Flow Through Porous Media

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Lecture - 01
Introduction (Definition of Porous Media)

I welcome you all to this course on Flow Through Porous Media. My name is Somenath Ganguly. And today first I am going to talk about this introduction to the course Flow through Porous Media.

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Here, I am going to discuss briefly about, you know definition of Porous media; the essential you know characterization parameters of a porous media, I mean, what constitutes a porous media? When we call a media to be a porous media? And what are the you know applications that comes under these flow through porous media?

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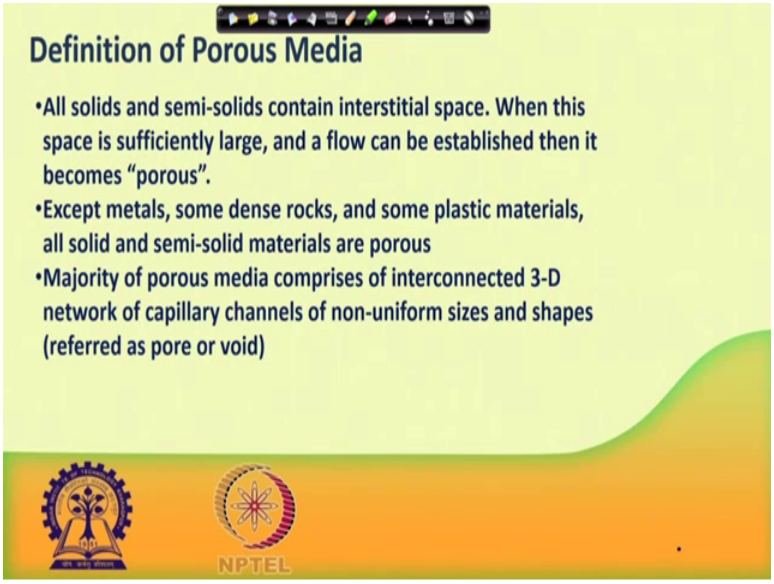

We all know that, everything around us is porous; the human body is porous; the mother earth is porous. So, this porous media or how a transport process takes place inside a porous media, how a fluid flows through a porous media is extremely important.

If we want to know ourselves; if we want to know how we behave, how different materials different fluids. When they travel through the human body or when they travel through mother earth or when they travel through any such you know simulated material for that any such material that simulates mother earth that simulates the various needs, it is that simulates various engineered that that simulates various items various engineered items, where we have this flow to porous media. This is this is a very important concept.

So, what we see here is that, all solids and semi solids contain interstitial space; when this space is sufficiently large and flow can be established, then it becomes porous. So, essentially all solids and semi solids everything we see around us they have interstitial space. However, when we establish a flow through them, then we call them a porous medium. So, except metals some dense rocks and some plastic materials all solid and semi solid materials are porous by the definition that I gave just now.

Majority of porous materials comprises of interconnected 3D network of capillary channels of non uniform sizes and shapes. So, that what we refer these as pores or voids. So, essentially this is a this porous media with it is pretty much you know ubiquitous; we have it everywhere and we need to understand the flow through porous media for various reasons; be it obtaining some resources from mother earth or be to understand, how when we when we when we when we take a drug, when we take a medicine, how that medicine travels through human body.

So, it could be it could be due to various reasons; apart from various engineered applications we have; for example, absorption column or membranes or the reverse RO unit that we use for separating dissolved solids from water. So, those are engineered items, but apart from that there are various reasons for which, we need to study the porous media and flow through porous media.

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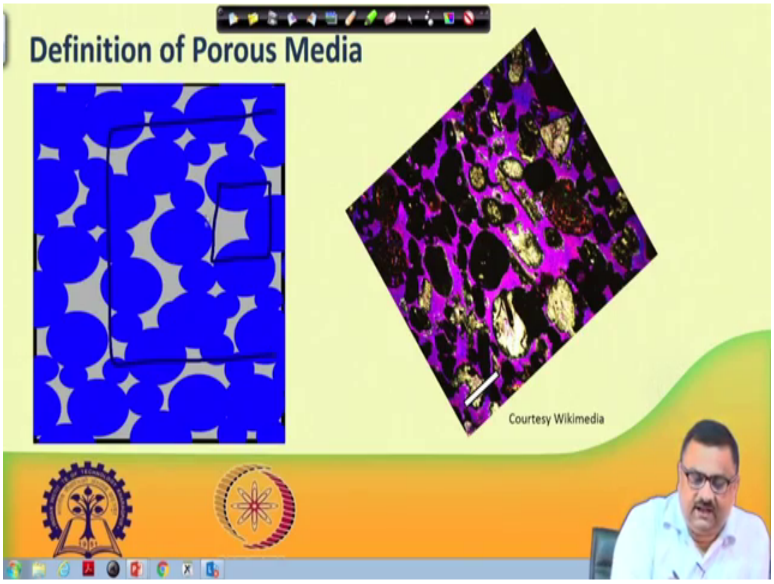

So, if we try to look at, how the porous media looks like, this is basically, some basically schematic picture of how a porous medium will look like., We see here various grains and there are some void spaces within. So, I can see here, these blue colored, blue colored spheres; these are basically, so to say grains and we can see some empty spaces within, which we call interstitial space or void space.

Now, if we take a; if we cut a section and take a top view we can see there are pathway, which is reflected on the right side on the right figure; which is reflected here as the void space through which the fluid can travel.

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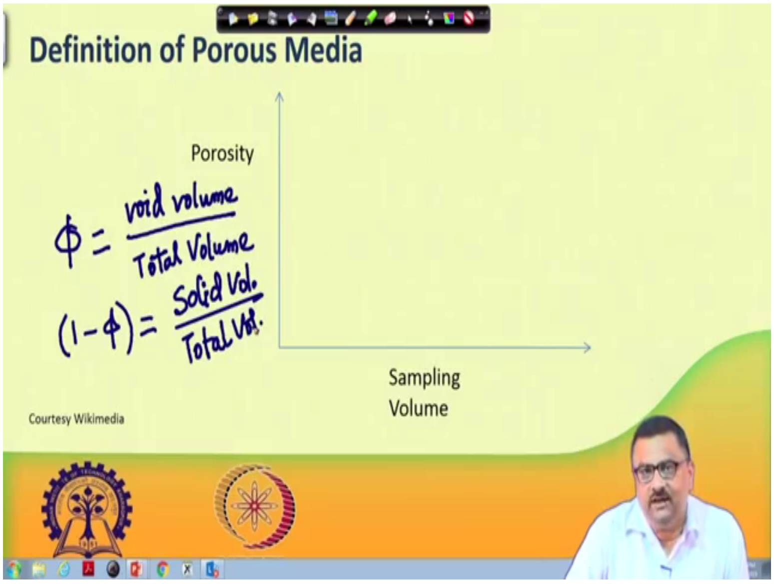

So, here the first term that, we define for a porous media is called porosity. So, porosity is essentially the volume of the void space divided by the volume total volume; that means, porosity we define as void volume divided by total volume. So, what that means is that if the total volume of a porous solid porous material if the total volume is 100 milliliter out of that, if 20 milliliter is the void volume and 80 milliliter the rest of it is the solid; then, we can say that, the porosity would be here 20 divided by 100, that is equal to 0.2.

Now, when it comes to this definition of porosity; so, one can see that, it is first of all if phi is called the porosity then, we can write 1 minus phi. So that, gives me the solid volume; that gives me the solid volume divided by total volume.

So, basically this, the 1 minus phi 1 minus porosity, that gives me the solid volume by total volume. So, now this porosity, when we define we are assuming that this porous medium is completely homogeneous. So, when can we define this porosity this way? See, it depends on what kind of sampling volume we have in mind.

For example, if I go back to my earlier slide; we can see here, that we can pick up a sample volume, the sample over which we measured the porosity; the sample over which we can measure the porosity; we can take the sample volume of size of this much or we can take a sample size of this much. So, this is let us say, I have a sample volume here and you have a much larger sample volume here, over which we measured the porosity. Now, if we try to go and measure the porosity this way.

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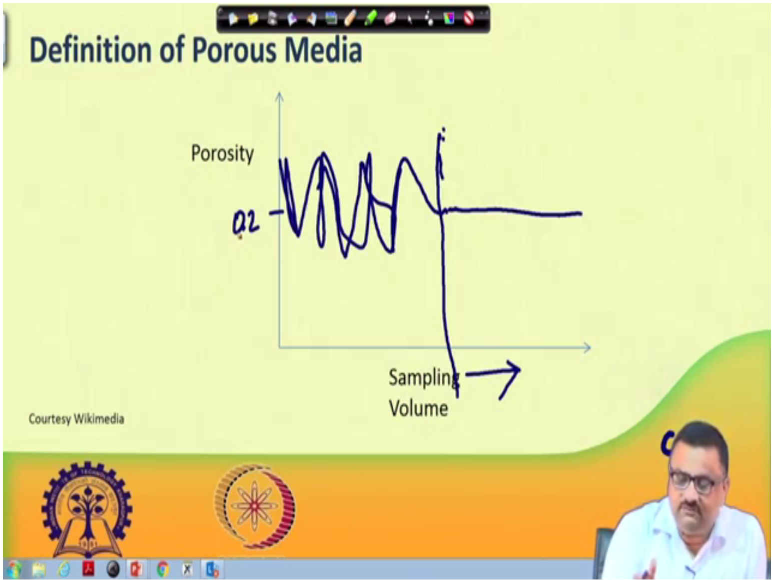

Then, when we discussed about this porosity? We have a something; we have we have the sampling volume; so, we can choose a sampling volume which is large or we can choose the sampling volume which is small.

What you would see in these case is, when the sampling volume is large we will consistently see a porosity, which is let us say, you said 0.2 right 100 milliliter out of that 20 milliliter is void volume and 80 millimeter is the solid volume. So, you will find that, it would be consistently it is coming to about 0.2; porosity is coming to 0.2, but if the sampling volume is much smaller then, it could be the major part would be the void and there would be a small part in the solid.

Or at some other location you will find it is mostly solid and very small amount would be the void; in that case you will find that, below a threshold value of the sampling volume you will find that the porosity would be; porosity would be all it would follow a random you know randomly it will vary depending on the sample volume.

So, as long as you work your; see in whenever you draw a continuity in a porous medium for any flow equations you have to draw a continuity. So, whenever you want to develop a continuity equation one (Refer Time: 09:01) one thing you assume there is that, either differential volume on which you draw the continuity, that has to be greater than this volume ok.

If it is less than this volume; obviously, the micro level you know changes are to this porosity and accordingly the micro level changes in the velocity and everything that would feature. So, one has to go for discrete modelling, one has to follow every you know nook and cranny of the pores and how the velocity changes.

On the other hand; if, the sampling volume is larger than these or when you choose the differential volume on which you draw the continuity equation; when you choose a volume which is larger than this; larger than this sampling volume; when it is larger than these threshold value. At that time you will see that, you can draw you can consider the velocity to be continuous you can consider these material to be homogeneous this the porosity, when it comes to porosity you can treat this material as homogeneous as it is shown in this figure 0.2 as the porosity.

So, when we talk about continuum, when we are going to apply you know equations of continuity in flow through porous medium; one basic assumption we make here is that, my reference, that differential volume on which were doing it is sufficiently large. So, the sufficiently large; that means, larger than these threshold value. So, I have already defined porosity phi, which is void volume divided by total volume and you can write 1 minus phi as the solid fraction. So, one is the void fraction another is the solid fraction. Void and pore these are these two terms are used interchangeably in this course.

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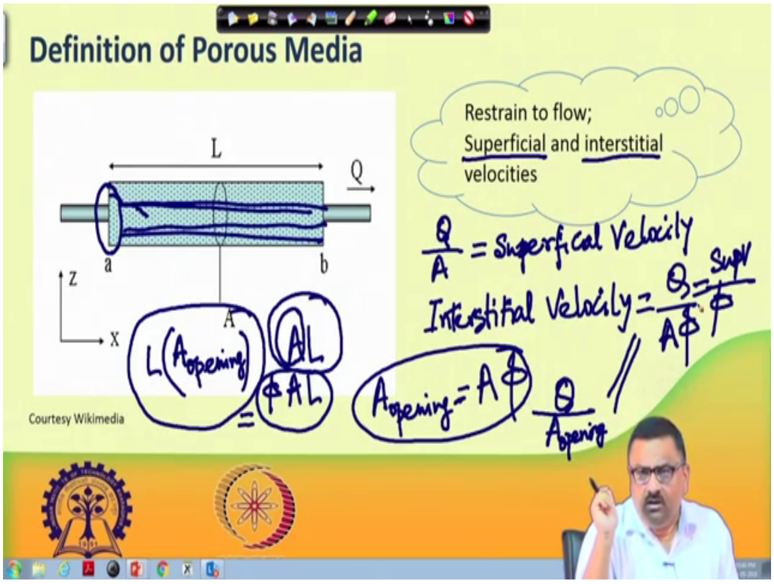

So, now here, we are trying to see that, when the flow takes place what are the basic methods that we can apply to define such kind of a flow? So, one thing is for certain that, there are these solid fractions and which will impose certain restraint on the flow so that means, if I have these as the porous medium, if I have this porous medium and this has a cross sectional area A. So, fluid is flowing through this and then, it is entering into the porous medium and then, the flow is taking place through this cross section.

Let us assume for the time being, that the flow is one dimensional; that means, flowing is flows unidirectional from left to right. Let us say, the flow rate is given here as Q and the length of these porous bed is capital L, cross sectional area the overall cross sectional area is capital E.

So, when a flow takes place. Let us say, it has a porosity of 5, when a flow takes place; there would be some resistance there would be some restraint to flow and we need to characterize these restraints somehow.

Now, in this context first of all, I would like to point out these superficial and interstitial velocity; the concepts of superficial and interstitial velocity. See, I have a flow rate Q and I have an overall cross sectional area A. So, one velocity could be simply Q divided by A. So, this is referred here as superficial velocity. So, this Q divided by A is a superficial velocity; that means, I am treating this whole porous bed as a black box; the some flow is going in that, flow rate I know Q in. So, many meter cube per second let us say and I have an area overall, that from outside I can see the area of that black boxes cross sectional area is capital A. So, in that case, I can always say, there is a velocity which is superficially; I can see the velocity is Q divided by A.

Now, there would be another velocity which is important in this context which is the velocity which is actually there. The velocity which is actually the fluid, that is flowing through these you know this pathways; that will have a much higher velocity; you must appreciate. Why, because this superficial velocity assumes that the total that overall area A as if this entire area is available for flow.

But actually you have the area available for flow, which is much less. In fact, I can see here these porous bed it has a cross sectional area A out of which a fraction of that is available for flow; rest of it is all blocked by solid. So, in that case, the actual velocity that by which, the fluid is flowing through these interstitial space would be different and that, velocity is referred as interstitial velocity.

So, now what is the relation between the two, interstitial velocity and superficial velocity? The interstitial velocity; one it typically referred these as, the superficial velocity. And then, they divide this superficial velocity by the porosity, these gives the interstitial velocity. So, the superficial velocity is smaller interstitial velocity is higher. How do you arrive at these Q divided by A phi? What is the A phi? What is the rationale behind this? The rationale is something like this that, if I think of these area A, that we are talking about; this is the area A through which the flow is taking place right.

Now, out of this area A, let us say, these porous medium; I approximate these porous medium as some bundle of capillaries ok. So, these capillaries they will have length L. So, they will have length L. So, then to overall area is capital A. So, what is the total volume? Total volume is A into L, that is the total volume and what is the void volume? Void volume is phi into A into L. So, this is the void volume ok.

So, now we have these capillaries. Now, if I try to find out; out of this total area A; let us say, the capillary is having opening total opening of A capillary. Let us say, I have or we can write these as A opening. So, what I am trying to say here is that, I have a total area A, out of this total area a apart is A opening through which fluid can flow; because, I have bundle of capillaries running like this; I have bundle of capillaries running like this.

So, I have some A opening amount of area, which is open to flow and I have the other part of the area which is blocked; because, that is the solid space.

So, what is the volume of the capillary in that case? Volume of the capillary would be A opening multiplied by L. So, A opening multiplied by L would be the volume of the capillary. So, A opening multiplied by L is the volume of the capillary; AL is the total volume and also we know that, phi into A into L is the void space.

Now, if we assume that, this porous medium is comprising of a bundle of capillaries, in that case this AL into a opening, that has to be equal to phi into L. So, these two term, they have to be equal right. So, what is then in that case A opening? A opening would be equal to; A opening would be equal to, total area multiplied by porosity; because, the L will cancel out.

So, now if we try to find out what is the interstitial velocity? What is interstitial velocity? Total flow rate Q divided by; total flow rate Q divided by the area available for flow; that means, A opening. That is A opening. So, total flow rate available for, that the Q is of total flow rate divided by A opening, which is the area available for flow. So, Q divide by A opening and A opening is already we have shown here, that A opening is A multiplied by the porosity. So, that is why, we write Q by A opening is basically, equal to Q divided by A into phi; because, A opening we have just demonstrated that, is equal to A into phi; so A into phi. So, that is why interstitial velocity is defined as Q divided by A into phi.

So, essentially superficial velocity is. What is the relation between superficial velocity and interstitial velocity? Interstitial velocity is equal to superficial velocity; superficial velocity divided by the porosity. So, this relationship we can see here, that this is the relation between superficial velocity and interstitial velocity.

So, I must point out at this time that, both these velocities are important to us and most of the time we would be working with this superficial velocity and in this context very soon I will introduce an equation and a form of equation which is called Darcy's law.

So, in Darcy's law it works with this superficial velocity and the superficial velocity is ,I mean down the line you will see, that there would be a tremendous use of superficial velocity wherever we will we consider continuum in the flow. So, we can write it in terms of superficial velocity just like any equation we had written earlier in fluid mechanics.

So, now, you understand that, there would be restraint to flow and because of these restraint to flow, we can write these flow equations in terms of superficial velocity and interstitial velocity. There is some reference, that the superficial velocity lot of times are referred as Darcy velocity also, in many references you will find, that supervision velocity is referred as Darcy velocity.

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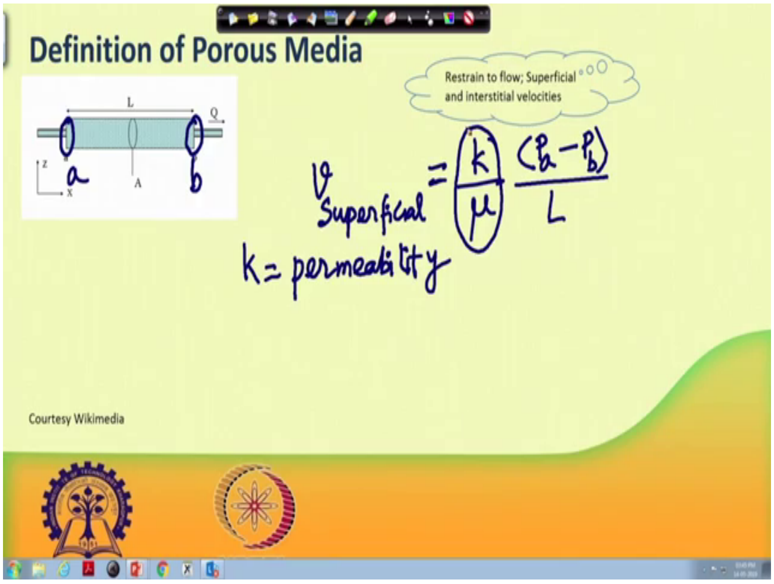

So, with this understanding; I would like to go to the restraint to flow we have already talked about the superficial and interstitial velocity.

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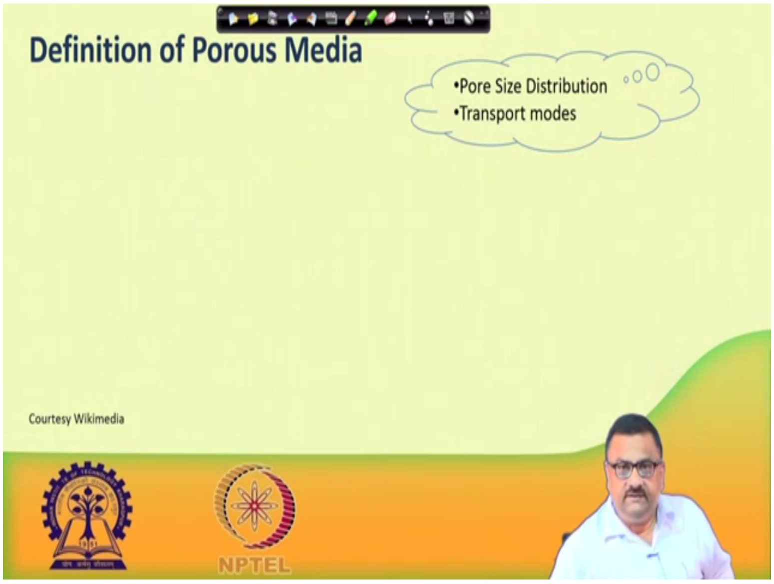

Next, what we are interested in is pore size distribution and transport mode. I think before that, we must at this time point out that, what we learn about is Darcy's Law? Let me quickly give a glimpse of it. I in the next lecture, I will follow this up. The Darcy's Law says that, the velocity is equal to; velocity superficial is equal to k divided by mu into P a minus P b divided by L.

So, the superficial velocity is equal to k; I have not defined what is k? Mu is the viscosity of the fluid. Viscosity means, water has a viscosity of 1 centi poise; 1 poise is gram per centimeter second. So, viscosity of water is 1 or near, I mean it depends on the temperature close to 1 centipoise.

k is referred here as, permeability; k is equal to permeability; k is called permeability and P a minus P b, that is the pressure difference. We are talking about, a is here at this edge and b is here at this edge. So, this is b this is a. So, P a minus P b, the pressure difference. This, you know somehow we can we can intuitively understand that, it is basically, it is following some kind of a cause and effect type relationship. I have a pressure gradient. So, that is why, I am having a flow P a minus P b. P a is on the higher side, P b is on the lower side. So, P a minus P b there is a pressure difference and because of this pressure difference, there is a flow happening.

So, because of that reason, we are having a velocity here and this k by mu term, I can understand P a minus P b by L is so called pressure gradient. In case of heat transfer we have temperature gradient. In case of current flow of current we get; we have these voltage gradient. So, there we always have this kind of cause and effect relationship here, there is a velocity of fluid; why because, a pressure gradient exists, P a minus P b by L that is the pressure gradient.

Drop in pressure P a minus P b overall length L P a minus P b by L is the pressure gradient and that, has to be multiplied by some kind of we have you know voltage current and voltage there is a resistance term ok. In case of a heat transfer we have a thermal conductivity term. Similarly, for this flow through porous medium we need a similar term, which defines the resistance to flow and this k by mu or k in particular is; basically, permeability is inverse of resistivity. So, we need a term like these. So, this equation makes perfect sense to us as a cause and effect type relationship. I need a pressure gradient to establish a flow through porous medium.

I will continue with these with these section on definition of on this definition of permeability in my next lecture. I will introduce this permeability in or I will introduce the flow equation in differential form and I will show, how this permeability what are the units and what are the considerations you have with these permeability. So, I will continue with the next lecture.

Thank you.