Environmental Geotechnics
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Lecture - 34
Contaminant transport through porous media – 3

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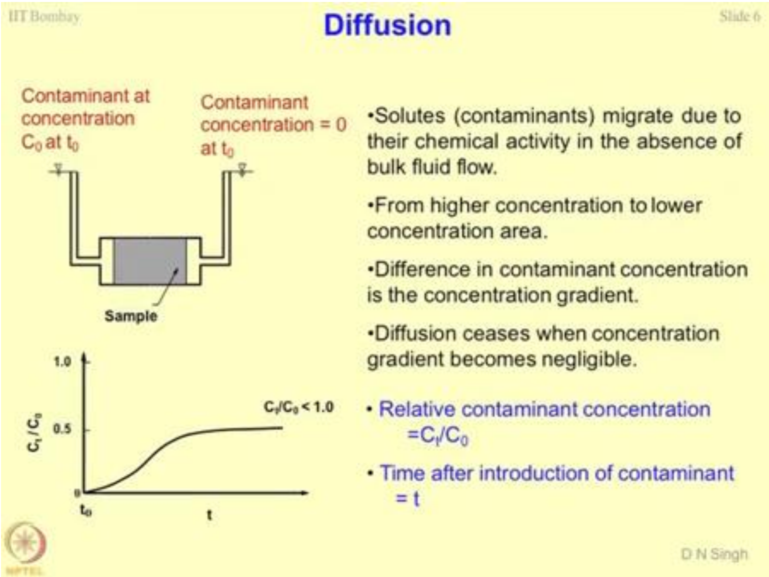

Now, let us talk about Diffusion Mechanism. So, again I will repeat the experiment which I discussed. Till now what you have been doing is you take the soil sample, pack it in a container or a glass tube, connect both the ends to different reservoirs. Apply on this end h_1 and this end h_2; water happens to be fresh water deionized water or Millipore water, so it's a case of simple advection. But suppose if I put the boundary condition that contaminant at concentration C_0 at t_0 time and contaminant concentration equal to 0 at t_0 time is this, clear.

What is going to happen now? Yes, I can create several situations out of it now. By changing h_1 and h_2 I can create advection to take place. By keeping h_1 and h_2 same I can rule out advection; but because of this boundary conditions what is going to happen? Diffusion going to take place.

So, I am going to talk about now the situation where there is no advection taking place as only the diffusion which is going to occur and the boundary conditions have been fixed in such a way that there is no advection taking place, only diffusion is going to take place; clear? Now, this becomes a pure diffusive contaminant transport. However, if I play with the boundary conditions and if I change the boundaries as h_1 and h_2 at the same time there is a concentration gradient of C_0 to 0. What type of contaminant transport this could be? This would be advective-diffusive contaminant transport that means, there is a advection term associated with this, there is a diffusion term associated with this and contaminants are transporting; is this part clear?

So, simple experiment which you can do in your laboratory to determine the diffusion characteristics of the soil; ultimately, what do you get? Ultimately, if I normalized the concentration which I am getting at another end with respect to the initial concentration, now this becomes a normalized concentration and normalized concentration is plotted with respect to time. So, the relationship which you get is known as a break through curve, BTC, break through curve how contaminants are breaking through the porous system. I hope you will agree with this issue that the maximum value of C_t/C_0 can be 1, because C_t cannot be more than C_0.

So, as time increases what happens to C_t? The concentration of contaminant which is coming out at this end will start increasing and the maximum possible situation would be at t equal to infinity where this concentration and this concentration would be same. So, this is where the diffusive contaminant transport will cease; is this part clear? So, C_t/C_0 is the relative contaminant concentration, t is the time after the introduction of contaminant.

Now, let us talk about the definition of diffusive contaminant transport. Solutes or the contaminants they migrate due to their chemical activity in the absence of bulk fluid flow. This is the pure diffusive contaminant transport. But if advection is also there it becomes advective-diffusive contaminant transport. The biggest question is how would you make sure that whether the contaminant transport mechanism is pure diffusive or pure advective.

And I hope you will agree with the fact that no single phase of contaminant transport is going to govern the real-life situation, clear? So, again this subject becomes quite complicated where you have to filter out what fraction of contaminant is migrating through advection and what fraction is migrating through diffusion. In short, what is the combination of advection diffusion is going to control contaminant transport, clear.

But as far as the fundamentals are concerned let us talk about only pure diffusive contaminant transport by ruling out any bulk fluid flow. So, what you have to do is keep h_1 and h_2 same on both the ends so that there is no advection taking place and the concentration migration is only governing the process. When you say saltwater intrusion, though there is a fluctuation in the tidal activity but the extent of the soil mass which you are talking about is in kilometers, so few meters are not going to change much of hydraulic gradient and hence no advection is going to take place it becomes almost a pure diffusive contaminant transport.

So, the attribute is that the migration of concentration is from higher concentration to lower concentration difference in contaminant concentration is concentration gradient $\Delta C/\Delta X$ or $\Delta C/\Delta L$ whatever. Now, this is where the diffusion process will stop. Diffusion ceases when concentration gradient becomes negligible. So that means, that is the most stable state where this C_0 becomes equal to C_t, and C_t and C_0 all values are same. Now, my question to you is why C_t and C_0, suppose if I ask you a question, why they cannot be equal to 1, what is going to happen? What is happening inside the porous media, so that C_t is not equal to C_0. Say even after infinite time.

Student: Some of the contaminant can get trapped (Refer Time: 06:31).

Sorry.

Student: (Refer Time: 06:35).

Well, whatever you are saying is nothing but sorption, clear. So, that is one way to understand that sorption mechanism is always governed by some contaminant transport mechanism. So, you are right, whatever gets trapped in the porous system is not allowing C_t to become same as C_0 even after infinite time. Now, this is also known as sometimes retention capacity of the soil.

Now, there are lot of people who have done consolidation of saturated soils or saturated clays with sodium chloride to obtain diffusion coefficient of sodium chloride. So, you replace the pore solution with sodium chloride solution and perform a regular consolidation test. So, what is going to happen? The excess pore pressures are going to dissipate. So, excess sodium chloride which is present in the soil mass will migrate out of the sample. Where is the maximum pore pressures available in the sample? At the midpoint. So, that is where the concentration should be maximum or less? More, because the concentration gradient is also from midpoint of the sample towards the outer ends, clear.

So, that is another good way of finding out the diffusion coefficients for a soil mass, by performing a slightly modified consolidation test where the soils are mixed with sodium chloride solution. Still you can get your M_v C_v parameters, if density difference is not much of the pore solution. So, these are the ways you can find out C_v, M_v of the soils which are contaminated with soil solutions.

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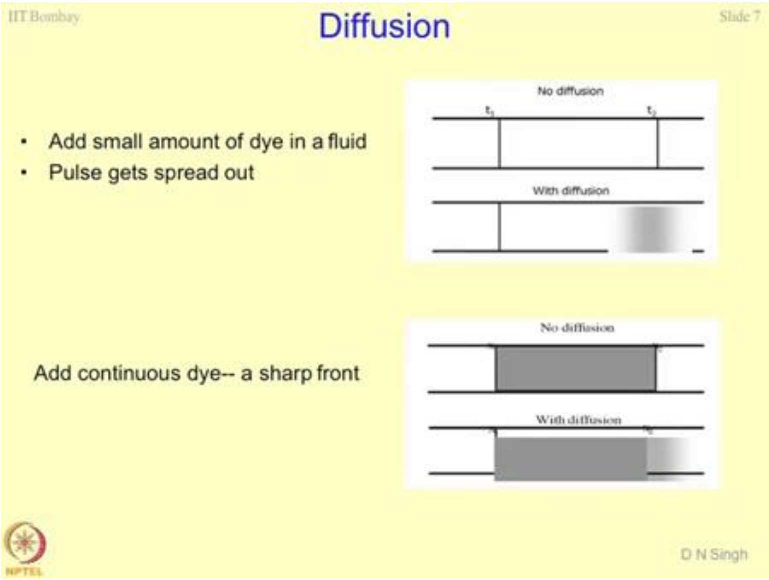

Now, the basic model which is used to understand a diffusion mechanism is add a small dye in a fluid. I am sure during your childhood you must have done this experiment you take some potassium permanganate and drop it in water in a glass of water. So, what happens slowly and slowly? The entire glass water becomes reddish. It is a simple good example of free diffusion.

Exactly, ink also one drop ink if you drop slowly and slowly it disperses but I have used the word here disperses it is not diffusion, clear. It is not a pure diffusion because the amount of energy which you have given to the drop the kinetics gets changed, ok. So, I have used the word dispersion here. While in another case the kinetics is different, but then potassium permanganate goes in the glass, it settles down there, starts diffusing slowly and slowly. So, in this case no diffusion is taking place, but the moment you add some dye what is happening? The concentration of the dye gets diffused in this form.

Now, this is a continuous process. You keep on adding the same concentration or dye what happens. You will find a very sharp front and then this sharp end will simply defuse. This is how the diffusion mechanisms can be studied. Nowadays, lot of researches are trying to use some color codes. It is a very good research topic those of you are working in this area can try; they are using color code traders to study what concentration of colors is migrating from one point to another point.

So, particularly in textile industry when they do coding of colors for different fabrics they use basically laser pointers to determine how dyes concentration changing from one point to another point and that would be the uptake capacity of the cloth for a given color or a dye. So, that is a good example of how diffusion mechanisms can be studied in clothes also.

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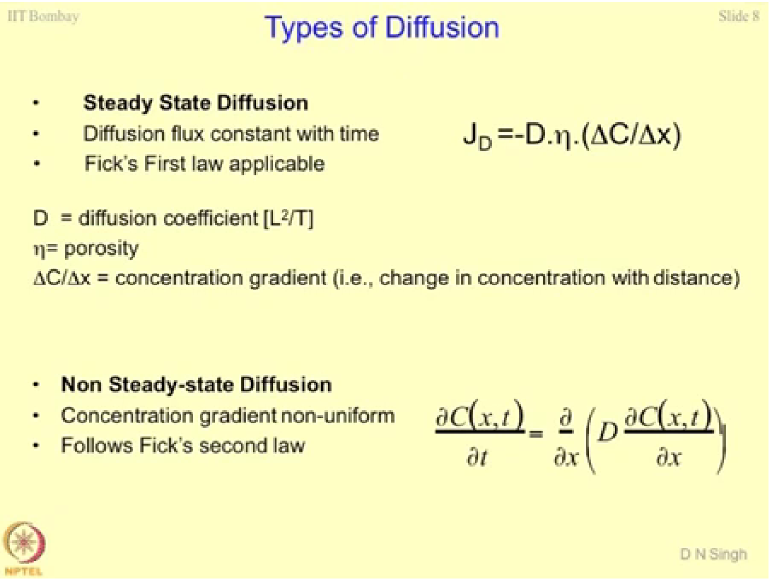

Now, let us talk a bit more you know intricate things of the diffusion, steady state diffusion. So, as the name suggests the diffusion flux is constant with time. So, this is where you can use simply the Fick's first law and the Fick's first law is:

$J_D = -D.\ \eta.\ (\Delta C/\Delta x)$

Where, D is Diffusion coefficient

$\Delta C/\Delta x$ is concentration gradient.

There is a negative sign here, why?

Student: (Refer Time: 11:40).

So, concentration keeps on decreasing, ok, as diffusion takes place. Could you recognize this L square by t thing dimension?

Student: Coefficient of consolidation.

Coefficient of consolidation; so, basically D is nothing, but equivalent to C_v diffusion coefficient. The only difference is there you are talking about the diffusion of water from the pores of the soil, clear; and this water has 0 concentration of the contaminant. So, consolidation phenomena are a very interesting and very challenging phenomena.

The second type of diffusive contaminant transport is non-steady state. So, concentration gradient is non-uniform and this follows Fick's second law. So, what is Fick's second law? This is a very well-known equation $\Delta C/\Delta t$. The way I have written here C is x_t that means, concentration is changing in time and spatial domain is equal to rate of change of C/x that is this is nothing but the concentration gradient in terms of distance.

Now, most of the time D is assumed to be constant, but there could be a situation where diffusion coefficient itself may be changing because of spatial variability. So, from one point to another point to another point you may encounter different type of soils where the D may not remain constant, but for all practical purposes we can say $\Delta C/\Delta t = D.(\Delta^2 C/\Delta x^2)$. So, this becomes so simple second Fick's law which will define non-steady state diffusive contaminant transport.

And as you rightly identified if you replace C by u that is the pore water pressure this becomes your diffusion coefficient. So, there D gets replaced by C_v. So, it is a simple non-steady state diffusion of water which is taking place through the pores of the soil mass; is this clear?

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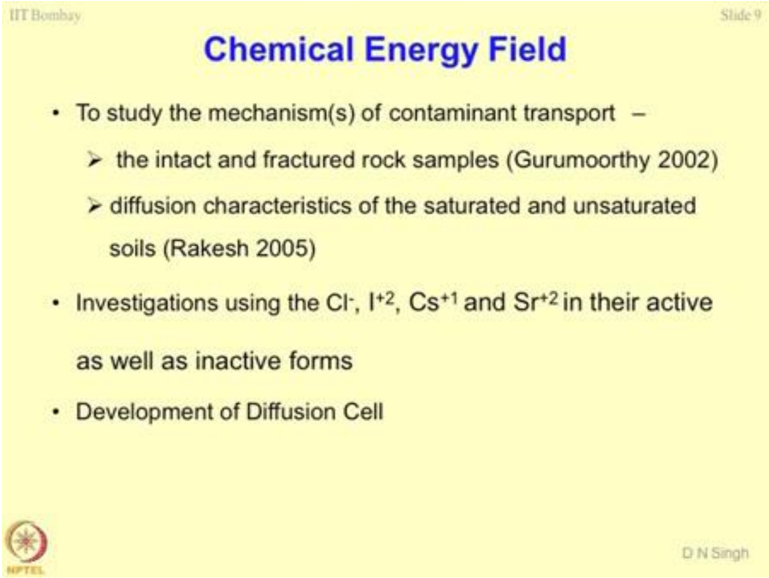

Now, this is where the chemical energy field can be you know utilized very well to map the properties of porous system. So, to study the mechanism of contaminant transport the intact and fractured rock samples were studied by Dr. Gurumoorthy one of my PhD Scholars. And diffusive characteristics of the saturated and unsaturated soils were studied by Rakesh in 2005. And what we did is we did our investigations by using chloride ions, iodide ions, cesium and strontium in their active as well as inactive forms. What are the active forms? Active forms are nothing but the radio isotopes and then this is where we developed diffusion cells. I will show you how diffusion cells were developed.

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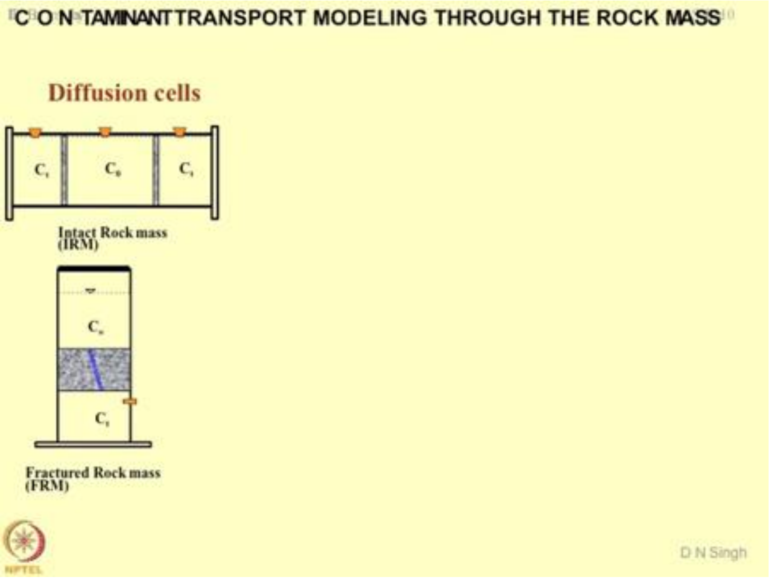

So, to study the contaminant transport modeling through the rock mass this type of a diffusion cell was fabricated, where it has three chambers and there are three top caps. So, in the middle of the chamber you can have fresh water and then these are the two samples of a geomaterial. So, you can take soil, you can compress it and you can make a pallet out of it or you can make a control volume which you can fix in the diffusive cell somewhere here.

The C_t corresponds to, I am sorry C_0 is the concentration of the contaminant and C_t is the concentration of the contaminant which is diffusing into the fresh water. So, this is one of the diffusion cells which can be designed for intact rock mass where there is no fracture in the rock sample. However, if you have a fracture in the rock sample you can stack the water column or a contaminant column on the upside and let it come through the fracture in to the fresh water and from here you can take the dose of the sample every now and then.

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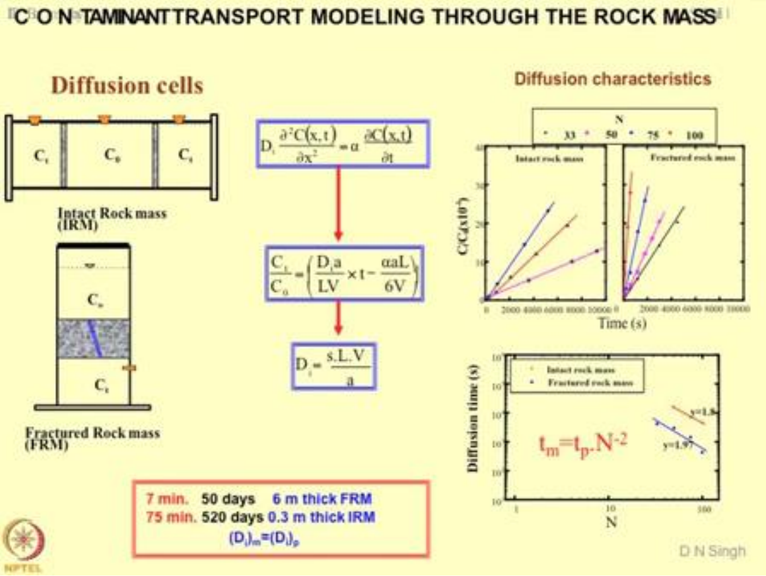

So, this type of diffusion characteristics you will be getting these are known as BTCs, break through curves, and if you plot normalized concentration with respect to time what you will notice is that the concentration keeps on increasing almost straight line with time, we have gone up to almost 1 lakh seconds or more than that and what we notice is a straight line portion. So, we stop the test over here.

So, this type of simple exercise can be done to obtain the diffusion coefficient of the material. That means, if you know the slope of these lines, so the C_t/C_0 divided by time will give you the slope of this curve. So, the slope of this curve is nothing, but s. So, if I multiply this slope with the length of the sample or the thickness of the sample multiplied by the volume of the cell in which the contaminant is stored divide by area cross section of the sample, I will get diffusion coefficient. So, this is one of the ways to obtain diffusion coefficient of the porous system.

Now, if you solve this equation what you will notice is that you get this as the solution, that is C_t/C_0 equal to D_i into area cross section upon L.V volume multiplied by time minus alpha is a coefficient which is known as retardation factor or sorption capacity multiplied by area cross section into thickness of sample divided by 6 time volume. So, a simple interpretation of this curve would be if C_t/C_0 is 0; what is the meaning of this, C_t/C_0 will be 0 at t equal to 0 in initial condition. So, this term becomes same as this term.

So, if I know D_i if I know these are the geometrical properties area of cross section, thickness of sample, volume, certain time what I can get is alpha. So, alpha is nothing but sorption capacity of the material. So, by doing this simple test what you can get is you can get sorption capacity as well as the diffusion coefficient of the porous system.

Now, just to highlight that the importance of this study was that for 7 minutes which correspond to 50 days of centrifugation, a fragmented rock mass of 6 meter could be studied and 75 minutes of centrifugation which corresponds to 520 days, 0.3 meter thick intact rock mass could be studied. And when you go for the modeling of models, what is the feeling? $(D_i)_m$ should be same as $(D_i)_p$, where m corresponds to model and p corresponds to prototype. So, you think that this should be same or it should be different, diffusion coefficient? Why?

Student: (Refer Time: 19:13).

No, any other attempt, exactly, that is right. So, this is a fundamental property of the porous media contaminant system. So, like your C_v remains constant or what you assume is that C_v will remain constant in modeling prototype what you will find out here is that the diffusion coefficient because it is a combination of a porous media and a contaminant that also remains constant. This is part, ok; any questions or doubt. I just very quickly shown you that how these parameters can be estimated by doing simple experiments.

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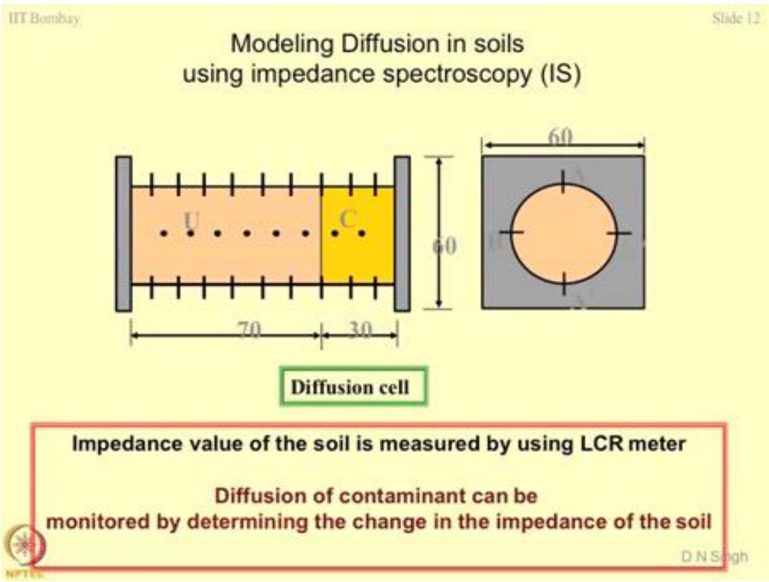

Similarly, this part also I have discussed earlier, that if you want to find out the diffusion coefficient from the soils which are unsaturated, the best way is you take a diffusion cell put lot of electrodes across this and then if this side happens to be contaminated soil and this happens to be uncontaminated soil if you keep it on a horizontal platform there will not be any advective flow.

If you keep it vertical, what will happen? The top portion of the soil will start flowing out water into the middle portions because of gravity. So, if you just place it on a horizontal plane the contaminant will migrate from right-hand side to left hand side. So, this is how the diffusion cells can be utilized for studying diffusion coefficients in soils. These tests take lot of time and most of the PhD thesis have come out of developing the methodologies and interpretation methodologies. This work was done by Doctor Sudeep who is now a faculty member at IIT, Guwahati for his PhD thesis.

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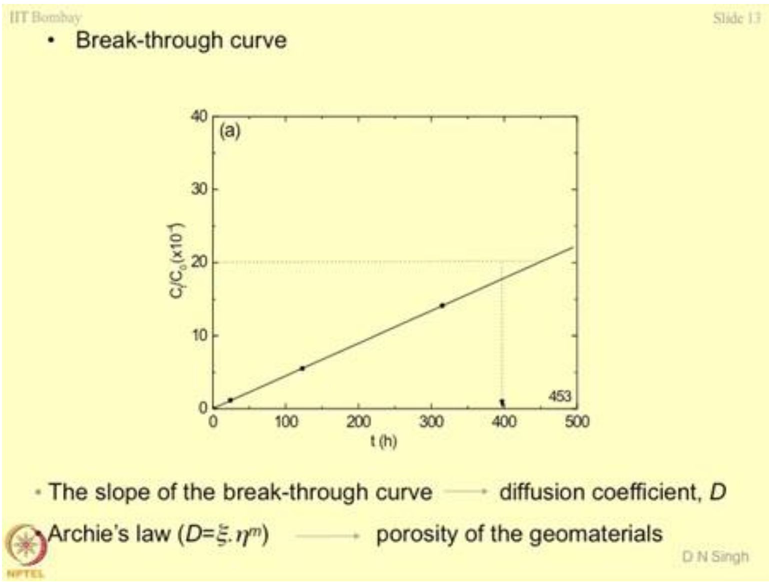

So, just to wind up today's thing this breakthrough curve which is nothing but a relationship between C_t/C_0 and time in most of the situation this could be a straight line. We assume consider this steady state portion of the graph and for a given time you can work out C_t/C_0. So, if you know the initial concentration of the contaminant you can multiply it by C_0 and you can get the C_t value. So, the slope of this curve will always give you diffusion coefficient.

There is another interesting thing those of who you might get a chance to work in this type of research areas and know that there is some law known as Archie’s law. Archie’s law is a very famous law, you will find everywhere. Where else you find Archie’s law? In science and technology, in thermal sciences, in electricity also, conductivity, yes. So, basically the terms may change here the diffusion coefficient is equal to some constant multiplied by porosity power ten. Now, this is what is known as a generalized Archie’s law for diffusive contaminant transport in porous media.

So, the beauty is if you know the diffusion coefficient you can work out its porosity. You need not to have any of these instruments which we have talked about earlier or you need not to rely on these instruments to get the porosity. Vice versa, if you know the coefficients eta and m and if you know the porosity you can work out this diffusion coefficient. So, both the ways you can use this in studying the contaminant transport through porous media.