Flow Through Porous Media
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Lecture - 33
Miscible Displacement (Viscous Front)

I welcome you to this lecture of Flow Through Porous Media and we were discussing this Miscible Displacement or miscible flow when a flow takes place in a porous medium and then there is simultaneous mixing taking place. So, where all the what all complications one can the complications that can arise and how we can put some theories behind it and to get more characteristic parameters of this porous medium just by studying this mixing process itself.

So, we have found out how to find. So, we have found some ways to you know to estimate what is the dispersion coefficient for a flow through a porous medium or for that matter, how to evaluate, how to estimate the aperture of a fracture when fracture is embedded in porous media and similar such exercises we had done.

So, this dispersion experiment not only it will help one to estimate or characterize the porous medium, this will help one to understand if a being a porous medium there is second fluid which is injected and this fluid mixes with the fluid that is already in place, then how these mixing will take place, how these fluids will behave and what do we expect as the concentration of the; concentration of the fluid that is flowing and various locations inside the porous media.

So, I think by now we have developed sufficient background to this these particular process and whether you have this for that for the sake of tracer test, where the objective is to characterize the porous medium or the fluid is injected to extract something out of porous medium or to not the porous medium is simply an engineered porous medium say an electrode, where this fluid is flown through the medium for some; for some; for some gain for some; for some engineered gain I would say.

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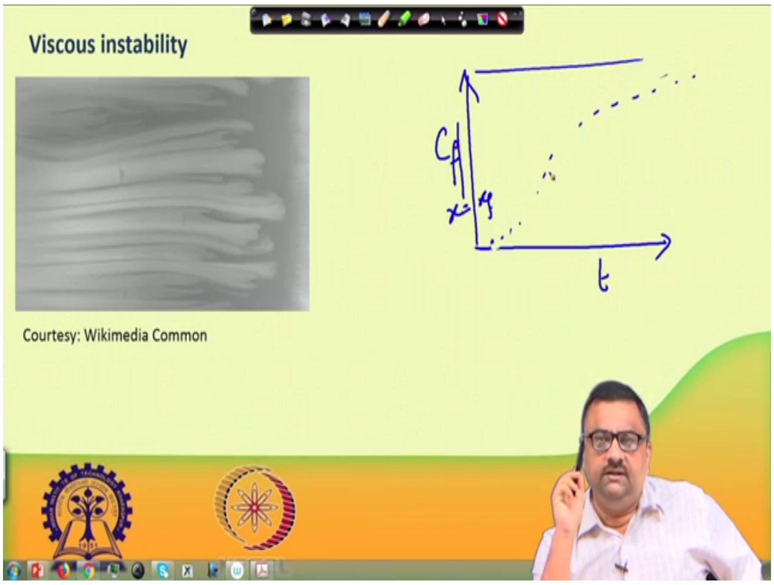

So, with these I must continue this exercise here, I have been talking about this flow through a fracture and we have already found out we have already; we have already found out that if one plots the concentration C f at x equal to x f the outlet as a function of time and then if they get a curve like this they how to what are the theoretical theoretically what kind of curve one should get and if somebody gets experimental data point instead of a curve, if one gets these experimental data points. So, these experimental data points can be fitted to some line and what would from that line how we can generate these characteristic parameters.

The other way of looking at it is if it is an engineered material and already we know the aperture. We have already created of aperture created a channel and that channel has a fixed aperture and now we are having a transport process going on inside. So, then what kind of concentration we would get at the outlet of the channel? So, fracture can in that case would be simply flow between two parallel plates. So, two parallel porous walls that there is so, fracture we here we talked about the fracture you can for an engineered system you can call it flow through two parallel walls which are porous.

So, that is it is; so, how the concentration will change at the outlet, how the concentration will change at various axial locations? So, we have already found how we have already talked about the theories and one can use those theories to predict the concentration and then accordingly one can use those that information to the design of the design has required. Now before we close this before we and close this miscible displacement chapter, there are a couple of issues one must make note off then that is something which is something like this.

Suppose one has we said that this is a displacement right. So, the porous medium there is a fluid existing and another fluid is being injected. So, as this other fluid is injected one expect that see the other fluid is injected and so, this other fluid that is being injected that is simply that will displace the fluid which is already placed in the porous medium; that means, if this is the conduit.

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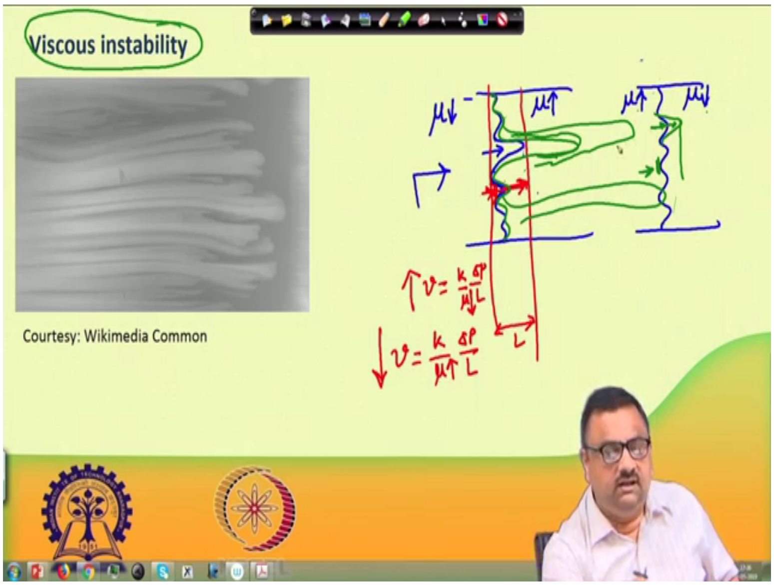

So, we have one fluid that is existing one fluid that is existing and then the other fluid is being injected. So, this is let us say this is the fluid that is injected and this is the fluid that is existing. So, this fluid is simply pushing the fluid in the front and then pushing this out from the conduit. This is something which we had this as an idea we are calling it displacement; that means, a fluid is already there we are displacing it by injecting some other fluid or may be miscible means that the fluid that we are injecting is miscible to the fluid that is already in place.

Now in this context, we always we assume we tacitly assume that the viscosity of the two fluids are same. Now let us come to a situation where the viscosities of the two fluids are different they are miscible, but there would be some fuzzy there would be some diffusion happening across the interface, but they are one is more viscous than the other.

I can give a quick example here for example, I have water there and I have water glycerol mixture water and glycerol water and glycerine the mix and at various ratios so, but that viscosity of this mixture would be high. So, let us say we have is do we have two situations here one in one situation we have higher viscosity fluid is here and the lower viscosity fluid is this side and we have another situation where we have the low lower viscosity fluid is here and the higher viscous.

Let us say this is here in this case mu is a lower and this in this case on the left hand side the fluid that is being pushed that the fluid that we are injecting and the fluid that is being displaced the viscosity is higher. And in another case this viscosity that is injected is higher and the fluid compared to the fluid that is being displaced that has a lower viscosity. So, in this case suppose by because of some reason; because of some reason there is a because of some reason there is a perturbation developing.

This perturbation can develop because of various reasons it could be some fluctuations some for some reason there is a perturbation at the interface. Now let us see whether this perturbation will be supported or this perturbation will be will subside. So, now, let us see here what would be let us say I have now fluid here that is being flown inside I mean in a very in a simplistic term, I can see there are a fluid has two choices. The fluid that one is injecting here, this fluid can travel through this part of this is commonly referred as finger.

So, fluid can flow through this finger or fluid can flow through this which is a smaller one or even very little one and this is a larger one. So, now, I can see here this pressure drop across these points if I now; if I now look at what is the pressure drop across these points say a pressure drop with reference to this and this. So, pressure drop across this if we look at the pressure drop that would be encountered by the fluid which is flowing through this particular section, that pressure drop would be what? For the same velocity v would be equal to this pressure the velocity is k by; k by mu and delta P I am writing which is minus delta P by this length let us say this length is L.

So, this length L ok. So, now, here in this case, I can see that the viscosity here is already the fluid has gone to this point. So, the viscosity that will apply here is this here and now let us say I am imposing the same pressure gradient everywhere. So, the delta P remains same. So, for this particular the fluid that is flowing through this particular section, it will have a velocity which is k by mu delta P by L, but mu is on the lower mu. Whereas, this particular section here also the flow will take place, but here the velocity would be then the there would be it would be this section this is the fluid is having a viscosity which is having higher viscosity and this section which is the fluid is having lower viscosity. Let us say it is completely; it is completely the fluid of higher viscosity that is dominating in this case ok. So, then in this case one will find that the velocity would be k divided mu which is at higher viscosity delta P by L.

So, automatically the fluid if fluid gets a choice or if you or so, essentially if the fluid is flowing I mean if the fluid gets a choice here, I can see in one case the viscosity is lower; that means, here the velocity would be higher and here the viscosity is higher basically this entire length section is dominated by the higher viscosity fluid.

So, that velocity of this fluid will dominate the pressure drop here. So, naturally the velocity of velocity at which the fluid will travel in this direction the flow higher viscosity fluid, that will define how at what rate the lower velocity fluid will travel. So, then this velocity would be automatically much lower and these velocity would be much higher. So, I mean one can see in this case, I mean the bottom line here is that one will see that these viscosity sorry these this particular the perturbation, these will start growing all the fluid will tend to flow through this direction.

So, one will see these there is a the perturbations they are growing. On the other end when this situation is reversed; that means, when viscosity on this side is higher and viscosity on this side is lower and when the same situation is happening here. So, in this case one will find that the one where you there is already a perturbation made say there is a perturbation already made.

So, if you compare if you do the same comparison, you can see the where the perturbation is not made if you find out across this pressure drop I mean what would be the velocity, you will find that since this viscosity is lower and this viscosity is higher. So, fluid will tend to flow more in this direction than this one flow will be in this through this section rather than through this section.

So, automatically the perturbation will die. So, this is; this is; this is referred as viscous instability. So, viscous instability what viscous instability means here is, you can see some fluid which is of lower viscosity is going into a fluid which is of higher viscosity. So, the front is not straight rather there are perturbations and that have grown. So, one can create this kind of a pattern there. So, this is something which we this is very much present in porous medium and this is something which one does not want because if this kind of.

So, I mean the entire our entire understanding is as if there some fluid I am injecting and that fluid is flowing like a plug and through pushing out everything from the from these from everything that is already resident there. So, that is what we had thought about and then next we saw we found that if there is a capillary there would be a parabolic velocity profile and because of that there would be some velocity distribution and because of that there would be some cases; that means, at the center of the capillary the velocity is higher and other places the velocity is lower and near the wall velocity is 0.

But that has a fixed pattern parabolic velocity profile and a. So, but this is something which is difficult to handle because if such type of pattern starts forming. So, then you one will find that this there would be one perturbation this perturbation will continue to grow maybe another perturbation grow. So, this these areas on the other hand they will remain undisplaced, this particular fluid remains undisplaced.

So, that is why whenever it comes to pushing something out from a porous medium, one always prefers higher viscosity fluid to be injected rather than lower viscosity fluid to be injected. So, that is one reason any such displacement process from a porous medium one put additional thickener so, that the velocity so, that the viscosity increases.

So, that such type of viscous instability does not develop at the interface ah. In fact, one example I can draw from hydrocarbon recovery, there is a process which is known as polymer flooding in a in enhanced oil recovery or any recovery process, where water is injected to displace oil from the reservoir lot of times they inject they add polymer to water so, that the viscosity of the injected fluid increases so, that such type of instability can be avoided.

So, this is one thing we must keep in mind that depending on the difference in viscosity, there could be some pattern developing and which we were where the movement of the front and the front will not be all very straight. Whereas, if the if you have the viscosity which is higher the injected fluid viscosity which is higher, which is the case in this here we can expect a very straight front and no such instability or no such perturbations protruding out such thing will not happen. So, this is one note I must put here.

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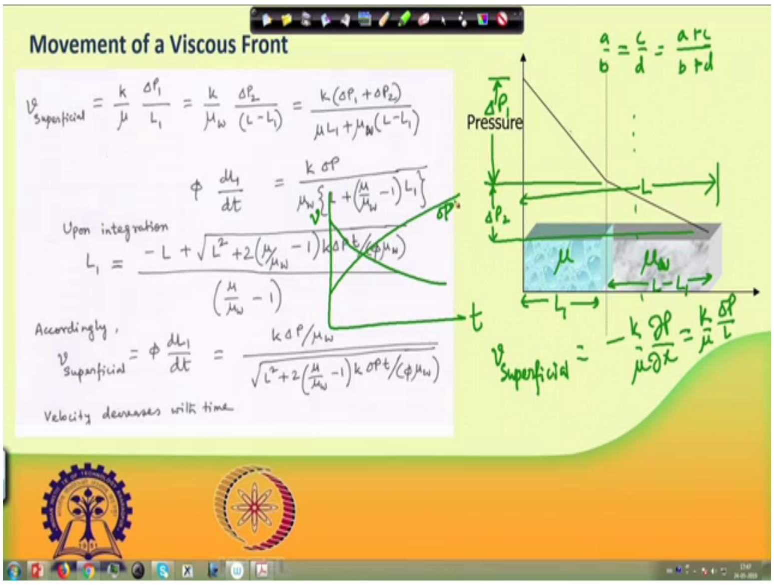

Since, we talked about this movement of a viscous front and we said that the fluid that we inject, where the fluid that is injected to displace a fluid from a porous medium so, and if that injected fluid should have a higher viscosity. So, what kind of complications can develop if you have two different viscosities; one fluid which is present there is of lower viscosity and the fluid that you are injecting is of higher viscosity. So, what all how to handle that kind of a flow?

So, first of all I can see very well that when this entire porous medium is at a lower fluid is fluid that is inside this porous medium is at a lower viscosity, then the for a particular flow rate the pressure drop would be less or for a particular pressure drop pressure gradient the velocity would be more; whereas, if I have a higher viscosity I mean its all common sense is that if we have v superficial, we had written v superficial is equal to minus k by mu del P del x or in a linear sense we write k by mu delta P by L, here delta P is P in minus P out.

So, then this is if this is so, then we can very well see that if the gradient remains same, then superficial velocity is inversely proportional to viscosity or if the velocity remains same, then this gradient is directly proportional to viscosity. So; that means, for a higher viscosity either the gradient would be more because viscosity increases means gradient will increase superficial velocity remaining constant or if I hold the pressure gradient as constant then higher the viscosity superficial velocity would be less. So, in that case if a viscous front travels into the porous medium where a less viscous fluid is present.

So, we expect that with time either the pressure gradient will change if we maintain a constant velocity or if I maintain a constant pressure drop constant delta P by which the flow takes place, then the superficial velocity will change with time. So, that is something which we must make note.

So, we are trying to probably the see we generally if we set the superficial velocity then there is a there could be a problem in the sense if I set the superficial velocity I do not know what kind of pressure gradient I will encounter, I do not know what of delta P I will encounter I started the flow was taking and the flow was taking place and then suddenly I find that this delta P is increasing as the front is travelling inside and then this delta P exceeds the limits set by the experiment, limit set by the design, limit set by the engineered system.

So, every, so that may not be that I mean a better idea would be to do this at constant pressure the constant delta P. So, I impose a constant delta P across this length and then study how superficial velocity changes with time; I think that would be easier to accomplish easier to implement. So, what we did here is we have written here v superficial is equal to k by mu delta P 1 by L what is delta P 1? If this is delta P, so, we are saying this is delta P 1 and this actually this is we have gone up to this. So, this is the. So, I should remove this.

So, then this is delta P 2. So, this is delta P 1 and this is delta P 2 delta P 1 is the pressure drop across the viscous front and delta P 2 is the pressure drop across the lower viscosity fluid the front. So, now, I can see when they are. So, I have put a pressure drop here which is delta P 1 plus delta P 2. So, delta P is the overall pressure by which this viscous fluid is injected overall the total pressure drop is delta P which is basically delta P 1 plus delta P 2.

Now as this position of the front moves as the position of the front moves, this dynamics changes for example, when the position of the front is here let us say. So, this would be somewhere. So, this they will constantly align ok. So, now, with this being known now let us see how we can work on it here, the superficial velocity see whatever fluid is whatever rate fluid is flowing the viscous front is flowing at the same rate these other fluid has to flow ok.

There is no nothing that it can leak off leak out somewhere or something or some other fluid or you can sit there that is not possible. It is a steady state process whatever velocity this viscous fluid is flowing same wave velocity this one also has to flow. So, superficial velocity would be k by mu delta P 1 by L 1. So, this length is L 1. So, at any time it is delta P at some point of time frozen delta P 1 by L 1 and that is equal to k by mu w.

So, we are calling this as mu the viscosity is mu and here the viscosity is mu w let us say water was present and some other fluid is injected. They are miscible, but they have high this is one this one is at a higher viscosity and a mixing we are not that at the interface there would be some mixing so, that has to be handled separately we are just trying to focus on, only the effect of higher viscosity or in the injected fluid.

So, then the second case it is k by mu w into delta P 2 divided by L minus L 1because this length would be if the overall length is L; if the overall length is L. So, then this length would be L minus L 1 because this length is L 1. So, it is k by mu w delta P 2 divided by L minus L 1. Now these two velocities are to be same as I said because it is a steady state process.

So, these are to be equal. So, if these are to be equal then there is something called componendo of dividendo we can do this a by b if a by b is equal to c by d and that would be equal to a plus c divided by b plus d. So, same thing has happened here k into delta P 1 plus k into delta P 2 divided by mu L 1 plus mu w L minus L 1 this plus this ok. Now what we did here k is the permeability and that is remaining same in both cases. So, now, this superficial velocity can be written as phi into dL 1 d t dL 1 dt is the velocity d L 1 dt is the velocity at which this interface moves right L dL 1 dt is the change in L 1 with respect to time t. So, dL 1 dt is this ok.

But since this front is moving it is by interstitial velocity not superficial. So, one has to multiply this by the porosity. So, phi multiplied by dL 1 dt that is what we have on the right hand side. So, now, if we take this and if we upon integration we get L 1 as this is the expression for L 1 and then now if you go to the superficial this would be simply phi into dL 1 dt and you take the derivative of it and you get this as the expression. Now if you look at it here v superficial it would be this t is appearing in the denominator.

So, what; that means, is I expect the velocity to decrease as time increases ok. So, if you if somebody looks at dL 1 dt the velocity of this front if somebody looks at the velocity of this front, they will find that the velocity of the front would be decreasing with time; velocity of the front would be decreasing with time. So, velocity of the front would be faster initially and then it would decrease with time because you are holding a constant pressure across this length of the porous medium ok.

So, the other way if we plot if we hold the superficial velocity same and if we try to find out the pressure drop delta P overall delta P, one can find out in a similar way how the pressure drop because if you hold up well superficial velocity same we expect the delta P 2 increase with time. So, delta P would increase with time. So, this is this one can find out from this exercise.

So, these are some of the issues one must keep in mind when it comes to displacing a fluid from a porous medium by injecting another fluid. So, we talked about the dispersion process the mixing process, but in this particular lecture the lecture that I had just now, here we talked about some other issues that may come up when one conducts a miscible displacement with regard to viscosity of the two fluids.

If the viscosity of the two fluids are different then there are such issues coming up. For example, viscous instability can happen if injected fluid is of lower viscosity than the resident fluid viscosity and this can be avoided this instability can be avoided by injecting a fluid of higher viscosity, but when you inject a fluid of higher viscosity one can expect that the velocity will not remain constant with time it will vary with time.

If pressure if the delta P the pressure drop across the length of this porous medium is held constant or in other words if the flow rate is held constant, then the pressure drop will change with time. So, with these takeaway message I want to close this discussion on this chapter on miscible displacement and what I would do next from next lecture, I will talk about the immiscible displacement where the two fluids that are one fluid is pushing the other fluid, but then the two fluids are not miscible an example of immiscible system is water and oil.

So, if you have water and oil and something is already present and you are injecting the other type of; other type of fluid. So, how they will behave? They cannot mix, they cannot flow together, they cannot have dispersion being they are the; they are the physicist somewhat different. So, we will get to a discussion on this in the next lecture. So, this is all I have as far as a miscible displacement is concerned.

Thank you very much.