Environmental Quality: Monitoring and Analysis

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Lecture – 45
Interphase Mass Transfer – Application to Environmental Interfaces

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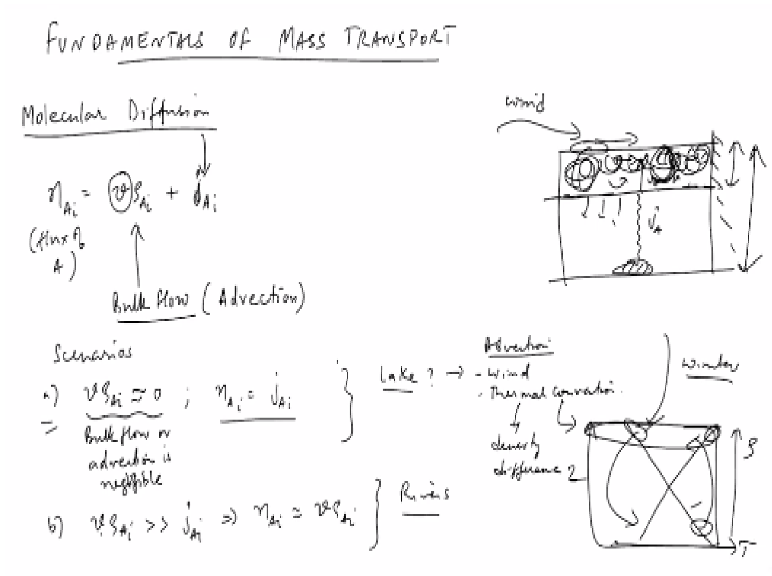


Today, we will continue with the discussion of the fundamentals of transport. So, last class, we had discussed the issue of molecular diffusion, the flux of any species A generally is the combination of velocity and the concentration $n_A = v.\rho_A$. So if you are looking at the concentration, so we will make it a generic thing, so we call it as ρ_{Ai}, so, i is 1, 2 for air or water okay plus j_A.

$$n_A = v.\rho_A + j_A$$

So, this is a generic term for our flux, the molecular diffusion is $j_A$term, $v.\rho_A$ term is called as bulk flow. Bulk flow essentially means there is a velocity that is carrying the concentration wherever is there from one point to another point.

The term j_A is the molecular diffusion term. So, in any physical scenario from the combination of two, you can decide whether the bulk flow ρ_{Ai} is almost zero, negligible, which means there is no bulk flow, there is no velocity. So, this velocity bulk flow is also given another term called as advection. Sometimes, people use advection also as a representation of bulk flow, which means there is a flow and the main mechanism of mass transfer is flow, material being carried by flow. So, if $v.\rho_A$ equals 0, nAi is only due molecular diffusion.

So, there are certain scenarios in the environment where the bulk flow is negligible or advection is negligible and there are scenarios where the bulk flow, ρ_{Ai} is much greater than molecular diffusion, j_{Ai} and this implies that thenn_{Ai} is approximately equal to the $v.\rho_{Ai}$. So, in this diffusion is very small compared to the bulk flow, which is usually true if bulk flow exists diffusion is fairly small and we made that assumption in the diffusion in atmosphere, Gaussian dispersion model also. So x direction, there is velocity, the convection so we are neglecting the diffusion.

So, the convection is much faster, higher than diffusion is, still we are neglecting that convective term, dispersive term. So, if this is happening, then we do not really stop, at all times diffusion is happening, you cannot say diffusion is zero, diffusion is never zero unless there is no molecular motion or it is equilibrium. So, either of these cases should be there for diffusion not to happen, but the bulk flow can be zero or close to zero. So, there are approximations in environment that you can make.

Scenarios:

a) $v.\rho_A \approx 0 \Rightarrow n_A = j_A$, bulk flow or advection is negligible
b) $v.\rho_A \gg j_A \quad \Rightarrow n_A = v.\rho_A$, molecular diffusion is negligible

So, in systems like revers where there is a flow, the flow is significant, this is most likely true. The second case is most likely true. Is there any system that the first one is true? Any environmental system where the first one, where the advection or bulk flow is very small, the diffusion is what primarily drives mass transfer? Can you think of any environmental system? we have talked about lot of cases where pollutant transport is important, chemical transfer is important, so which of the systems where this diffusion becomes the primary mode, which means it is very slow, but that is still there, diffusion is the only method in which chemical can transfer.

Student: lake?

Professor: In a lake, okay. We will come back to that in a minute. Any other system? Can there be bulk flow in lake? I think we discussed this long back. So there is advection because of wind, wind induced circulation can happen and thermal convection can occur.

So, it depends on the depth of the lake and the season. While we are at it, we can discuss it quickly. So, if there is a lake, this is a deep lake, very deep lake, and there is wind and because of this wind there is a shear, there is a force on the water, so which means this top layer of water is moving okay and it induces circulation inside the water as it moves because there is a boundary in the sides. So, this will go here and it will circulate like this. So, there is a region inside the water where this effect of the wind is felt.

So, if this is a shallow stream or a shallow lake, the entire depth of water may be circulated, but if it is a very deep lake, there will be a region below which the effect of wind is not felt. So, if I put a chemical here, it will diffuse, in the bottom part it is diffusion jA, but then here in the top it is jA plus v. So, whatever the v is, so v is now a function of whatever is the wind and how much the wind energy is transferred into the water that will be the corresponding velocity. So, there will be a velocity of this direction so chemical is transported from here to here, it is mixed in this region or there is a rate at which it is going so, yeah. So, this is what is called as a stratified lake. The lake is stratified. So, you have one region of the lake which is well mixed, the other region is not well mixed. So, depending on if I put a chemical on the top surface, this surface chemical will mix well into this region and then it will slowly start diffusing downwards that is possible because the gradient is downwards, yeah.

If you put a chemical in the bottom, it will slowly go to this point and then mix well, this is one. The thermal part of it is true when thermal convection, thermal convection indicates that this mixing is driven by density, density difference driven. So, when will there be thermal convections? The profile of temperature in the water has to be in a certain way. So, if this is a temperature scale and this is the height scale, the temperature has to be like this.

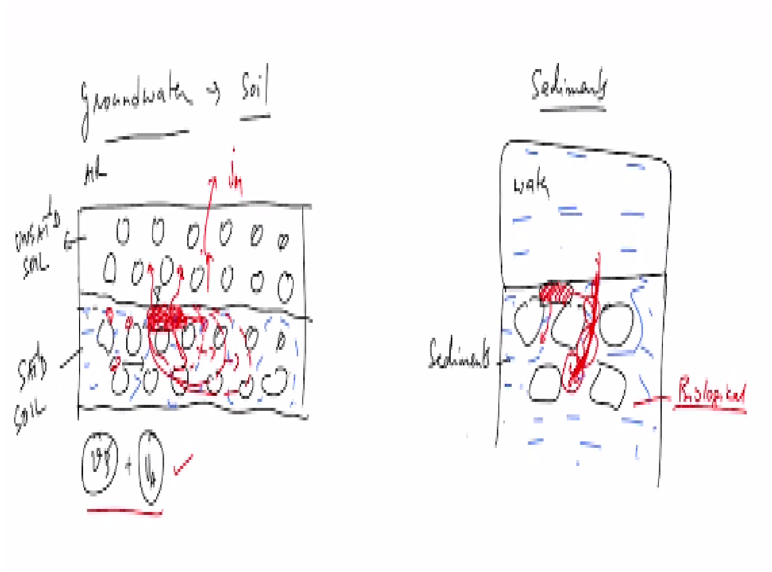
If the temperature is like this, the density is in this direction, this higher density at the top, lower density at the bottom, because higher temperature in the bottom. Lower density in the bottom means this will rise, higher density will go down. When does this happen? This temperature profile is like this is in winter times, the temperature in winters lot of times you will see that the top layer of the water is very cold because heat transfer is occurring in this direction, so heat is being getting lost.

In winter heat is getting lost from the system and it is getting lost from the surface primarily, so surface cools down quickly and then there is a gradient this way and so there is mixing in winter. This is usually not seen in places like where we are, it is usually seen in, there is a certain temperature below which this is very significant and so in those cases, there is churning of the water okay. So, this is thermal case.

So, in the lakes the reason I put a question mark is depending on the location, the season, and the temperature profiles and the depth and all that, it may be diffusion only, it may be diffusion plus convection or it may be convection only completely. So it varies depending on the structure, geometry of the lake. Is there any other system for which this applies? So we have covered what are different environmental systems that you can think of, we go through them one by one. Rivers is done, lakes is done, oceans?

Oceans are also like lakes. So, a lot of it is wind driven. There are also density driven movement in oceans, which are also lateral, not just vertical. Oceans, there are also density driven flows that happen in a larger circulation scale. So, you have this large circulation scale, which induce lateral movement also. It is a large circulation system, which will look like a current, it is a current. So, you see a lot of currents in ocean systems. We have a long current going from several countries, it goes along certain sea coasts.

There are currents which are like revers inside the seas. So, there is bulk flow. Ocean system is fairly well studied. So they are depending on the season and depending on the type of location, which location there are ocean currents also, so they are also moving. So, which other system is remaining? It is groundwater. **(Refer Slide Time: 12:23)**



So the pollutant transport in groundwater. Groundwater essentially means it is soil, we are talking about soil systems. So, soil systems, there is a water table and there is an aquifer, these are porous media, I am exaggerating the thing here. So there is groundwater, this is unsaturated soil, this is air, this is unsaturated soil, this is saturated soil, water saturated soil, so this is full of water. This region is full of water and then if there is a chemical that is sitting here.

This chemical then moves in this direction, so here there is a velocity in the direction of the gradient of the groundwater. Groundwater, most of the times depending on the geology, there is a gradient, there is a flow, there is a pressure difference, and therefore it flows and depending on the packing, the size of the particles and whatever is there, there is a flow. The velocity of groundwater changes, varies from place to place depending on whether there is clay soil, sandy soil and all that, geology of that region matters a lot.

So, there is a velocity, but this velocity is very small. We are talking about groundwater flows, which are similar to if I take a packed bed, if I pack a column full of sand and I add water to it, the water is not going to flow like it is flowing in a pipe, it is restricted because there is a lot of friction and the only pressure difference it has is gravity. So gravity drives the flow down and there is a certain flow rate, Q and therefore velocity. This velocity is very small okay, not like a river, and therefore in these kinds of systems, you have to consider both of these, both at the same time okay.

There is groundwater flow. So, $v.\rho$ and j both of them are important in ground water flow, so you cannot neglect flow or you cannot neglect diffusion also in this case, both of them have to be taken into account. Is there another system where the velocity can be neglected, any other scenario where only diffusion is the predominant mechanism? We are in the soil system, so which other problem in the soil does this correspond to? Liquid film around the soil system.

Liquid film around the soil, so where does it happen? You are right which means there is not enough water for flow. So, what else can there be? Unsaturated zone. In the unsaturated zone why are you worried about mass transfer? Will there be mass transfer in the unsaturated zone, this red chemical can it go into the unsaturated zone? So, where all can this go, say I have some red chemical sitting here, where can it go? Capillary action may be there.

So, all this is capillary action. The groundwater level is after capillary action, it has risen to some distance and it will stop, it will not keep going, it will stop there. After that, can this chemical go? Let us say this chemical sitting here, where can it go? So, we have already said that it can go in this direction, by groundwater flow and diffusion in this direction. So, what will happen is with groundwater flow, you will see that there is a certain concentration like diffusion, plumes that we are drawing, the contours that we draw, here also you will see at different times this front is moving

There is a region where there is concentration is high, slightly higher, even higher, and so and so like dispersion contours we drew, this will also move, pollution will move, but where else can it move? This is moving in the water where it is moving as a combination of these two. Where else can it move? It can move wherever it wants. See we have determined that diffusion occurs because molecules are there, wherever there is a gradient, it will go, okay. Where else can it go?

In the air. It will go in the air, yeah, it can go here. Here, there is no flow of air. Nobody has a pump from here pushing air from here. So in this particular scenario here, we only have diffusion. There is no advection, there is nothing. There is no obvious flow of air through this. So, if you are looking at pollutant transport in the unsaturated zone, it is primarily diffusion in this zone. Similar to this system, there is another system, which is the sediment.

It also looks like this, sediment. There is a chemical sitting here, it can move down because this is all water now, this entire thing is water. So all this is saturated with water, it is just like the groundwater system, but this is also water, but this water may be moving or it may not be moving, it is part of a lake or a river or ocean. So, this part is what we already discussed the water side. In the sediment side, nothing is moving, everything is fixed, there is no flow, usually there is no flow.

So, when chemical moves in here, also it is by diffusion predominantly, there is no advection in this case also. There are a few exceptions in this where you can have advection. These are not general rules; these are very specific cases where you can have advection. One case where you can have advection in the sediment system is there is generation of gas within the sediment and this gas is going out, it is buoyant, it will want to go out. When it does that, there is a velocity. There is a flow in the vertical direction, in this direction okay.

So, it is carrying the chemical whatever is near it along at that velocity. Why is the gas formation in sediments? Why do you expect there will be gas formation inside sediment? Any guess? Some biological reactions. So, usually in this case, this is anaerobic typically and if there is microbial presence here, there are biological reactions here which can lead to the formation of things like methane and all that or some other gas depending on what is there.

This gas will accumulate over a period of time and it will go out. So, this is quite common in or there is any other biological life that is there. You can see that in lakes for example when you go once in a while, if you observe surface of lakes, you will see bubbles coming out, and these bubbles are formed sometimes very deep inside the sediment. So, you cannot observe the sediment, so you cannot see it, but if you go and look at the sediment itself, you can see sometimes bubbles coming out of sediment, they are not very fast, they are very slow.

It is coming out slowly and it accumulates and then comes little by little that is one mechanism by which it comes okay. So, diffusion becomes a fairly important in these kind of systems, where it is a slow process, but it is definitely there and that is why some of these pollutant transport in sediments it comes to the front, people observe it after several decades okay. This is the reason why people call them as historically contaminated sediments because it is happened 20 years ago, 30 years ago, but you are only seeing it now.

So you can also use these diffusion models in order to predict what will happen, something is there now but what is the extent, when will you see an effect and whether in that time can you do something to fix it.