the liquid. So, that that part also I am going to discuss today, now first let me discuss that, what is what do you mean by mass transfer. Now here you see that mass transfer basically, it is the transfer it is net movement of the mass from one location.

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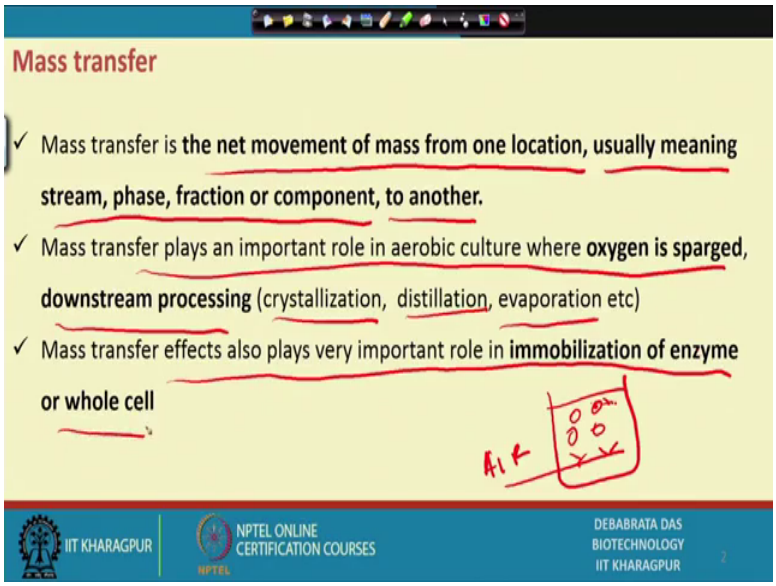


Usually the meaning of stream, phase, or fraction, or component to another so, I was talking about suppose, this is the vessel and this is the liquid, we have we are sparging air, So, air bubble is going out this is air in and so, when it goes, then oxygen present in the air that goes to the liquid, that is the that. So, this is remain oxygen present in the gaseous form gaseous phase, then it coming to the liquid phase.

So, this kind of example that we have then mass transfer plays important role in the aerobic culture, where oxygen is sparged downstream. processing And other downstream processing like crystallization, crystallization we know that you know crystal that crystal formation; that means, from the soluble liquid that has no temperature the crystal formation takes place, I can give you a very typical very easy this simple distance that is the sugar crystals, we can if you keep it at low temperature, then crystallization of the sugar that take place.

Then we have distillation there also, we distill the liquid from one phase to another that from if we liquid to vapor and evaporation etcetera, mass transfer effect place a very important role in the immobilized and whole sale system.

This also I discuss, when I when I discuss the immobilized enzyme and immobilized whole system and, I told you that particularly that in case of enzyme suppose we are handling the soluble enzymes and, major drawback of the enzymatic process is that after the reaction is over, that enzyme remain an impurities in the reaction mixtures. So, you

have to you have to you have to you have to purify you have to take the enzyme out from the reactor, that is again that incurs some additional expenditure.

So, by this can be avoided by using immobilized enzyme because, if you if you fix the enzyme under the solid matric and pass the sub state through the column your sub state will be converted to products.

So, you do not like you do not have to separate the enzyme from the liquid mixture, but the problem is that as soon as the immobilized the soluble enzymes will be will be fixed on the solid matric is the insoluble soluble matric, so it is a heterogeneous system. An heterogeneous system I told you that the heterogeneous system major factor that plays important role that is the division problem.

So, that the mass transfer effect is very important in the immobilization enzyme and the whole sale system.

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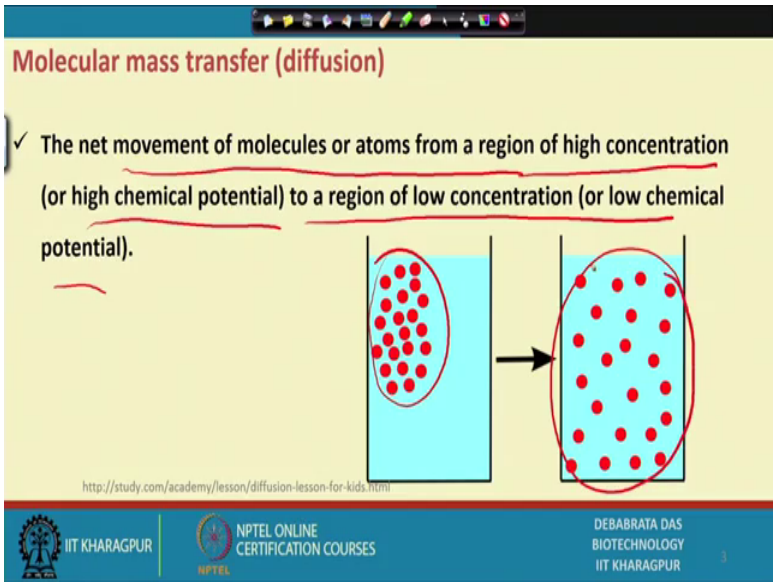


Now, what do you mean by molecular mass transfer, this is a very very simple example I have given, the net movement of the molecules or atom from a region of high concentration, or high chemical potential to the region of low concentration potential like this.

Suppose here this is some concentrated you know that very solute is there, or solution is there. So, if you keep it then slowly slowly is diffuse uniformly throughout the liquid like this. So, this is this is kind of what you call molecular transfer that take place.

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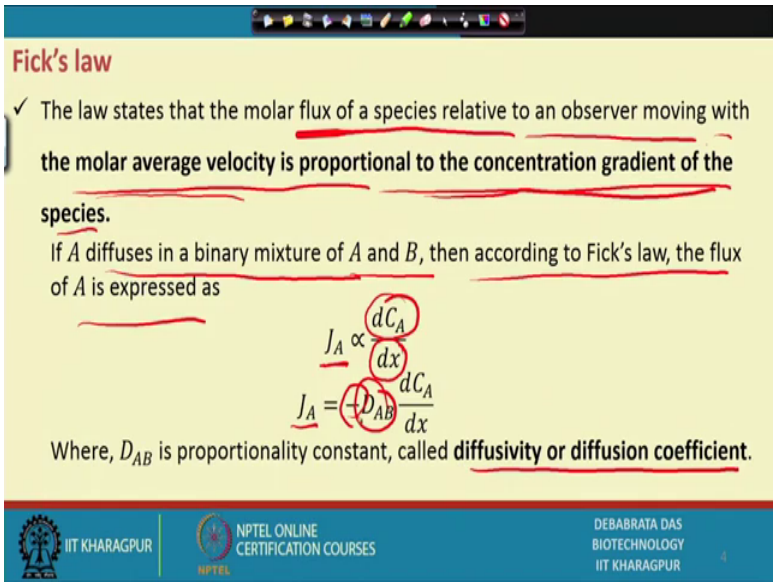


Now, Fick's law we know the this is the we will use for explaining the how this mass transfer take place, the laws states that the molecular flux of a species is relative to a observer moving with molar average velocity, is proportional to the concentration gradient of the species.

Now, so what is happening that molar average velocity molar? What is the velocity? Velocity is the length per unit time, am I right? So, molar average velocity that you know; here actually call the that depends on the proportional to the concentration gradient of the species.

Now, a diffuse let us let us take the example A B is diffused in a binary mixture A plus B and, then according to the Fick's law the flux of A C an be expressed k this J A J A is proportional to this is the concentration gradient and, this is x is the is the is the distance that you know that.

So, the so this is equal to that D in D A in D A B is the is the constant, what you consider as a diffusivity, or diffusion coefficient. So, J A that rate of flux of a can be expressed as minus D A B so, d C A by d x.

Now, question why this negative term is coming because, concentration of the always movement of the solute, they take place from the high concentration to low concentration, that is why this negative term has come.

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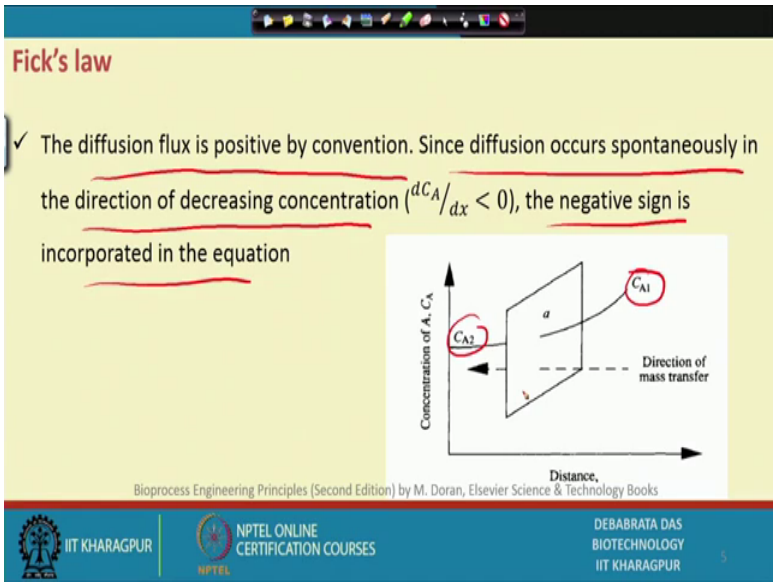


Now, this is the Fick's law; Fick's diffusion flux is positive by convection and, since the diffusion occurs spontaneously in the direction of decreasing concentration, the negative sign is in incorporated, this is the high concentration and this is the low concentration this is how the negative term has come.

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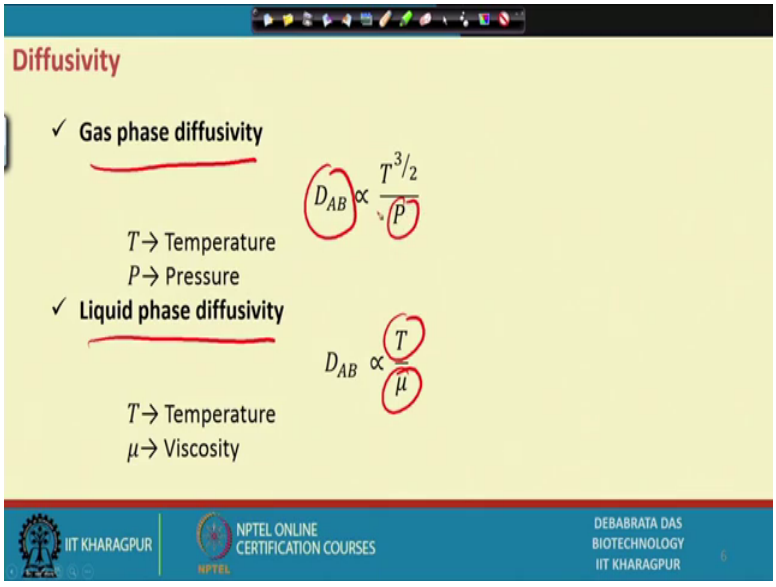

Now, diffusivity that depends on temperature that like this D A B A B is proportional to T to the power 3 by 2 by P. So, this is how this is gas phase diffusivity, another is the liquid phase diffusivity D A B equal to T by mu this mu is the viscosity of the liquid, here is the P is the pressure of the gas.

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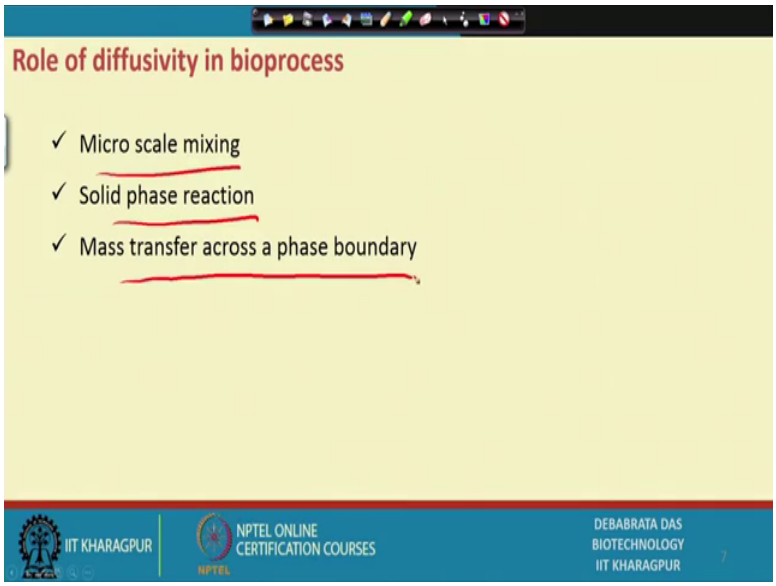


Now, role of diffusivity in the bio process is the microscale mixing, solid phase reaction and the mass transfer across the phase boundary. So, three different things simultaneously take place, then micro scale mixing, then solid phase reaction and the mass across the phase boundary.

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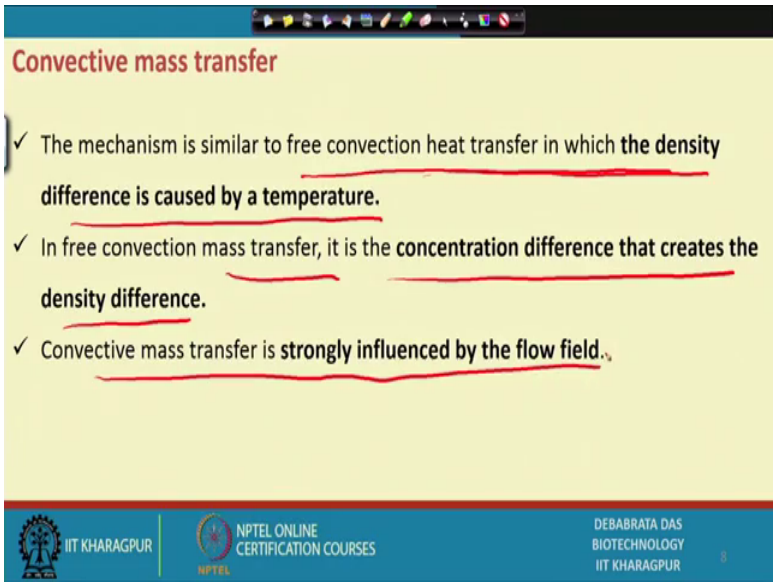


Now, let us first discuss the convective mass transfer the mechanism similar to the free convection heat transfer, I think the last lecture, I try to discuss the difference between the convection and, conduction and the radiation with respect to extinguishing a fire from a water source; So, here that the mechanism is similar to convection the heat transferring which the density difference causes the by the temperature.

So, in case of heat transfer we have temperature difference that is the gradient and, here the density that is the gradient is the concentration gradient here you use. The free convection mass transfer is the concentration difference create the density difference and, convective mass transfer is strongly influenced by the fluid flow field that you know how liquid is flowing that strongly, I shall I shall give you lot of example; So, that this conception will be clear to you.

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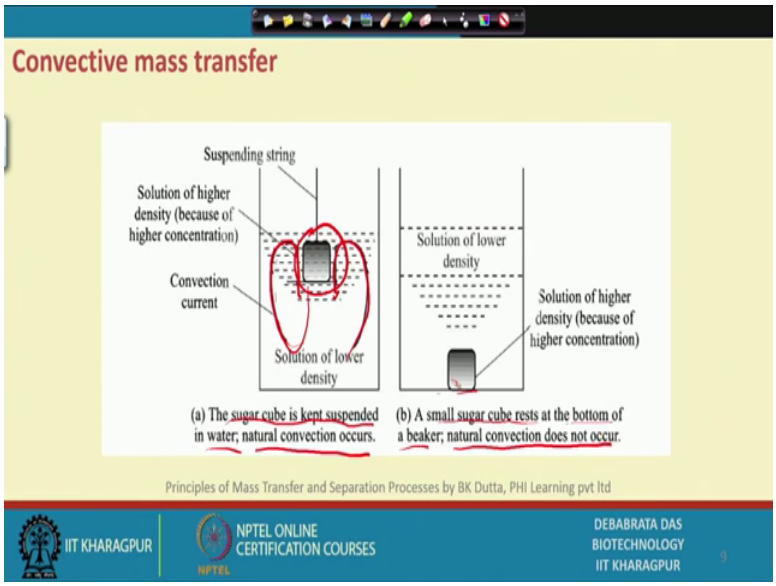


Now, this is the first example I can give this convective mass transfer. Now, this is the sugar cube you can see this is the sugar cube, we keep the sugar cube in two different fashion, one is this is the hanging fashion, you see that we just hanged the sugar cube. In the in a solution then what is happening this there will be convection current, this is we will we will then the concentration will go like this see this current of convection current, this is we will the high concentration to low concentration this will occur.

But when and this the sugar cube escaped in suspension in water and natural convection occurs, but when it gives the at the bottom with touching the bottom surface, then a small sugar cube raised at the bottom of the beaker natural convection does not occur beaker one side is blocked. So, natural convection will be effected by that.

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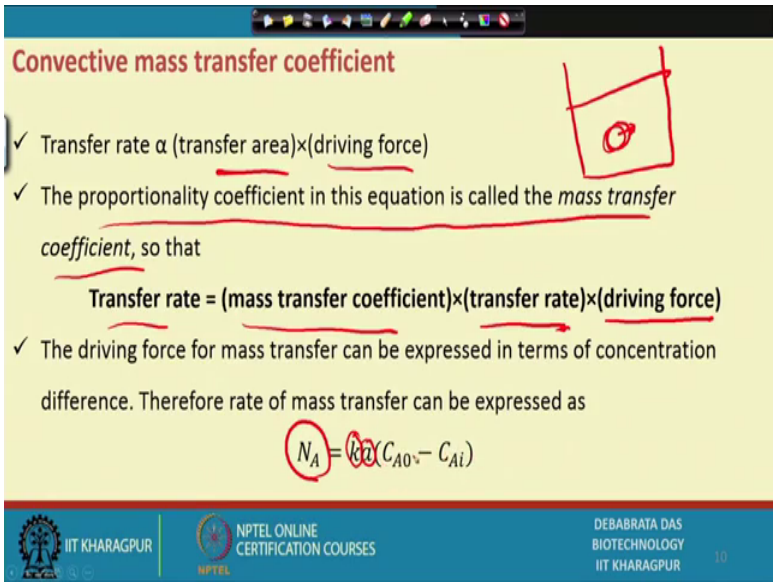


Now, convective mass transfer coefficient how you can write the transfer rate is proportional to transfer area and driving force, that you know that a that a I hope a that we understand that in suppose there is a liquid and the liquid there is a bubble, so, we want to if we want to transfer oxygen, this gas to liquid, it depends on two factors, the one is that the driving force driving force means concentration gradient and, another is the transfer area is a more area more will be the mass transfer.

So, this is like this the proportionality coefficient in this equation is called the mass transfer. So, transfer rate equal to mass transfer coefficient into transfer rate, and into driving force. So, this is a and the this can be explained, express like this mathematically and I if we consider the mass transfer of A we N A is equal to k a k is the mass transfer a k is the mass transfer coefficient and a is the area and, and this is the driving force that we have.

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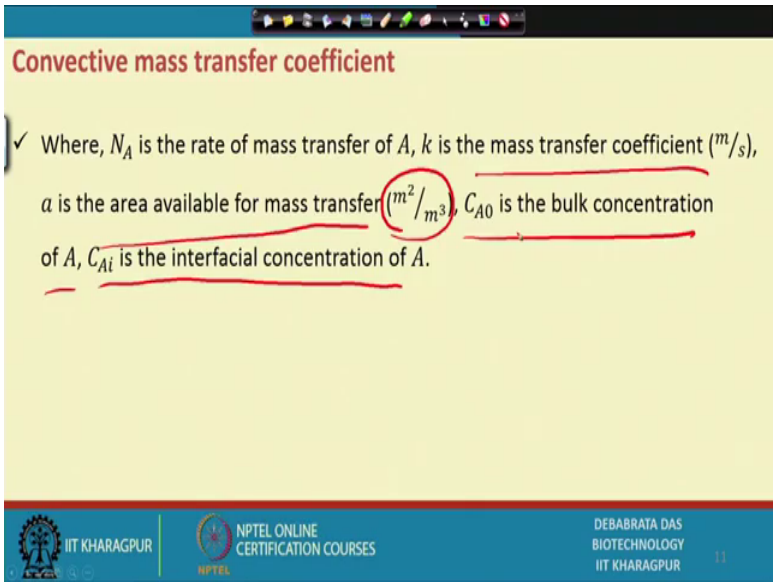


Now, N A is the rate of rate of mass transfer that and k is the mass transfer coefficient, as I told you a is the a area available for the mass transfer and, this area always we express like this what is this that surface area per unit volume of the of the of the of the particular material that, you know that per unit volume that how much is the surface area.

And C A 0 is the bulk surface concentration of a and C A i is the interfacial concentration always less the bulk surface concentration. So, it is C A 0 minus C A i.

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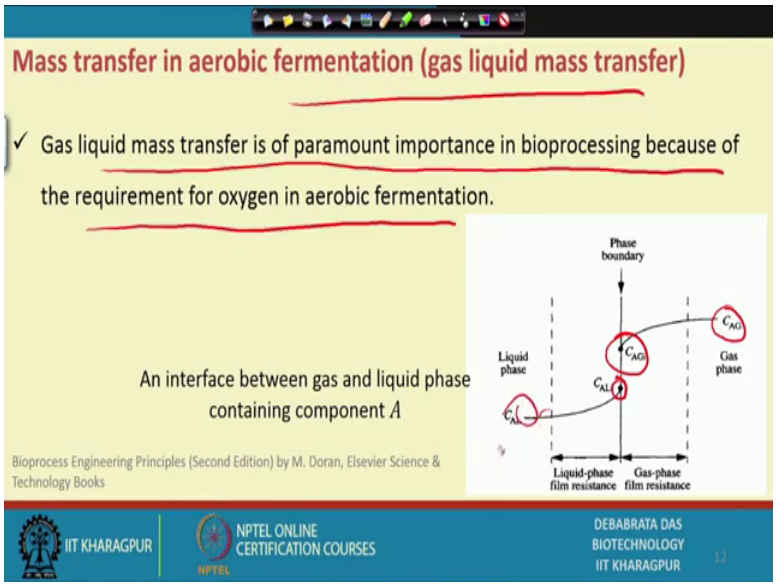

Now, let us see the how the transport take place mass transfer in the aerobic fermentation process, gas liquid mass transfer gas liquid mass transfer is the important in the bioprocess because, the requirement of oxygen in the aerobic fermentation I told you.

This is the limiting factor as the as per the biochemical industries is or, microbial fermentation is concerned. So, this is the gas space this is the concentration of oxygen in the gas space, this is the concentration of oxygen in the at the phase boundary between the liquid and gas and, this is the concentration of oxygen at the phase boundary in the liquid phase and, this is the bulk am I right.

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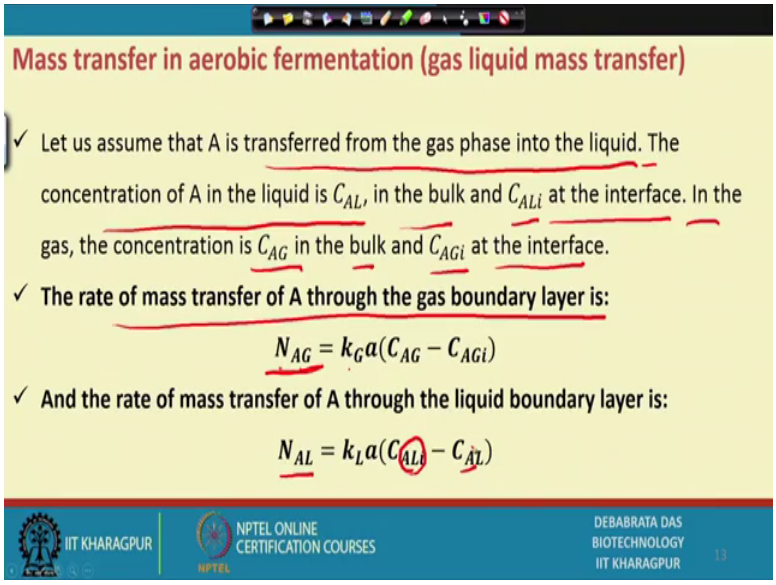


Let us assume a is the transfer a transferred from gas phase into the liquid phase. And the concentration of a in the liquid phase is C AL in the bulk in the bulk and C AL i at the interface, I showed you before and in the gas phase, it is C AG i n the bulk and C AG i is that the interface.

Then what is the rate of mass transfer a through the gas boundary layer, is what will be that N A G that mass transfer take place, in the gaseous phase is K G in to a C AG minus C Ai and this will be, but in case of liquid phase the interfacial oxygen concentration will be higher as compared to bulk because, it is mass transfer take place from the gas phase to the liquid phase.

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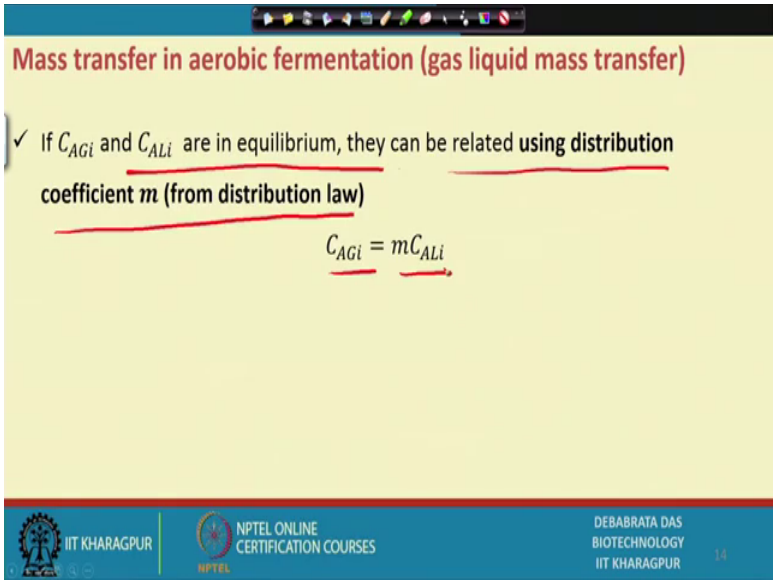


So, C N A N A L equal to K L a into C Ai C L A L i minus C AL mass transferred C Ai and C A L i this two are in equilibrium, and they can be related by using distribution coefficient from the distribution law C AGi equal to m into that the how much of that oxygen present in the gas layer that mean dissolving the in the in the liquid layer, that is n is the distribution co efficient that we have.

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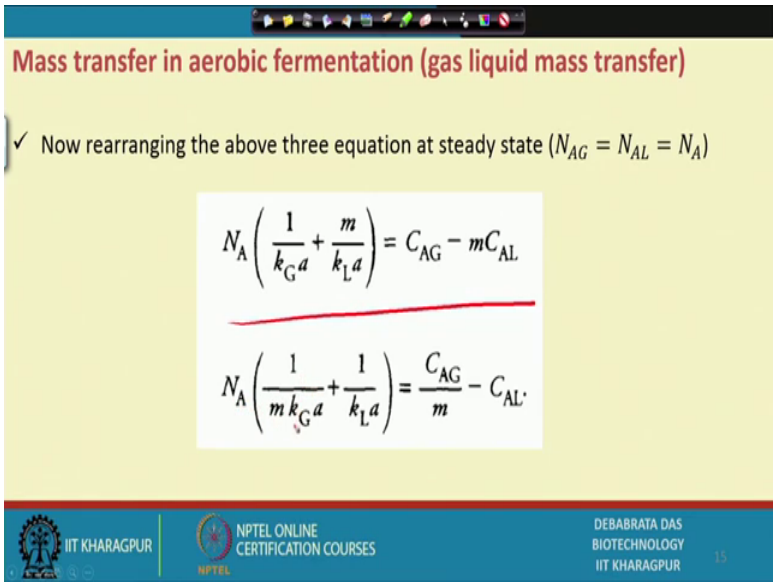


Now, rearranging the above equations we will we will come across this kind of correlation N A equal to that this N A into 1 k G a m by k L a C AG m into C AL and in case of other equation we can m a a a 1 by m k G a 1 by k L a you know C AG m by l into l this equation we can rewrite from that.

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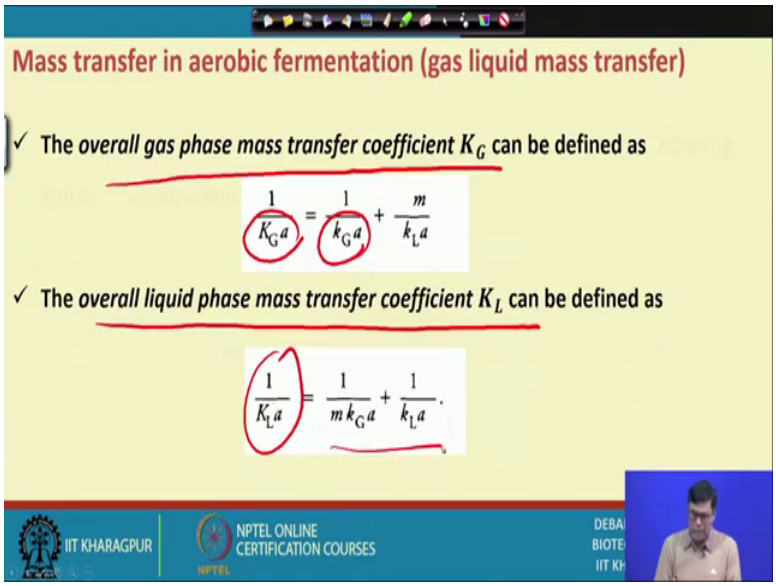


Now, these equation if you look at this equation that from this equation, we can write that one k this is this whole portion, what we can write this you can write 1 overall that overall, this we can write this overall gas phase mass transfer coefficient k G that is capital k G a not. So, this is small k G a and, this is capital this is overall.

Now, this will be equal to 1 by k small k G a by plus m by small k L a, but similarly overall the liquid phase mass transfer coefficient can be expressed this is like this.

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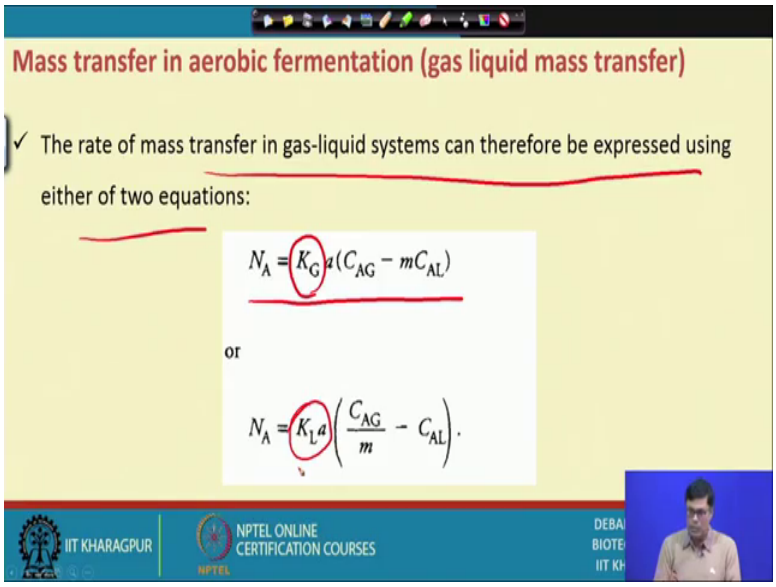

So, we can write that we have this equation that is the rate of mass transfer gas liquid system can therefore, is using the 2 equation, N A equal to K G a C AG minus m into C AL and N A equal to K L a C AG by m and on the basis of gas phase and the and the basis of liquid phase that, we can we can express this equation in the two way.

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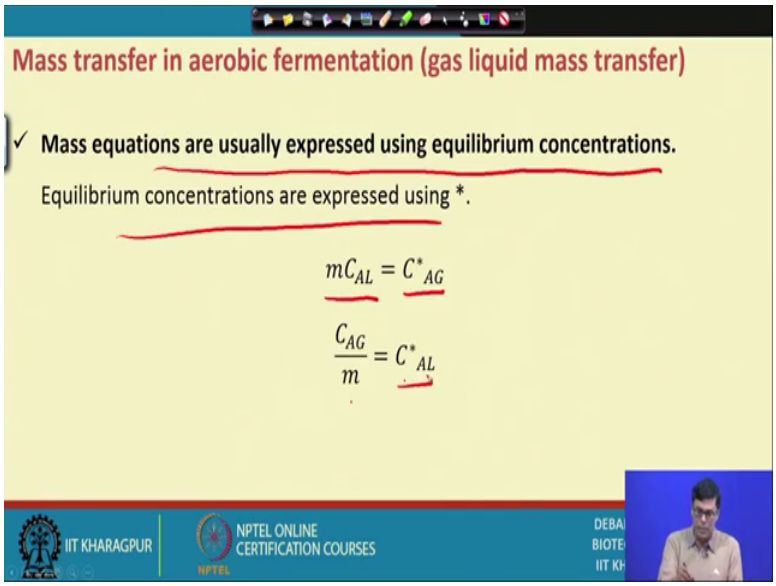


Now, mass equation are usually expressed using the equilibrium concentration, you can the express as that mC AL equal to C dash AG a is this is the equilibrium concentration. So C AG by m equal to C star AL that, we can write like this under equilibrium conditions.

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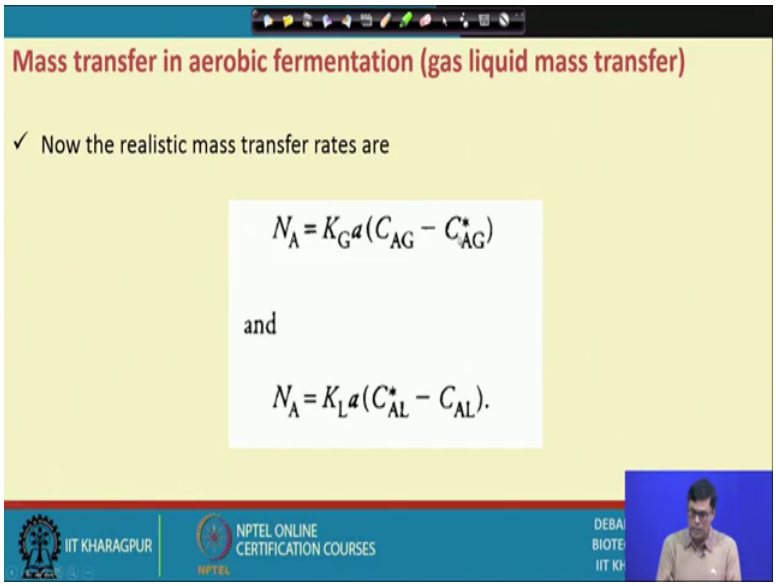


Now, this equation can be rewrite in this form N A equal to K G a this is the overall mass transfer in the gas phase overall mass transfer liquid phase C AG minus C A A star A.

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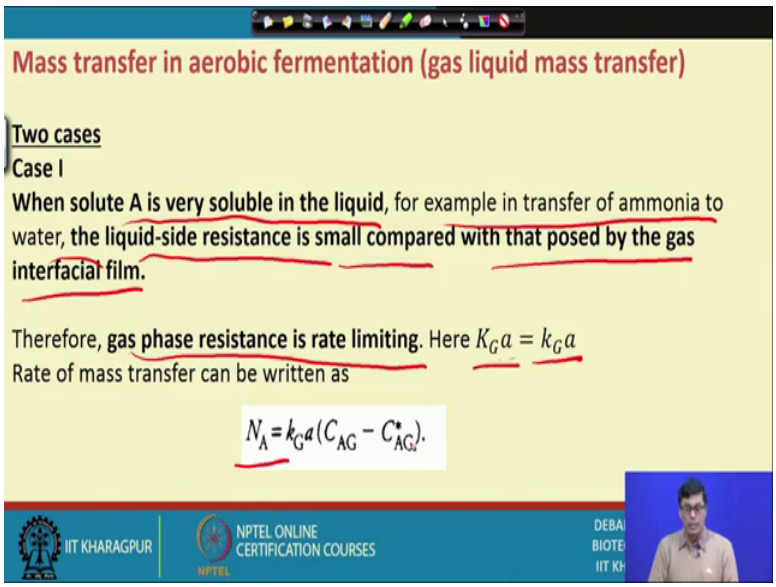


So, mass transfer in the has two cases a first case if you look at when a solution is very soluble in liquid for example, transfer of ammonia to water the liquid side resistance is small, as compared to posed by the by the gas interface because, where the solubility is more, then the resistance will be less therefore, gas phase resistance rate limiting is the K

G a a a equal to capital K G a equal to small k G a. So, we can write N A equal to small k G a C AG minus C A dash when your solute is largely soluble in in the liquid phase.

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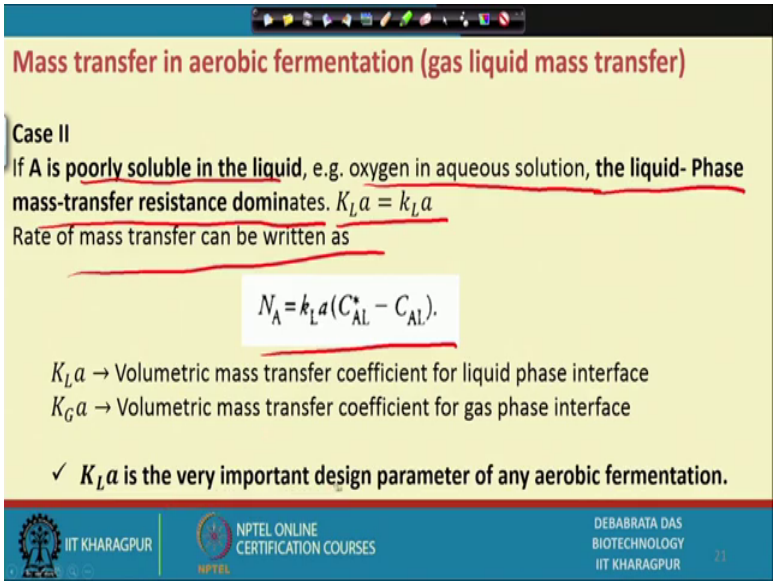


Now, in the second case, if a is poorly soluble in liquid. This is another case poorly soluble liquid as per example oxygen, in the aqueous solution the liquid phase mass transfer resistance dominates and, there that we can write K capital K L a equal to small k L a and rate of mass transfer can be written like this. So, that is the that happens that is controlling by the liquid phase in when gas is highly soluble that that controlled by the gaseous phase.

So, this we get the K L a is very important design for a aerobic fermentation process and, k L a we consider as the volumetric mass transfer coefficient.

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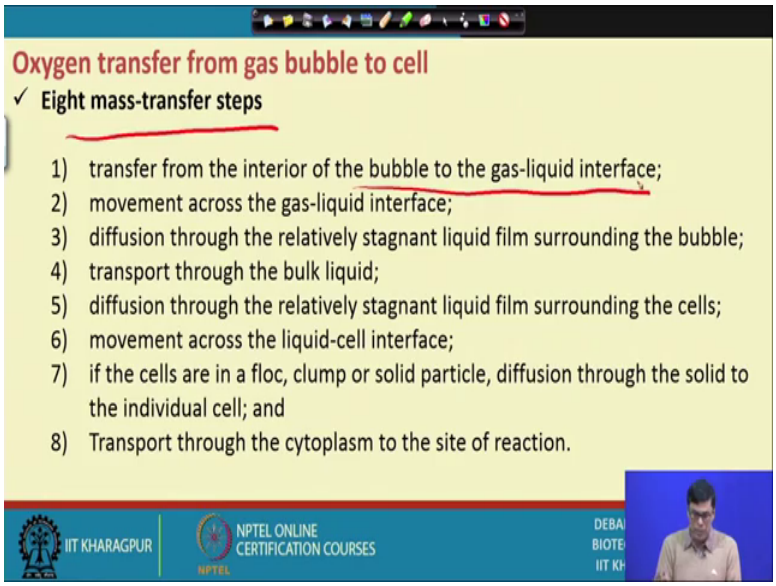


Now, oxygen transfer from the gas bubble to the cell, that can be has eight different steps. Transfer from the interior to the bubble, in the gas liquid interface, I hope let me show you the diagram, then things will be very clear this is like this.

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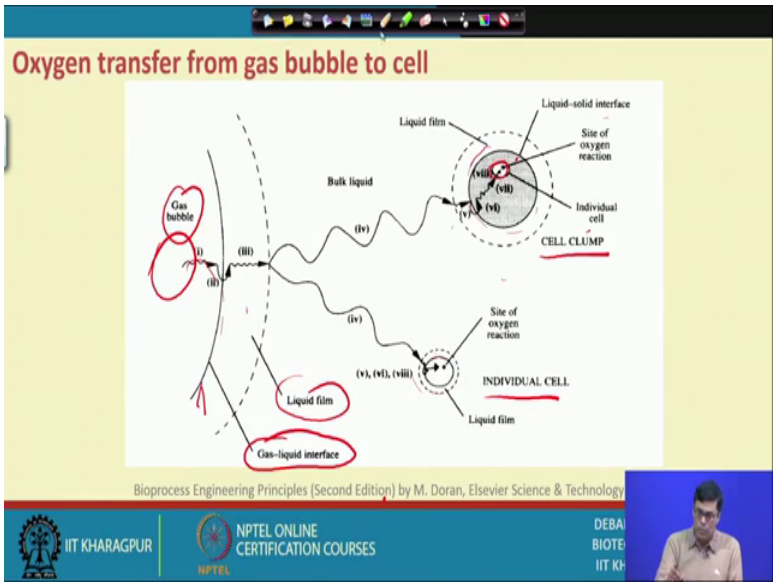


This is the, you see this is the gas bubble here, am I right this is the gas bubble. So, it is going it is first layer, then it is come this is the bulk of the liquid.

So, then it goes inside and slowly slowly it enter into the cell, this is the again here you see this is the we have this is the liquid film that we have across the cell and, this is the

liquid solid interface here and, this is the individual cells that present inside the microorganism that is that how it occurs.

Now, this is in case of cell when remain in the clump, individual cells, if you consider it comes like this is individual cells, it comes this is the this is the liquid film and this enter into system and, individual cells the attack like this. So, here this is consider as the gas liquid interface and this is the liquid film that we have and, this is the and this is how transfer inside the cell.

So, when you when you come, when you consider that this steps.

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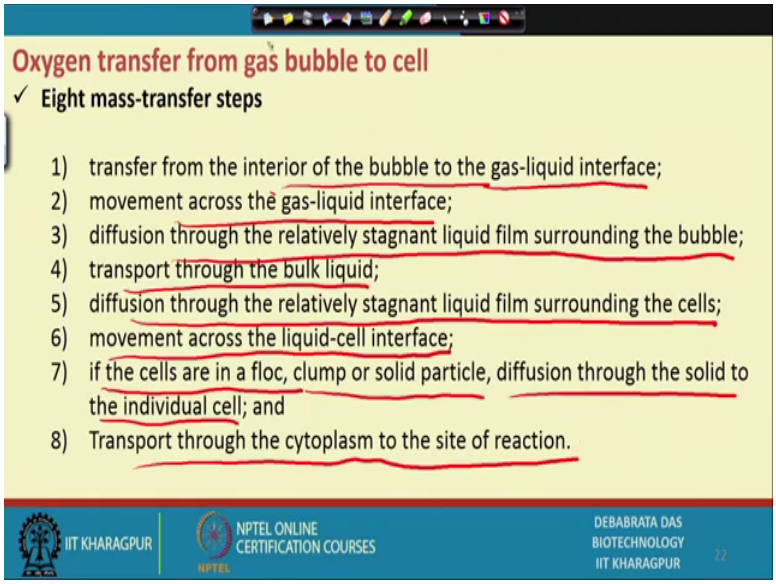


So, this can be written like this transfer from the interior of the bubble, then we are we can we can write the transfer of oxygen from the interior of the bubble, to the gas liquid phase and movement across the gas liquid phase diffusion through the relatively stagnant liquid film surrounding the bubble.

Then transport through the bulk liquid, diffusion through the relatively stagnant liquid film surrounding the cell, movement across the cell liquid cell interface and, if the cells are in a floc, clump or solid particle, diffusion through the solid to individual cells and, transport through the cytoplasm to the site of reaction.

So, there are there are there are eight different steps involved through which that this transport can be can takes place.

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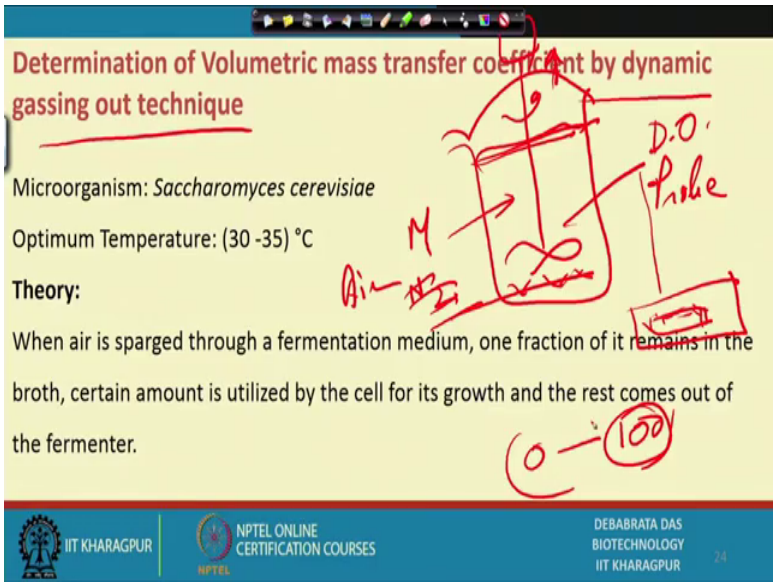


Now I have I want to give you very typical example that is how the k L a can be estimated in the in our in our laboratory, this is the method that is largely used what you call dynamic guessing of technique.

Now, what is what we do basically it is like this is the fermenter, this is the fermenter this is the aeration we have. So, what you what you can do we have we have here, we have a probe what is our this is called dissolved oxygen D O probe dissolved oxygen probe. So, it monitor there is a monitor, it monitor that concentration of oxygen.

Now, this concentration is the express on the basis of percentage the scale is 0 to 100. Now how you how you do that suppose this is the medium, you have taken medium and then what you do you sparge initially you sparge nitrogen, sterile nitrogen, then you take it out then you will find that it dissolve oxygen concentration keep on decreasing. And a time will come when it will constant that is the that you set it to 0.

Now, then again you sparge this is replaced by air, you sparge air and you will find the dissolve oxygen concentration will increase a time will come when it be fixed that will adjust to 100. So, when this 100 that corresponding to the saturated dissolve oxygen concentration. So, what I can if you if you will go through the any kind of hand chemical hand book, you can easily find out at different temperature. What is the dissolve oxygen concentration in water?

So, if you know the percentage suppose 19 percent, then you just multiplied by saturated dissolve oxygen concentration, you will get the (Refer Time: 25:34) actual dissolve oxygen concentration in the liquid. So, this can be done very easily.

Now, here the experiment that we have conducted by using saccharomyces cerevisiae temperature 30 to 35 degree centigrade, air sparge through the medium one fraction remain in the broth and certain amount of utilized by the cells growth and rest comes out when the fermenters.

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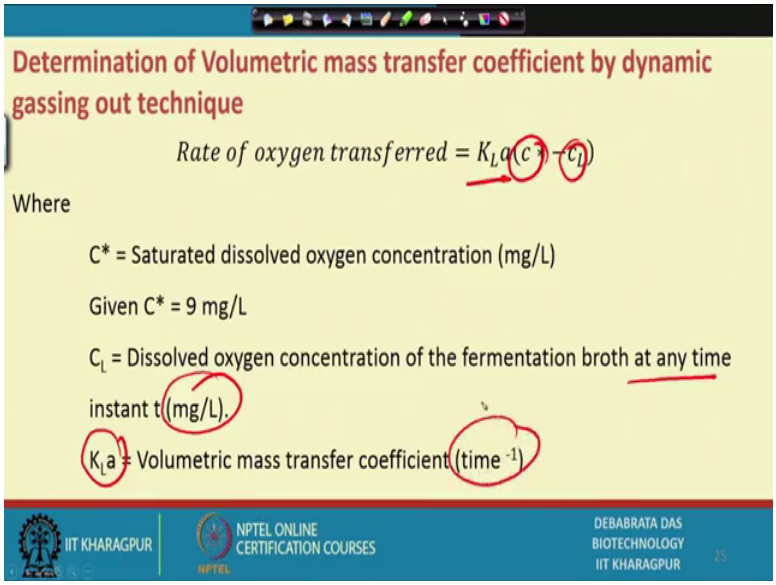


Now, rate of mass transfer will be what here rate of mass transfer, this is the volumetric mass transfer K L a and, this is C star is the saturated dissolve oxygen concentration, and C L is thus dissolved oxygen concentration at any time t because, any time t that is a a that the express as p p b milligram per liter and unit of K L a is the time inverse.

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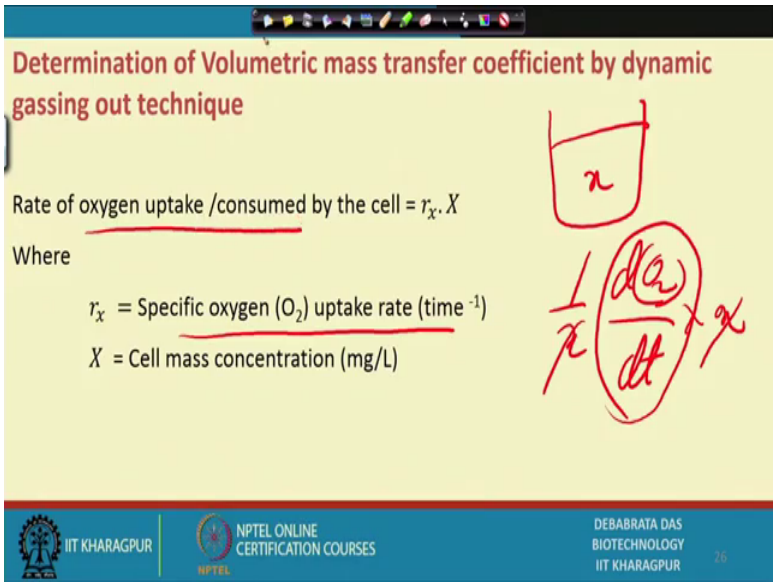


Now, rate of oxygen consumption how you can write that by the cell it is the r x is if we that, if we if we if we consider that suppose the if we consider the specific optic specific oxygen uptake rate, what do you mean by that 1 by x d o 2 by that means, gram of oxygen that that utilize per unit time per unit concentration of the cells.

Now, the in a suppose in a particular liquid, you have x is the cell concentration. So, how much oxygen rate of oxygen consumption will be there, this into x then x, x will cancel will get the rate of oxygen that is consumed in the in the month, this is called oxygen uptake.

So, what when you when you use the any kind of microorganism and sparge here, we call the condition is a dynamic, why it is dynamic because 1 is we are what is the purpose of sparging to increase the dissolve oxygen concentration and what is organism is using microorganism they are utilizing the dissolve oxygen for the growth and metabolism that. The two things simultaneous take place that is why we call it dynamic.

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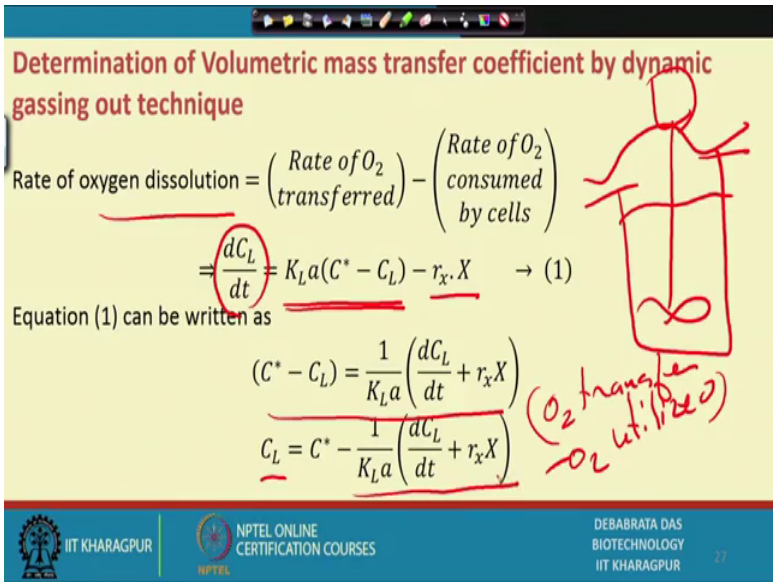


Now, this is the equation we can we can we can write, the rate of oxygen dissolution or rate of oxygen transferred, equal to that that rate of oxygen transferred minus rate of oxygen uptake by the cells. So, in a fermenter this is a fermenter so, two things simultaneously take place oxygen transferred one is o 2 transfer and another is o 2 utilize by the cell. So, the difference will get you, the how much oxygen that dissolve oxygen concentration increases in the system.

So, if you say the under steady state conditions this should be equal to 0 because, rate of oxygen transferred it should be equal to rate of oxygen used by the cells. Now, this equation we rewrite in this form very easily, and C L equal to we can write in the this is like this.

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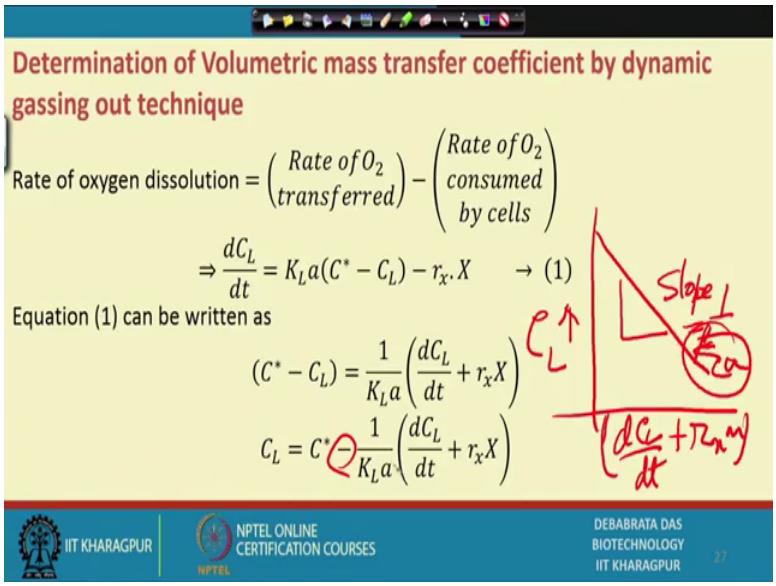


Now, here I want to point out that that in this that if you if you plot I just show you how you can plot that, C L versus this 1 d C L by d t plus r x into x. So, what kind of plot you will get negative slope this is negative am I right, this is negative slope and this slope will be what slope will be equal to 1 by 1 by K L a K L a.

So, the volumetric mass transfer coefficient we can easily determine, if you if you have the slope. Now, I shall show you how you can do that.

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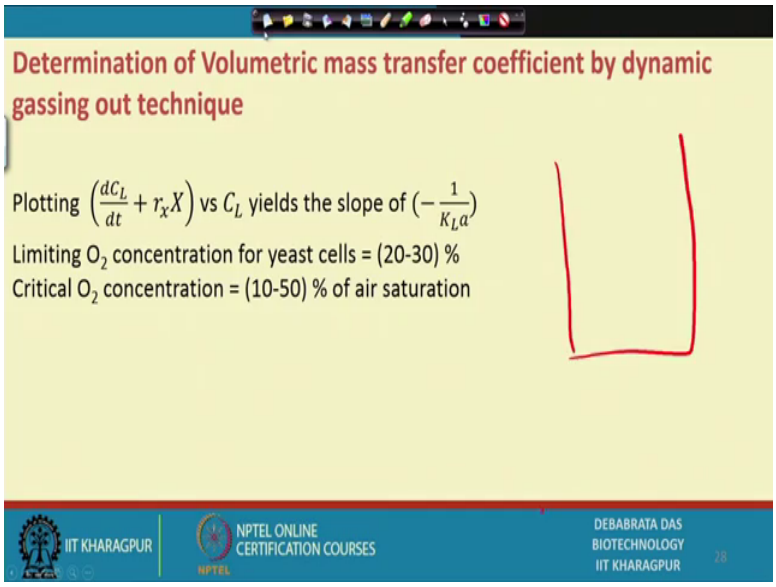

So, suppose you are carrying out the fermenter fermentation am I right your carrying out the fermentation. So, let me let me go to the next slide, then I think things will be very clear.

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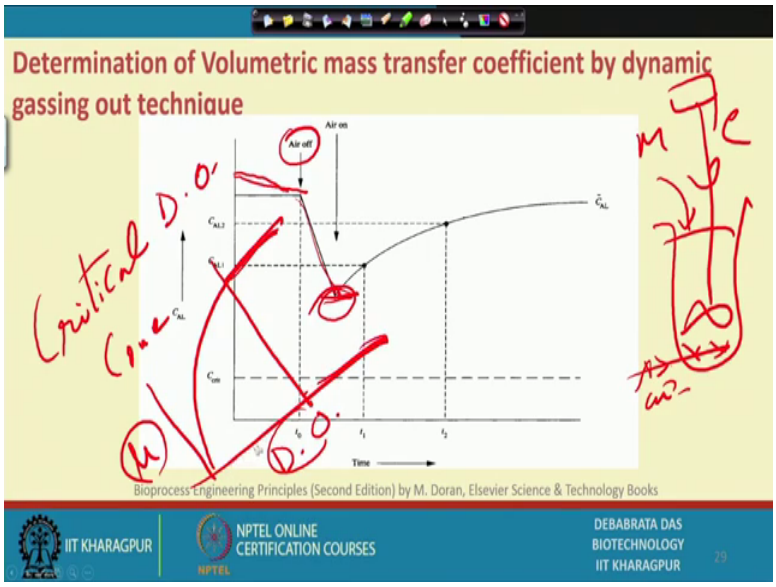


Now, this is the situation that we have suppose in the fermenter whereas, suppose this is the fermenter you have medium you have cell units. So, you put medium, we have cell and this is the stirrer you have am I right. So, this is moving and this is here you sparging.

So, what is happening that as you sparging here. So, initially the oxygen concentration will decrease will decrease and, then attain the Plato and, when this attain the Plato, then we put the Ad hoc, if we put the Ad hoc then what will be your you put this you close you do not allow any air to go inside, then dissolve oxygen concentration will decrease and why it will decrease due to the growth of the organism.

So, and again, where you put the air on here and when you put the air on we should remember, this should be above the critical dissolve oxygen concentration, critical dissolve concentration am I right, why because a what is critical dissolve oxygen concentration, if we if you write D O concentration and mu and it is like this.

Now, above certain concentration this mu is independent of D O and this is called critical. So, this value always should be this side not this side, if it is this side then mu will depend on the dissolve oxygen concentration.

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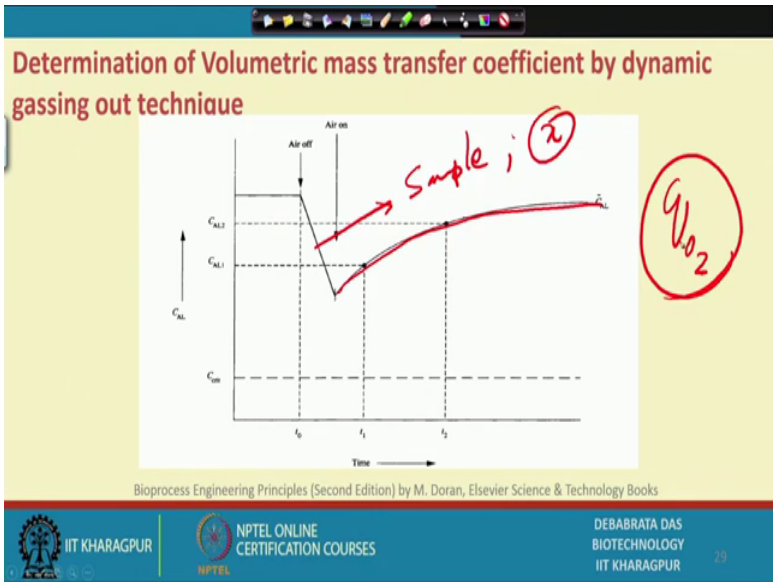


Then what you then you when you when you put the air on then you will find dissolve oxygen concentration slowly slowly increase and attain increases like this.

So, this is the pattern we will get now here a here if you draw a sample and find out the what is the cell mass concentration, then easily you can find out q o 2, what is q o 2 that that you know this specific uptake of the oxygen by the cell you can easily find out.

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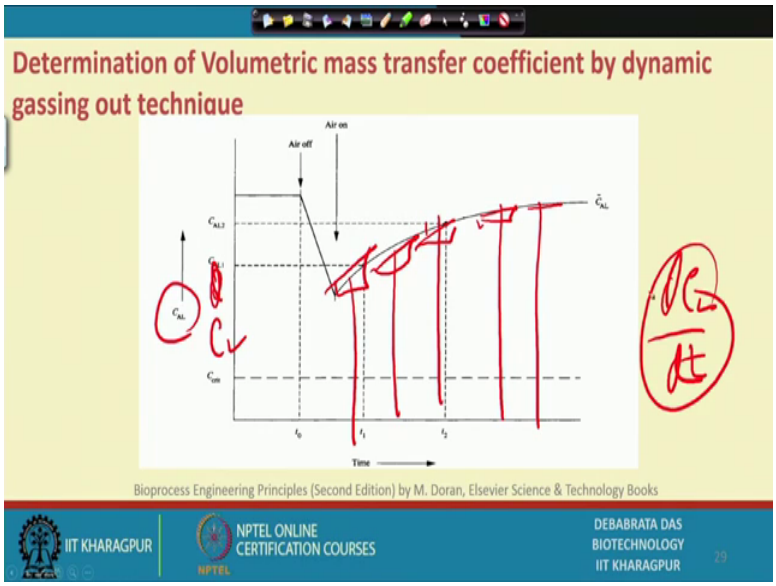


And here actually at different point you can find out that D i D L D C L by d t.

Because the, this is D C L am I right this is C L this is C L. So, you can easily is find out D C L by d t, if you take a slope here n a slope is nothing, but D C L by d t. So, so you can easily find out this slope ok.

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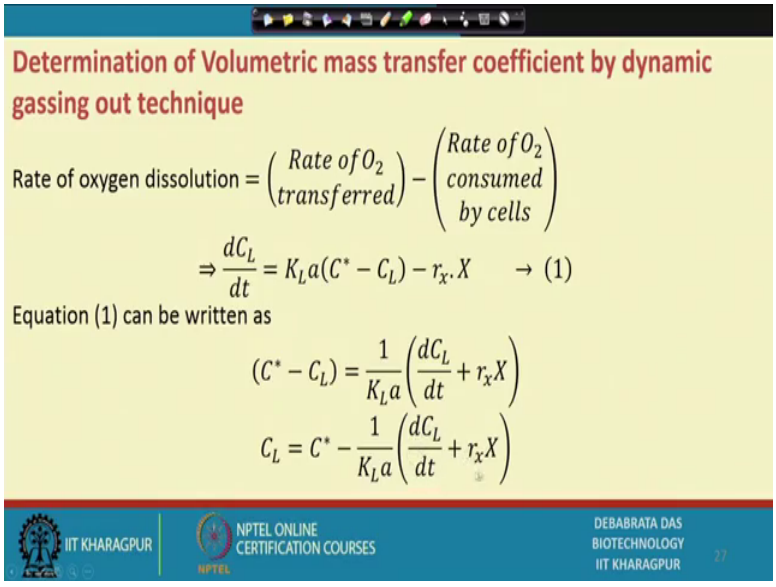


And, then you have seen this equation this, you know this you know if you know everything, then you can you can always plot C A C L versus this at different point, you can plot and then you can find out the K L a value.

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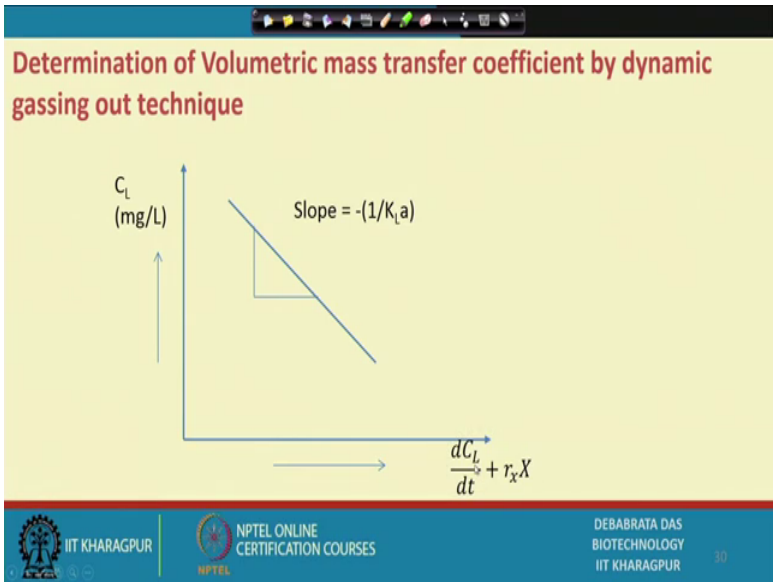


Now, this is exactly how it is done this I told, you this if you plot with respect to C L.

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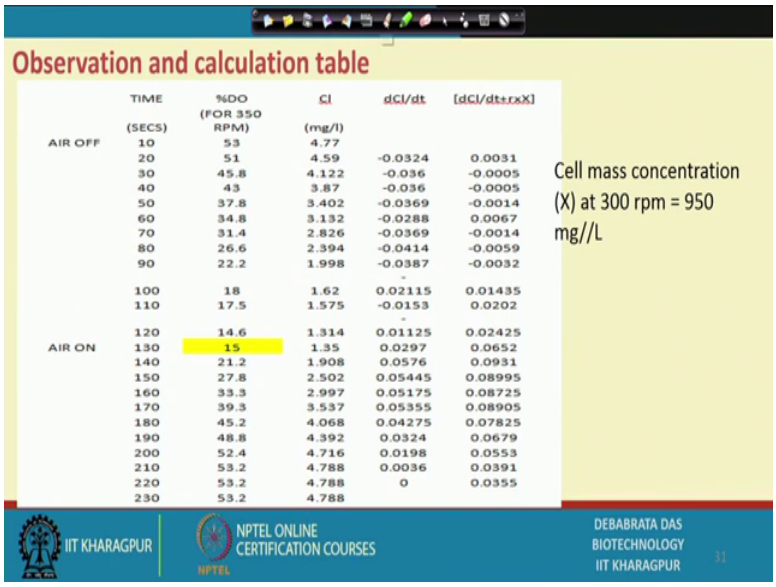


| | TIME (SECS) | %DO (FOR 350 RPM) | Cl (mg/l) | dCl/dt | [dCl/dt+rxX] |
|---|---|---|---|---|---|
| AIR OFF | 10 | 53 | 4.77 | | |
| | 20 | 51 | 4.59 | -0.0324 | 0.0031 |
| | 30 | 45.8 | 4.122 | -0.036 | -0.0005 |
| | 40 | 43 | 3.87 | -0.036 | -0.0005 |
| | 50 | 37.8 | 3.402 | -0.0369 | -0.0014 |
| | 60 | 34.8 | 3.132 | -0.0288 | 0.0067 |
| | 70 | 31.4 | 2.826 | -0.0369 | -0.0014 |
| | 80 | 26.6 | 2.394 | -0.0414 | -0.0059 |
| | 90 | 22.2 | 1.998 | -0.0387 | -0.0032 |
| | 100 | 18 | 1.62 | 0.02115 | 0.01435 |
| | 110 | 17.5 | 1.575 | -0.0153 | 0.0202 |
| | 120 | 14.6 | 1.314 | 0.01125 | 0.02425 |
| AIR ON | 130 | 15 | 1.35 | 0.0297 | 0.0652 |
| | 140 | 21.2 | 1.908 | 0.0576 | 0.0931 |
| | 150 | 27.8 | 2.502 | 0.05445 | 0.08995 |
| | 160 | 33.3 | 2.997 | 0.05175 | 0.08725 |
| | 170 | 39.3 | 3.537 | 0.05355 | 0.08905 |
| | 180 | 45.2 | 4.068 | 0.04275 | 0.07825 |
| | 190 | 48.8 | 4.392 | 0.0324 | 0.0679 |
| | 200 | 52.4 | 4.716 | 0.0198 | 0.0553 |
| | 210 | 53.2 | 4.788 | 0.0036 | 0.0391 |
| | 220 | 53.2 | 4.788 | 0 | 0.0355 |
| | 230 | 53.2 | 4.788 | | |

You will get the K L a value this is our, experimental result in our lab, that we guide out we got this results, the cell mass concentration at 300 RPM.

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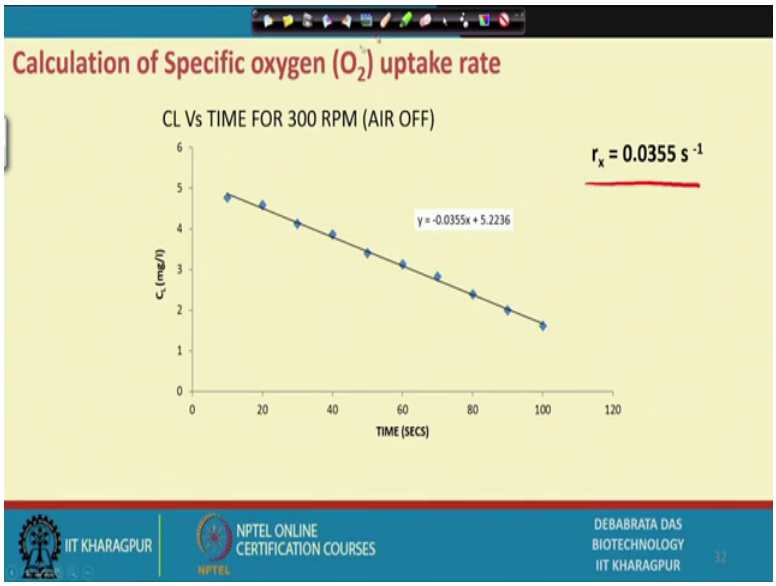


Then we find out the C L how the concentration of C L that decreases with respect to time that, we can find out this is just to find out the r x value, that we can we can find out that specific oxygen uptake by the cells, we can easily find out from this then we plot this.

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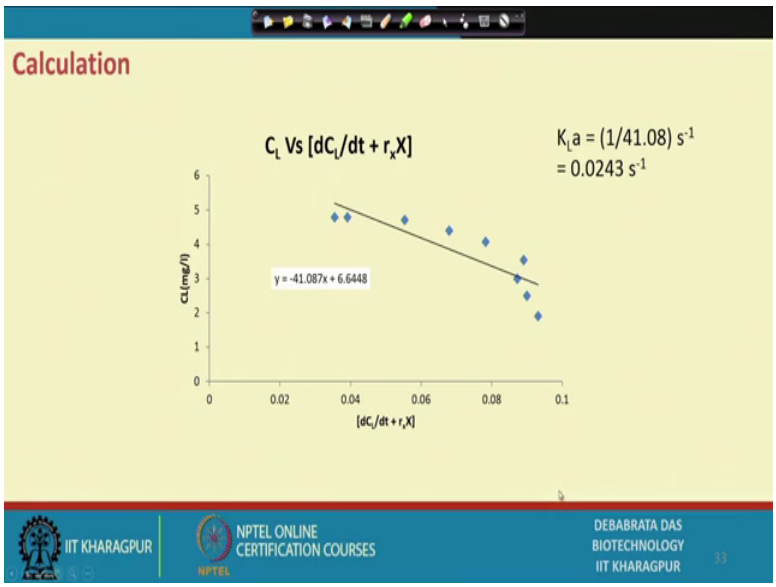


And we can we can find out the K L a value. You can see that we find out the K the value is coming about 0.0243 second inverse.

The in to this particular lecture we try to discuss about the mass transfer and, mass transfer plays very important role as per biochemical industry is concerned because, most of the biochemical process is carried out by the aerobic microorganism, where the dissolve oxygen plays the limiting factor.

So, how the mass transfer take place? What is the mechanism through which the mass transfer takes place? We talk about the gas film we talk about only a liquid film, how across this gas liquid film mass transfer take place, how it can be rate of mass transfer, how we can calculate we find out, then finally, we try to discuss the dynamic gassing out technique through which how we can determine the volumetric mass transfer coefficient.

Thank you very much.