Environmental Quality: Monitoring and Analysis
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Lecture – 48
Interphase Mass Transfer – Individual and Overall Mass Transfer Coefficients

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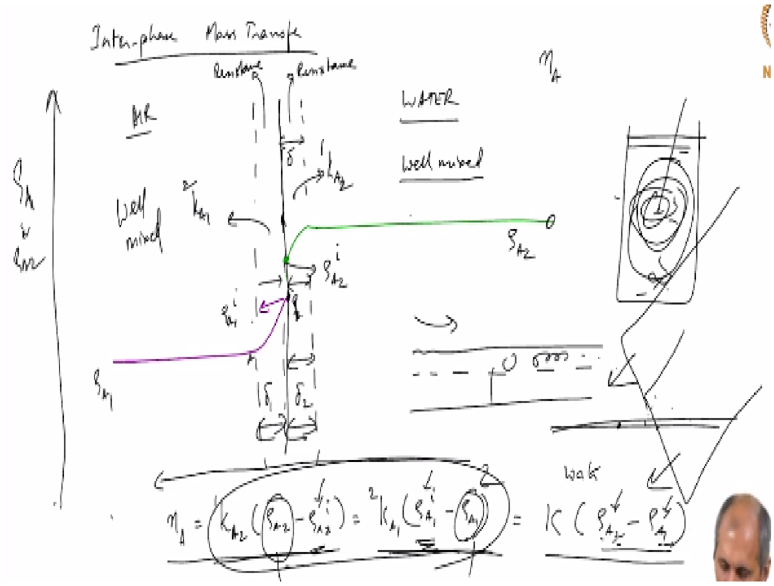

Now, we are going to look at what is called as an interface mass transfer. So let us take an interface, any interface. So this is a very classical mass transfer concept and it is applicable here also. So let us say we have air and water. That is two interfaces and applicable to all interfaces, but you have to understand there are assumptions involved in this. These assumptions are based on what we discussed in the previous slide about the boundary layer and beyond the boundary layer what exist.

So based on what we discussed, if there is an interface, what we are assuming is that there is a region, so let us make this interface bold line. There is a region on the side of the water and on side of the air in which there is a resistance okay. All the mass transfer resistance is in this. **"Professor – student conversation starts."** Why have I separated this with this bold line, anybody? Phase is different. What is different, phase is different. The phase is different. **"Professor – student conversation ends."** So, we talked about this diffusion is happening.

For example, the diffusion here is very different from diffusion here that is one thing. Is there a second reason? So if I want to write down the flux, if I am looking at something say from water is evaporating into air, there is a chemical say benzene is there in water and it wants to evaporate into air okay. Now, based on our discussion, what will be if I plot the concentration, the gradient, what will it look like here? What are the different possibilities? So it is very tricky thing. So first you have to decide.

If I am writing a gradient, I need 2 numbers, right? Two numbers which are measurable, where will I measure the water, I have to measure it somewhere, right, where will I measure it? So, I give you a beaker and say there is benzene in it, solution of benzene and water in the beaker and I am saying right tell me draw this gradient, initial gradient at least, so when the beginning of the process for which I need to know the measurement of concentration of benzene, where will I measure it? I have a beaker, where will I measure?

What is your natural tendency? Let us forget about concentration. Let us say if I ask you to measure temperature, where will you measure? What will you do? You will just put something here, middle, the middle is that enough. If I take a probe and put it here and taking a measurement somewhere here, how many of you think it is okay? When you ate taking any measure, I am sure you have taken measurements of temperature in water in your class somewhere. If I do this, is there any question? What is the question that you will ask?

This just goes to monitoring, we are going back to our other thing also. What is the question that if I report a value here, I just stick it in like this and then I say the temperature is such and such. Do you have any question, doubt? No. Temperature is uniform or not. Temperature is uniform or not, yeah, so why am I doing it here? Why not do it here, here, here, there are 100 places where I can choose to do it. Why am I doing it here? You have an answer. So I can do it at 100 different places, yeah.

So this is I think at the crux of the problem, this definition of the problem itself, the system, see in engineered systems, I can make it, I want to do something, therefore I can arrange the system to be in a certain manner. Because the environment does not care, it will do whatever environment wants and you have to follow it, okay? So this is very important, this is a problem in the environment. So what is the easy way out? If you want to make sure it is uniform, you mix, you mix, you mix and this entire thing becomes uniform.

So it does not matter where I take this measurement. So we start with this system, is there still an interface mass transfer resistance on the water side. So, if I do this mixing, how will I plot this? What will this plot look like? This is the scale of the concentration, it is a concentration scale on the x axis, sorry the this is z, this is the scale. This is the scale of concentration, both rho A1 and rho A2, what will it look like? When it is well mixed, what is it, what we mean by well mix is, uniform concentration which means it will be a straight line okay.

How far will it be a straight line, it will go it will come here and then at this point it will start going down. So, this is the gradient. The reason is we have defined that there is a small region with very close interface where all the resistance to mass transfer exist. So, we are stirring the water. So, if we do not stir the water, what will this look like? It may look like this, this gradient may extend to a long distance, right, but if I am stirring the water, as I stir it very well this things keeps moving. I can keep getting constant value for closer and closer to the interface okay.

So, if I keep on stirring very hard, there is a limit to it, this distance, let us call it as delta, this delta keeps reducing as my mixing efficiency keeps increasing, but at some point it will stop, it cannot go beyond it because at the surface interface because of interfacial tension, you still cannot have, there is friction offered by the other interface there. It will not go all the way to there, you will not get a profile which goes all the way into this thing, very difficult to get this. Theoretically, people have seen that there is a region here, however small it is, there is still a small resistance that exists there.

What we mean by resistance is this fluid does not mix well, it slows down there and therefore the resistance is higher, mass transfer resistance is higher okay. What is the concentration on this side? So, let us say now that we have, we will mark this line, let us say that I have, let me redraw all of this. This is my profile, we have established that this is the profile here, what is it on the other side? So, I will write this as rho A2 and this one, what is this one, I will label it as rho A2, I will call it as rho A2 interface because it is at the interface on the water side.

The gradient is continuing, mass transfer is continuing in this direction. So, what will be the value, what will happen here at the interface? There is a molecule is in the water, it is traveling, it is being brought into near the interface and the interface they travels here and it comes to the interface. Then what happens? It has to go to the other side, it wants to evaporate, so what will be the concentration on the other side? You do not know, but can you make an assumption what can it be?

Truly, we do not know, but there is assumption, can you make an assumption that what could it be at the interface? **"Professor – student conversation starts."** When you have. Steady state. No steady state, system is steady state, we will come to, but more than that. What is the assumption, say if you do not know a concentration of something, what can you assume? Zero. Zero, it is not zero. So there is other thing, this is steady state process. So, there is no this thing of time here. So, material is here, it is going here.

It constantly keep going, continuously going from one end to the other end, so it is a steady state process, which means it is not zero. Equal to that other thing. Equal, equal to the rho A2i. This is the question, is it equal to rho A2i? Let me give you a very simple example. Forget about benzene and all that, I have water. I have water, everything is water right. What is the concentration of water at the interface in the air? Liquid water is standing on interface, there are some molecules of water in the vapor phase.

What is the relationship between this one and that one? Is it the same? What is it? Less than the bulk in the water. Less than, how much, so is there a way to find out. Saturation. Saturation concentration on the water. What is that? Is equilibrium saturated vapor pressure, so what is it? So what are we assuming here? It is in equilibrium. **"Professor – student conversation ends."** So what the best we can assume is that this is in equilibrium with whatever is there on the other side. So it is gas-liquid equilibrium, in this case air-water equilibrium, in case it is Henry's constant in our case, for water it is very obvious, right.

You do not see water is there on interface, what is on the other side is vapor pressure, that is all. Amount of water vapor is changing, but it stops there, it will stop there. So very close to it, we are assuming it to be very humid and this is an assumption we are making, and so this theoretically. The assumption is valid because theoretically nobody knows where the interface is. We are never going to be able to go and measure the interface, it is a theoretical assumption, okay. We do not have any probe that is at the resolution of molecules that we can go and see yet.

We do not have it yet, maybe we will invent it in few decades, I do not know. So, this concentration here is we will mark it on this side, we will call it as rho A21i on the other side of interface and then this also will go like this. So we assume that the air is very well mixed and there is a small region where the mixing does not reach, so we will mark it with a different color, mark it with purple and so this number is 21i and this number here is rho A1. So we are assuming that this is all well mixed.

Now this thickness and this thickness, let us call it as delta 1 and delta 2, need not be the same, will not be the same usually depending on what is there. For example, if you are in a lake exposed to air, lot of wind on the air side, what is on the water side, we are not mixing anything and there is little bit of turbulence on the water side. So, if I have a lake surface, there is a lot of wind, but on the water side, this is pretty much this yesterday we discussed that there is a small region near the surface where there will be some amount of mixing, but this is nothing compared to the amount of mixing happening in the air side okay.

So the boundary layers on the air side and the water sides are very different. Therefore, the mass transfer coefficients are very different, yeah. So here is where we invoke a steady state assumption. So the steady state assumption is as follows. We have nA equals, so the resistance here corresponding to this phase we call it as kA12 and the resistance on this side is kA2, sorry this is kA21 and this is kA12. What we are saying is kA21 into rho A2 - rho A2i = kA12 into rho A1i – rho A1.

Its overall gradient is in this direction, mass transfer is happening in this direction from the water towards air. If we invoke the steady state assumption, this is true. What does steady state assumption mean at the interface? When we say steady stat, if you invoke the steady state mass balance, mass balance rate of accumulation equals rate in minus rate out. Steady state means rate of accumulation is 0, which means there is no accumulation at the interface. Whatever is coming from one side is getting transferred to the other side, nothing is staying at the interface. This is usually true.

Even if not true, we would not know until we actually measure it, but this is very good assumption to make for this particular this thing. There are very few cases where there is accumulation in interface, that happens a little bit, but special cases of that. So, here we have a problem. So, let us say I want to take this, I can use either of these equations to estimate the flux. What it means is that I can either use this the waterside equation or the gas side, either one is fine, right. It will give you the same flux.

It should give you the same flux, but the problem I have now is this number very difficult to measure. Likewise, this number is very difficult to measure. These two numbers are not easy to measure because I do not even know where the interface is. For example if I ask you to measure the interface temperature at air-water interface, I need a probe which is of the same dimension of the interface. So now, I am not even sure how thick is interface. Interface is molecules of liquid and suddenly there are molecules of air, which start moving and about the thickness of a molecule probably, this is my guess okay.

If you do molecular dynamics simulations, they are work like that. They work at the level of a molecule. So, the thickness of the interface is exactly the thickness of molecules. Now, I have to find a probe for that. Now, if this is the interface, my probe looks like this. The smallest probe we can look at is micron, nanometer thickness which is never stable, not at all stable, so thermocouples and all that are thick wires right. This is I am exaggerating this interface. The probe would probably look like this however close I go.

Some of it is measuring the air temperature, some of it is measuring water temperature, I am not really sure. So, I cannot relay on this, forget about measuring concentration at the interface, even worse, you cannot do. When we are talking about gradients in this small region, this region itself is very small, I cannot really get the interface concentration. So, my only best bet is I can measure this very with great deal of confidence and this with great deal of confidence.

So, I will stick to this, but if I stick to this, I cannot, I need another equation where I will say rho A2 - rho A1, yeah, with some imaginary K. This is not a legal way of writing a gradient. You cannot write a gradient in water and air because in between there is an interface and you have a thermodynamic equation in between and that will violate several things. So, we have to express this in terms of taking into account all of these things. So, tomorrow, we will derive that equation.

The purpose of this is I can measure these two in the bulk phases which are well mixed far away from the interface, okay, like this what we are doing here, without worrying about whether it is accurate or not, we are assuming as long as we know it is fairly well mixed and uniform, we will take that as if bulk concentrations, at the interface we do not care. We will not care, but then we have to incorporate this into that somehow. So, there is a derivation of the equation and we will see that tomorrow.