Flow Through Porous Media
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Lecture - 03
Introduction (Applications)

I welcome you once again to this course on Flow Through Porous Media. We were discussing about this we are on the Introduction section, we are discussing about various key features or key characteristics of flow through porous media and what are the; what are the areas where you need to look into if we try to theorize flow through porous media. So, now what I am going to discuss about is the applications that we have here in mind.

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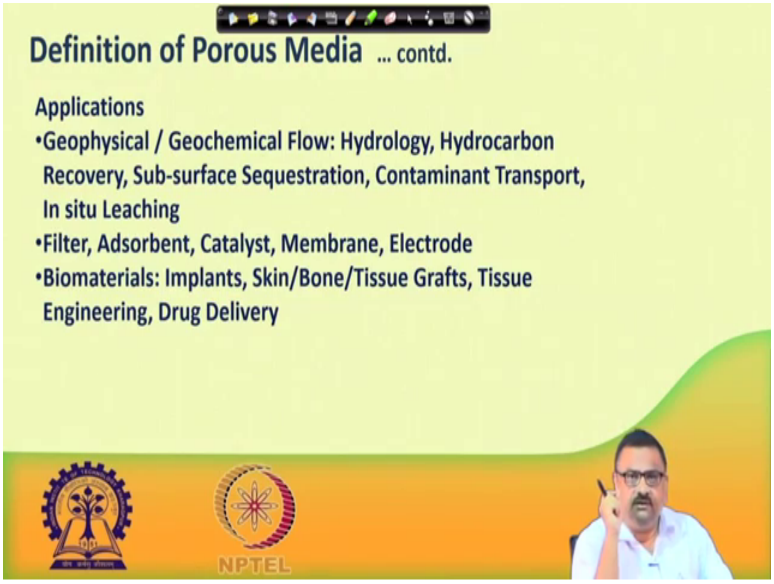

So, here we have the applications if I try to look at it very quickly, one is I can see geophysical or geochemical flow hydrology, hydrocarbon recovery, sub-surface sequestration, contaminant transport, in situ leaching. So, lot of these terms they are related to you know geological or geophysical you know reference ok. These are; these are; these are basically related to extracting, some you know useful materials from underground reservoirs underground from mother earth basically in various forms.

And also sequestering whatever we do not need and whatever we cannot keep on the surface of the earth, we are putting it below the surface. So, these so first section that first bulleted point is mostly the mostly about reservoir scale flow of porous media. The second bulleted point I can see here is filter, adsorbent, catalyst, membrane and electrode. There could be more such examples I mean I just picked up some of them here. These are some of the engineered materials that we are using every day in our in a very traditional sense, we have been using for some time.

These materials are extremely important to us as engineered material. What are the uses of them, I will discuss this in a moment. And the third category that I put here is biomaterials which is basically implants that is put inside human body for various purposes. Then grafts; grafts in the form of skin graft, bone graft that means some additional appendages or someplace where there is a loss of tissue material, the grafts are applied, so that the tissue can grow around them. Then this tissue engineering process which is the biomaterials in this biomaterial area we have these this subject called tissue engineering where this flow through porous media is extremely important and also drug delivery.

So, these are some of the applications that I am going to touch upon; obviously, there are more applications as I pointed out that in the beginning itself that every application will have some amount of flow through porous medium or transport to porous medium in some form or the other, but these are at least this came to my mind when I was putting together this slice that much I can say. There are more and more applications possible. So, when it comes to geophysical or geochemical flow or hydrology, let us first look at up to the slide on hydrocarbon recovery.

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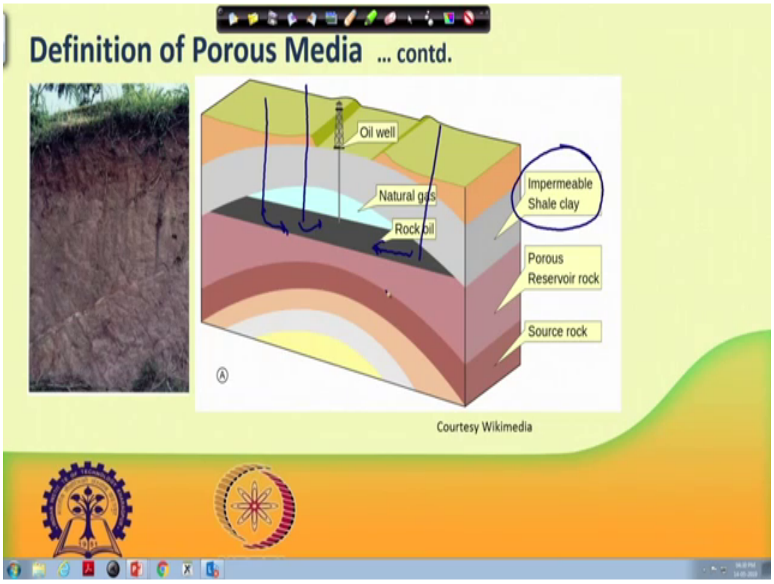

What we have here in this picture is this is basically a picture of a you know soil and you can see the porous nature here. If you put some water, water we percolate through these soil. And by these by you understand that this water percolates when the rainwater, it goes down it percolates and settles in a reservoir from which we draw water, these rain water is used for you know cultivation purposes. So, through soil rain water percolates.

So, basically the mother earth in there is a major amount of porosity in this in the sub-surface, where that we have here. So, now one major application in this context is hydrocarbon recovery. Here in this picture you can see there is a picture of a oil well ok. And this oil is drawn from here oil is held here by this impermeable shale clay. So, underground, there is a porous reservoir rock and oil is sitting there and when somebody goes there and digs a well, so the oil comes out of its own pressure.

So, then this after collecting some amount of oil, generally what they do is they inject some more wells and start injecting water through these; through these wells to maintain the pressure. So, as the water is injected, these water travels water pushes the oil from these reservoir, so that more oil can come out ok. So, this is these are so there are now, it is not just simple water lot of times to improve the movement of oil, there are lot of chemicals put into the put into water. It may not be water; it may be a gas; it may be, it may be, it may be a miscible displacement that means, the gas mixes with oil, it may be immiscible that means gas does not mix with oil, it may be near miscible partially mixes with oil.

So, there are whole bunch of methods, a whole bunch of fluids that one can inject with the water, one can inject surfactant, so that it can flush the oil better, one can inject polymer so that the water becomes thickened and that can push the oil better from this reservoir. So, there are; there are; there are whole lot of chemicals tested or chemicals tried for pushing this oil out from the reservoir. So, if there is a huge amount of flow through porous medium involved in as far as the; as far as the petroleum recovery or natural gas recovery is concerned, so, this is; this is; this is one thing.

So, there is lot of a flow through porous medium involved, lot of not just a single phase there are two phase flow involved. For example, oil and water you all know that they do not mix at each other. So, they are there they will remain separated. And now you are pushing one against the other, so how would it; how would it behave ok.

So, basically this porous medium contained partly oil, part of it is water, part of it is gas. And now when you inject water, this water mixes with the water that is present already. So, there could be different scenarios coming up and flow through porous medium is extremely critical in understanding those various you know oil recovery mechanisms, so that is one area where very much the flow through porous media is important.

Further you have the if I go back to my earlier slide, so we have this hydrocarbon recovery; we have this hydrocarbon recovery for which this flow through porous media is extremely important. Then we have this hydrology flow of water, where I mean it is extremely important how the water flows and water because you depend on this water for agriculture purposes for several other reasons. So, how the water flows through these porous medium is extremely important.

Also we have these sub-surface sequestration. What is sub-surface sequestration? Some unwanted chemicals, you want to put inside these rocks, I mean it is has to be secluded, it should not then you can find out such kind of cavity in mother earth, where it is otherwise secluded. It will not; it will not have contamination arising from this sub-surface sequestration.

One important thing that is being; that is being considered for sub-surface sequestration is carbon dioxide sequestration. Lot of researchers they have worked on saline aquifers, where carbon dioxide can be injected. Saline aquifers or a match your oil fields where carbon dioxide can be injected and this carbon dioxide will remain and we will get trapped over time. So, with that idea, the sub-surface sequestration has been practiced in many places in the world.

Now, other area which we have here is contaminant transport that is something which is important in the context. Suppose, one has a repository of some materials which is not good for health, so one needs to know that if at all there is any breakage in that repository, repository underground repository I am referring. If there is any breakage in that repository, how fast that contaminant will transport through the through the rock through the porous rock, so that how far it will travel or a generally this if it is a material which has which you where the extent of you know it is the malignant nature of this material it decays with time.

So, how far it will travel and with to what level of malignancy, so that kind of design that kind of studies can be undertaken with these contaminant transport models, which essentially depends on flow through porous medium. And then there is this other area which is in situ leaching this is used for minerals.

Instead of you know open cast mine in case so in instead of putting out the rock and then from that extracting the minerals, one can inject something called a lixiviant into a porous formation. And this lixiviant; lixiviant is some kind of chemicals with let us say some aqueous some water based water with some chemicals added. These lixiviant as it travels through the pore space of this formation, it picks up it leeches out those minerals. And they will be collected to another well.

So, there you can at the outlet what you get is those minerals that are leached out and now you need to extract these minerals out of the lixiviant and the lixiviant will be fed back again. So, this process is known as in situ leaching and in situ leaching is applied to many important you know precious minerals that we rely on every day. So, these are mostly, these are mostly with the; with the; with the sub-surface flow, I mean the all these applications that I mentioned here are related to sub-surface flow.

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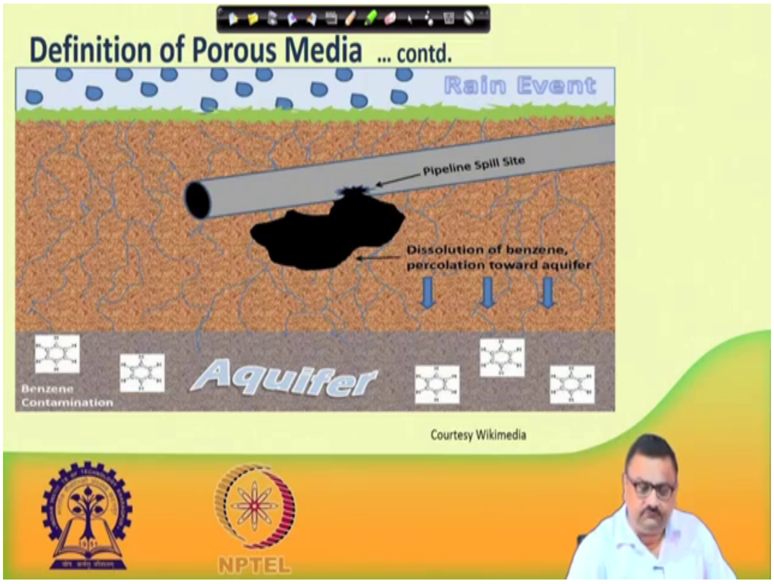

The next application that I have in mind here is, this is also another example of the sub-surface flow there could be a spillage and how fast the in how fast this spillage will travel. So, one can calculate them using these using this theories of flow through porous medium. So, this kind of contamination and spillage how far they travel because this is important, we can sign some from some place may be the water is drawn for many other purposes. So, these calculations are extremely important.

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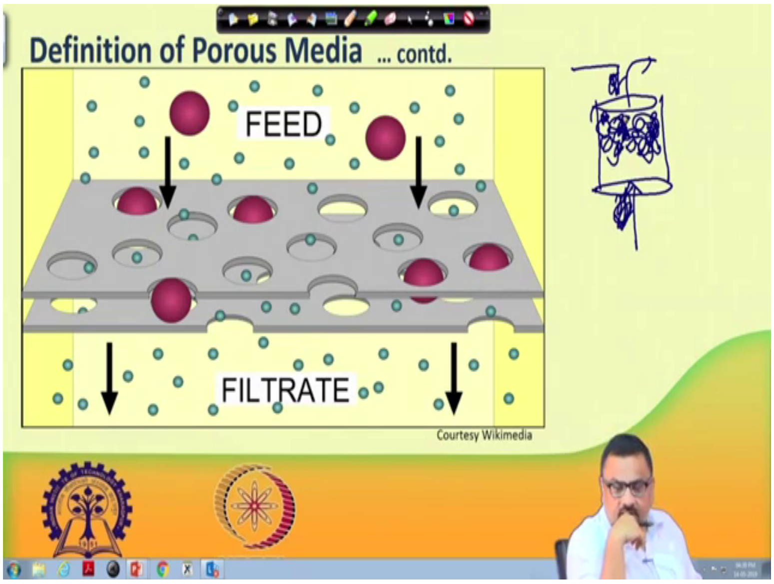

Then I that is the second category I had all those engineered materials. Now, porous medium can porous media can act as a filter. We have seen this kind of filter in our household, we have seen the household applications of these filters. And this could be a simple sand pack or this could be some you know filter cartridge. What you essentially see here is it is packed with; it is packed with these gravels sand or it could be a ceramic filter. So, pack there would be some amount of packing there.

So, once when there is a flow, if a contaminate the water containing some suspended solids, when they are flowing into this, these suspended solids they are held up at the nook and cranny of these this, this porous bed and the water that comes out would be clean. This kind of model we have studied a lot of times in our school days that where you have this kind of a pack and you see that contaminated muddy water you put and clean water comes out from the bottom.

Now, you can put some (Refer Time: 14:14) to it, you can control the pore size, how much you can filter to what size you can filter. So, one can work on those, but essentially this kind of filters you can this we are using every day. And it can be; it can be done in a large scale I mean for example, we need not have to be just household, for example, if you go to an offshore oil and gas platform, there you will find that the water that I said just now that water has to be injected into an oil reservoir for oil to be pushed out, so that what are the in of course, from an offshore oil platform in an offshore oil platform the water will be drawn from sea. Now, sea water has is lot of you know the suspended matters.

So, you need a large filter to filter seawater. So, there this design of a filter and water, what would be how the water would be spreading and what kind of packing your needs to use inside. So, these are these I have to be these are I have to be very well designed otherwise one cannot, but the quality is very important you are injecting into the porous medium. If it contains lot of a suspended solids, they will go and plug the porous that plug the reservoir around the well and so then the withdrawal of you know hydrocarbon would be a problem.

So, this so these, this kind of porous media use a porous media as filter we are all familiar with. So, there would be a feed from the top and the filtrate will come out from the bottom. Then when you need to clean this, because what time there will be collection of debris, what they do is they put now they reverse it, now they put water from the bottom. And whatever material they collect from the top that would flush out, this is called you know back flushing backflow. So, using a backflow one can clean this porous medium. So, this is one way of working with these packed beds.

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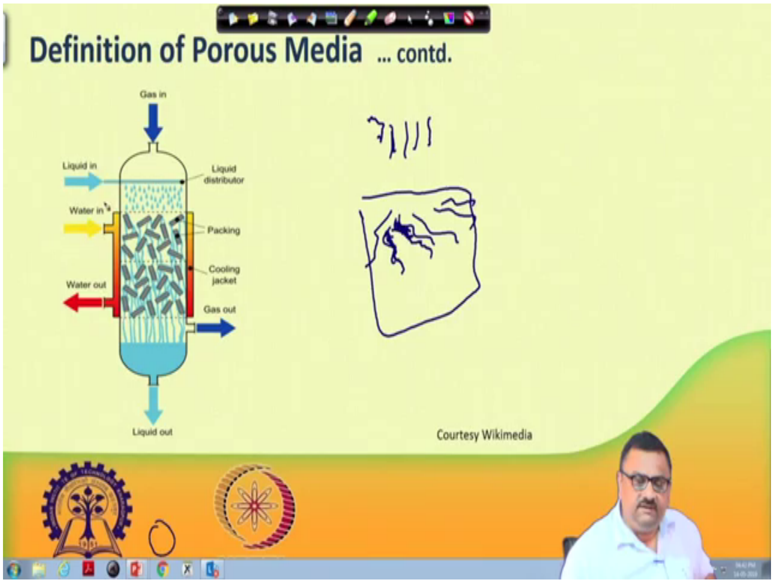

Packed bed is used for other purposes also. Packed bed can help in bringing in developing contact between a liquid and a gas. Suppose, I have a gas which is primarily air, which also contains some amount of sulfur dioxide. And I want to take out that sulfur dioxide, before I leave that gas into the environment, so that sulfur dioxide has to be removed. So, I would probably use some kind of aqueous chemicals or maybe simple water to remove the sulfur dioxide.

So, I need to bring this liquid that aqueous solution, we have to bring in contact with a gas. So, how will you bring that contact? So, in that case a packed bed serves the purpose, because around a packed bed that the flow will be completely distributed, I mean suppose there is a; suppose there is a flow taking place, suppose there is a flow taking place. So, it is the flow was coming in mass ok. And then when it enters into the packed bed, the flow is being distributed here this flow is split into several sections. And at each section, gas will be then forced through these.

So, the I am talking about counter current; here in this picture, it is co current. So, basically the gas and liquid they will be flowed side by side inside that small pore we are talking about 1 micrometer or maybe 10 micrometer of the pore width. So, these two phases they will be pushed into that small dimension. So, I am ensuring that they are having intimate contact with each other, so that the mass transfer takes place or the absorption takes place. That contacting was if we could have arranged that contacting, the other way of doing this contacting is put the gas and the liquid and stir it, or make sure that the gas bubbles uniformly over this liquid.

You one has to there are there should be some way to bring the two phases in contact, you have to split the two phases and then so that they can come in contact with each other. And that is possible once you put this two in a packed bed as I pointed out here. So, that this so there would be use of this packed bed for this kind of absorption purposes.

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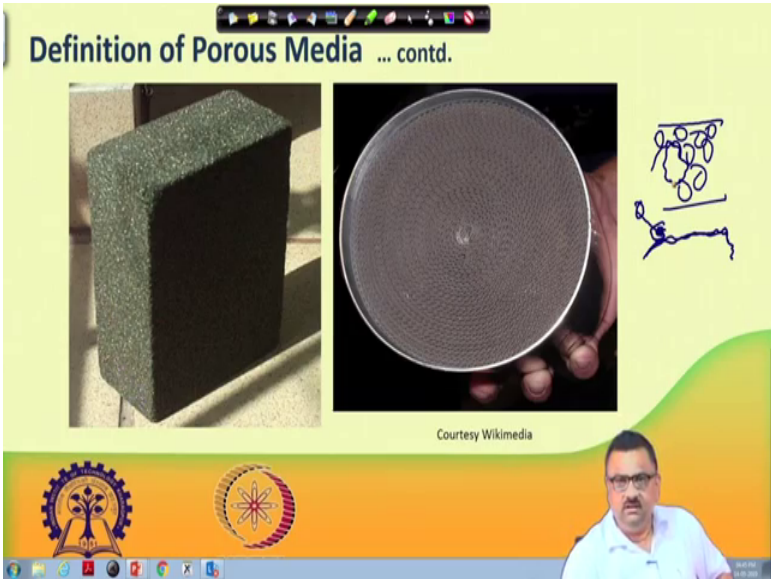

Packed beds are this porous media these are used for different other applications also. For example, there are this kind of porous ceramics or porous building materials that are available, so that if they are used the air inside will be trapped and that air being non conduct non conducting for heat. So, this will act as thermal insulation. So, there are lot of you know engineered materials which are made porous intentionally, so that one can have thermal insulation for example.

Similarly, there are but the porous materials are used as catalysts generally catalysts are put in a packed bed or there are other ways the catalysts are used there are many other ways it is it is probably now the right statement that it not generally it is in a packed bed, one way is to put it in the packed bed. Here I here there is a picture of a monolith of catalyst which is used in the in treating the effluent gas from an automobile. So, this is basically a monolith through which the gas will flow the purpose of having a monolith is that the catalyst, you need a substrate you need a surface, the way the catalyst works is that you need a surf surface where the catalyst will be present and the molecules they will come heat there and in presence of catalyst the products form.

So, one has to distribute this catalyst material. So, there are ways to do this it could be a monolith with there are capillaries present inside. And there is a wash coat of catalyst. So, there would be a catalyst layer as inner wall of these of these capillaries in this monolith. So, as the gas flows through this capillary, it comes in contact with the capillary and there could be reaction happening. There are other ways to do it one can form catalyst pellets. So, catalysts are put like in the form of a tablet and they are put inside a packed the inside a bed.

So, these are all catalyst pellets and the gas can flow through these and then it comes in contact with the catalyst pellet. And then there are you know there are ways to do things here. So, these this kind of porous structure or flow through porous structure is very important in the context of catalyst design or reactor design, where reactor contains catalysts. I have given a picture of monolith through which these gases will flow the automobile exhaust will flow, so that one can take out the unwanted gases from here or convert the unwanted gases to (Refer Time: 22:01) gases.

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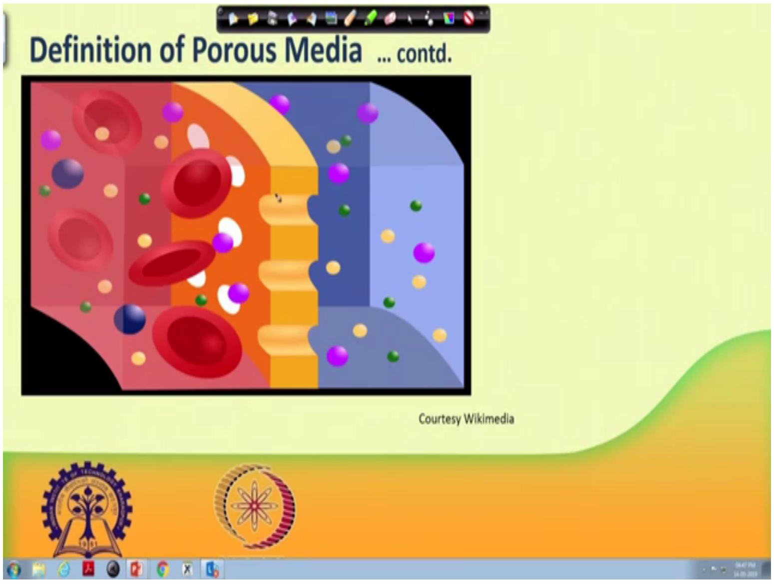

Similarly, here this is an application this is an application this picture shows an application of a membrane. Membrane here you can see that these here we have various different entities flowing on this side of the membrane. And membrane has certain holes through which only these entities could pass through, but these large red ones they could not pass through the membrane.

So, this is not exactly a filter there is a slight difference these are working first of all these dimensions are much smaller than a filter it is definitely not 1 micrometer or 10 micrometer these dimensions are much smaller. And the transport mechanism is not just you know straining, it is not just training as you apply strain straining in you know straining (Refer Time: 23:07), it is not that, there are other mechanisms to this transport involved.

But I want to point out that these this type of; this type of membrane this type of; this type of engineered materials are used in many different applications nowadays and to understand the transmission of some of them through this membrane and stoppage of some others through this membrane, one needs to understand flow through porous medium because after all these membrane materials are porous materials.

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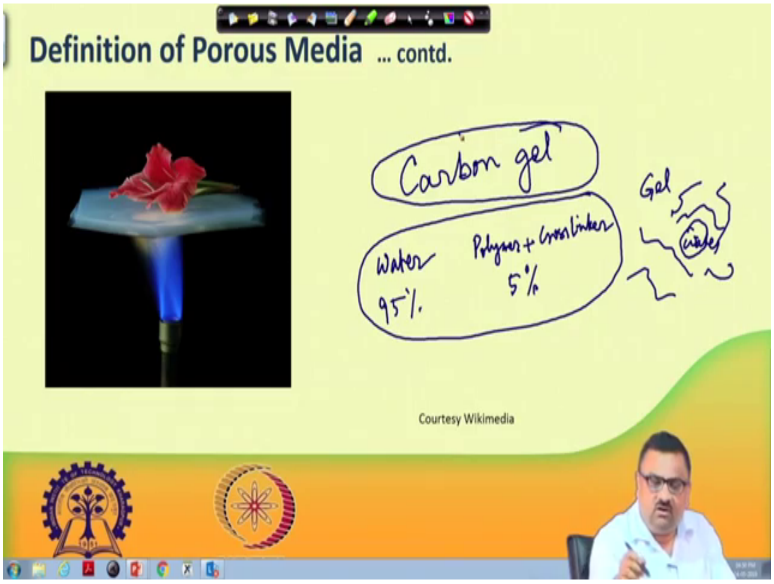

There are other materials available which is for example, this the picture that we have here, these materials are called carbon gel. These materials start they start with some kind of hydrogel material, hydrogel which is let us say we have a polymer precursor, we have water let us say 95 percent. And we have some polymer, plus cross linker, this constitutes about 5 percent. We have a mixture like this and this together they form gel which is basically a cobweb type structure cross linked network with water trapped inside. So, water is trapped inside in this cobweb type structure cobweb type gel network.

Now, by some means if you can remove this water, so you are left with this cobweb structure; and then this cobweb structure if one carbonize this, that means, if it hits to a temperature of let us say 800 degree centigrade in absence of oxygen, so one can get into something called a carbon gel. So, this is a picture of a carbon gel. These materials have many different applications for because they have some unique properties, they are; they are; they are; they are the also they are given different names xerogel, aerogel and all these things.

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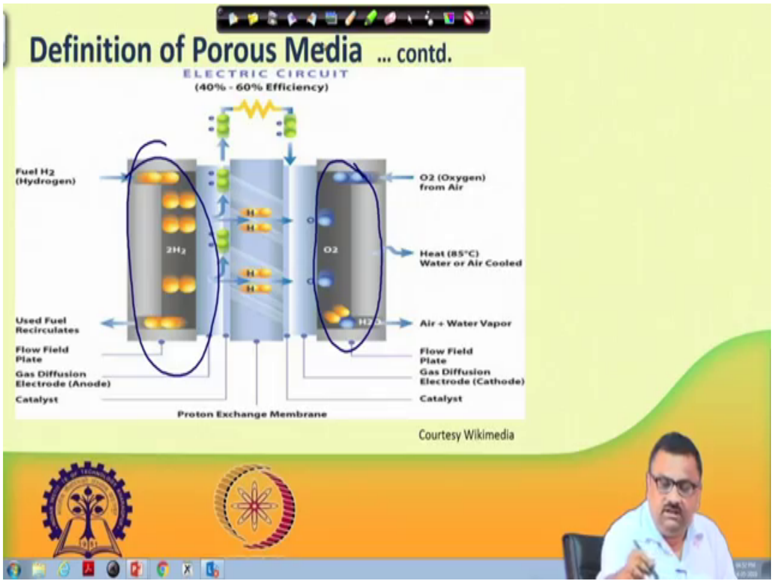

Now, these carbon gels one major application of this carbon gel is in the use of fuel cells. The electrode here has to be porous. This is the electrode; this is the other electrode. And they have to be porous, because there would be first of all there has to be pores through which ions will transport ions will go to the surface and also some gases needs to travel through them.

So, one has to have a porous electrode like these. So, one needs to have a very precise pore size distribution in them and the so for the purpose of these electrodes you can see many different carbon, carbon materials are very very common activated carbon different forms of carbon are very common for the as electrode material for these for this type of applications.

And here this has to be a very porous, porous material engineered perfectly to the for keeping this application in mind, one has to try this sudden say oxygen has to travel say when the ions have to go inside and the resistance to this kind of flows should be least. So, in these type of for this type of applications one has the these, the one has this kind of this kind of aerogel or xerogel material.

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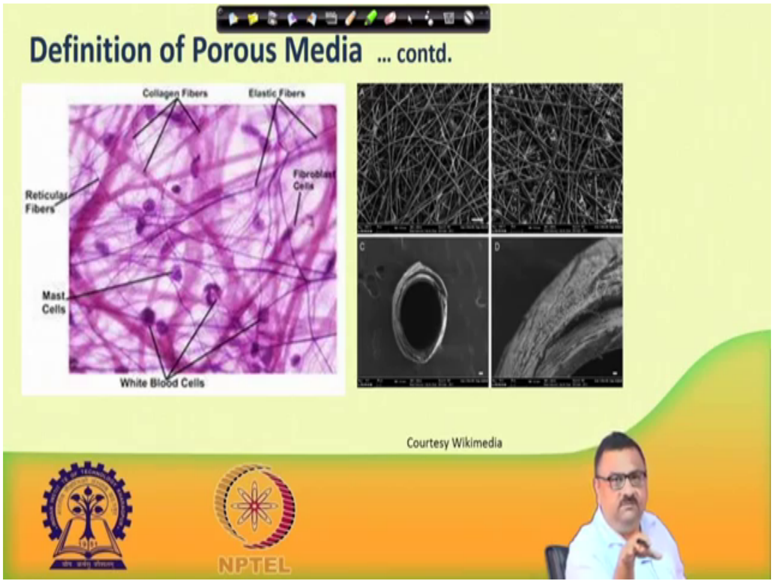

The next application that I have in mind here is the biomaterials. Now, this is a picture of a human a picture of a life a picture of a tissue cell. You can see it is highly porous. In fact, human body is known to be highly porous, it is for a kid it is even more porous for a normal adult person, it is 70 percent is comprising of water basically in that pore space and with is this content of water goes slightly down.

So, now these there are fibers there are some it so it is like as I said the cobweb of tread type of structure where lot of water is trapped. So, it is I can think of that type of a you know structure here inside human tissue. Now, if somebody wants to you know mimic this tissue, one has to come up with this kind of a cobweb type structure where water can be trapped number one.

And number two they needs to be functional, they need to be functionalized, for example, somebody has lost a tissue. So, one can fit this cobweb type structure there and some functionalization has to be there, so that they can attract the matrix forming cells, so that matrix can start building in those locations that the body can build its own tissue around those locations.

And as the tissue grows one would expect that the cobweb type structure that you have put from externally you have been put inside there, so that also has to degrade with time. So, one has to put some kind of biodegradable matrix of similar form as I similar form as I mentioned here, similar form as I mentioned here as I shown showed here.

So, one has to create that kind of porous medium first of all and one has to understand how flow takes place, because one applies trace, one apply some kind of water pressure, and water travels through these aqueous medium travels through these, so how they travel through this kind of medium.

So, these are some of the fibers, they have generated this the to can to construct this kind of a set to construct synthetic so to say these are these are made of biomaterials these are made these are generally sourced from naturally occurring biomaterials biopolymers. So, this cross these gel material they are they will form a structure something very similar to a tissue.

And on top of that there would be some amount of functionalization on the surface made, so that they can form that they can; they can; they can generate that they can generate these metal the tissue by assembling the matrix forming cells. So, this is one area where there is tremendous amount of you know flow through porous media equations used here.

Because one thing you must note here when it comes to flow studies in these context, here the flow would be of nutrients the growth factors they need to flow through this through this system. There will be diffusion it is more of a convective diffusive type transport of these nutrients growth factors oxygen. So, those have to travel through these this system and also the cells should be able to move freely within these structure.

So, it is a flow through porous media coupled with some other aspects as well one needs to consider. So, these so as you can see in this in these in this introduction section, we have talked about many different applications. And there this flow through porous medium or these equations for flow to porous medium that is the critical element, but they have to be used within a couple form with some other for example, when it comes to a catalyst packed bed reactors, then the reaction term will come in. When it comes to there could be some diffusive diffusion term coming in if there is a combined form of you know diffusion as well as viscous flow occurring together.

So, in down the line as we continue as we work with these theories, we you have to keep this in mind that our real life applications would be flow through porous media coupled with few other physical-chemical processes which is which we need to keep track of as well. So, that is all I had for this lecture. And I will continue this continue the; continue the flow equations from the next lecture onwards.

Thank you for today.